NASA

GPO PRICE $ ________

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Hard copy (HC) 2.00

Microfiche (MF) 2.00

ff 653 July 65

EVALUATION PROGRAM for SECONDARY SPACECRAFT CELLS

SECOND ANNUAL REPORT OF CYCLE LIFE TEST

prepared for
GODDARD SPACE FLIGHT CENTER

CONTRACT W11,252B

QUALITY EVALUATION LABORATORY
NAD CRANE, INDIANA

QUALITY EVALUATION LABORATORY
UNITED STATES NAVAL AMMUNITION DEPOT
CRANE, INDIANA

EVALUATION PROGRAM FOR SECONDARY SPACECRAFT CELLS

SECOND ANNUAL REPORT OF CYCLE LIFE TEST

QE/C 66-304 13 MAY 1966

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Enclosure (1)

REPORT OUTLINE

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 Statment 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 second annual report covers all of the cycle life test, the third phase of the evaluation program of secondary spacecraft cells, through 31 December 1965. 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 51 of the original 84 packs have failed. The remaining 33 packs have completed from 516.6 to 738.5 days (a maximum of 11,816 1.5-hour cycles) of continuous cycling as of 31 December 1965. 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 281 cell failures as of 31 December 1965. The table below shows the distribution according to test parameters and cell types.

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	6	3	2	11	55
		3.0	0	0	0	0	1	1	0	2	55
	25%	1.5	0	0	0	2	4	3	0	9	55
		3.0	0	0	5	0	6	0	0	11	55
25°	25%	1.5	6	3	7	3	6	3	3	31	55
		3.0	0	0	6	1	6	3	2	18	55
	40%	1.5	6	3	6	3	6	5	6	35	55
		3.0	4	3	7	3	6	4	6	33	55
50°/40°	15%	1.5	1/5	0/3	0/6	0/3	1/5	0/3	0/6	33	55
		3.0	0/6	0/0	0/7	0/3	0/6	0/0	0/4	26	55
	25%	1.5	0/7	0/3	0/10	1/2	2/4	0/3	0/6	38	55
		3.0	0/6	0/3	0/6	0/3	1/5	0/4	0/6	34	55
Total Failures			41	18	60	24	65	32	41	281	
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 and Figures 5(a) through 5(g).

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, Table VII, Tables VIIIa through VIIIg, and Figures 6(a) through 6(g).

V. CELLS ADDED TO THE CYCLE LIFE TEST PROGRAM

A. Cells Using Conventional Charge Control Methods.

1. Nickel-Cadmium Types:

a. Gulton 4.0 a.h. (Commercial), Six 5-cell Packs, 1.5-hour Orbit Period: These packs have completed from 7638 to 8136 cycles, with two cell failures.

b. Gulton 5.0 a.h. (NIMBUS), Six 5-cell Packs, 1.5-hour Orbit Period: These packs have completed from 3087 to 3795 cycles with one cell failure.

c. Gulton 5.6 a.h. (Neoprene Seal), Six 5-cell Packs, 1.5-hour Orbit Period: These packs have completed from 208 to 453 cycles with no cell failures.

d. Gulton 6.0 a.h., One 5-cell Pack, 24-hour Orbit Period: This pack failed after 545 cycles.

e. Gulton 6.0 a.h. (Improved), Three 5-cell Packs, 1.5-hour Orbit Period: These packs have completed from 4697 to 4793 cycles with one cell failure.

f. Gulton 12 a.h. (OGO), Six 5-cell Packs, 1.5-hour Orbit Period: These packs have completed from 4869 to 5739 cycles with eight cell failures.

g. Gulton 50 a.h., Two 5-cell Packs, 1.5-hour Orbit Period: One pack failed after 3227 cycles. The other pack failed after 1873 cycles.

h. General Electric 5.0 a.h. (NIMBUS), Six 5-cell Packs, 1.5-hour Orbit Period: These packs have completed from 3142 to 3874 cycles with no cell failures.

i. General Electric 12 a.h., One 5-cell Pack, 24-hour Orbit Period: This pack failed after 349 cycles.

j. Sonotone 3.0 a.h. (Triple Seal), Six 5-cell Packs, 1.5-hour Orbit Period: These packs have completed from 2576 to 2890 cycles with one cell failure.

2. Silver-Zinc Types:

a. Delco-Remy 25 a.h., Two 5-cell Packs, 24-hour Orbit Period: One pack failed after 80 cycles. The other one failed after 32 cycles.

b. Delco-Remy 25 a.h., Two 5-cell Packs, 3-hour Orbit Period: Four of the five cells were still functioning after 120 cycles, at which time the pack was removed from cycling. The other pack failed after 352 cycles.

c. Delco-Remy 40 a.h., One 5-cell Pack, 24-hour Orbit Period: Three of the five cells were still functioning after 139 cycles, at which time the pack was removed from cycling.

d. Yardney 12 a.h., One 10-cell Pack, 24-hour Orbit Period: This pack failed after 57 cycles.

3. Silver-Cadmium Types:

a. Yardney 5.0 a.h. (C-3 Separator), Three 5-cell Packs, 24-hour Orbit Period: These packs have completed from 61 to 104 cycles with two pack failures.

b. Yardney 5.0 a.h. (Radiated Separator), Two 5-cell Packs, 24-hour Orbit Period: These packs have completed from 34 to 63 cycles with one pack failure.

c. Yardney 5.0 a.h. (Pellon Control Separator), One 5-cell Pack, 24-hour Orbit Period: This pack has completed 63 cycles with no cell failures.

d. Yardney 12 a.h., Two 10-cell Packs, 24-hour Orbit Period: These packs failed after 210 cycles and 166 cycles respectively.

B. Cells Using Charge Control Methods and Devices.

1. Auxiliary Electrode:

a. Gulton 6.0 a.h. (Nickel-Cadmium), Six 5-cell Packs, 1.5-hour Orbit Period: These packs have completed from 2785 to 4855 cycles with three cell failures (none due to the auxiliary electrode).

b. General Electric 12 a.h. (Nickel-Cadmium), Four 5-cell Packs, 1.5-hour Orbit Period: These packs have completed from 665 to 1698 cycles before two packs were discontinued due to low capacity of the negative plates.

2. Stabistor:

a. Sonotone 5.0 a.h. (Nickel-Cadmium), Eight 5-cell Packs, 1.5-hour Orbit Period: These packs have completed from 747 to 2133 cycles, with four cell failures due to high internal pressure caused by high cell voltage.

3. Coulometer:

a. Sonotone 5.0 a.h. (Nickel-Cadmium), One 5-cell Pack, 1.5-hour Orbit Period: This pack has completed 6597 cycles with no cell failures.

b. Gulton 3.6 a.h. (Nickel-Cadmium), One 10-cell Pack, 1.5-hour Orbit Period: This pack has completed 805 cycles, with no cell failures.

4. Sherfey Upside-Down Cycling:

a. Gulton 3.6 a.h. (Nickel-Cadmium), One 10-cell Pack, 1.5-hour Orbit Period: This pack has completed 1871 cycles, with no cell failures.

5. Two Step Charge Regulator:

a. Delco-Remy 25 a.h. (Silver-Zinc), One 10-cell Pack, 24-hour Orbit Period: This pack has completed 19 cycles, with no cell failures.

SECTION I

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 second annual report summarizes the cycle life test work through 31 December 1965, including that contained in NAD Crane reports QE/C 64-274 of 15 June 1964 and QE/C 65-356 of 14 May 1965. 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 3.0 to 20 ampere-hours.

D. The purpose of the cycle program is to determine the cycling performance capabilities of packs of 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. Section I, paragraphs I through IV, of this report refers only to the original 660 nickel-cadmium cells. Cell packs and tests added to the original program are covered in section II of this report.

II. CELL DESCRIPTION

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

1. <u>General Electric Company (G.E.):</u>

a. <u>3.0 Ampere-hour:</u> 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. <u>12.0 Ampere-hour:</u> 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. <u>Gould-National Batteries, Inc. (Gould):</u>

a. <u>3.5 Ampere-hour:</u> 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. <u>20.0 Ampere-hour:</u> 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. <u>Gulton Industries, Inc. (Gulton):</u>

a. <u>6.0 Ampere-hour:</u> 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.

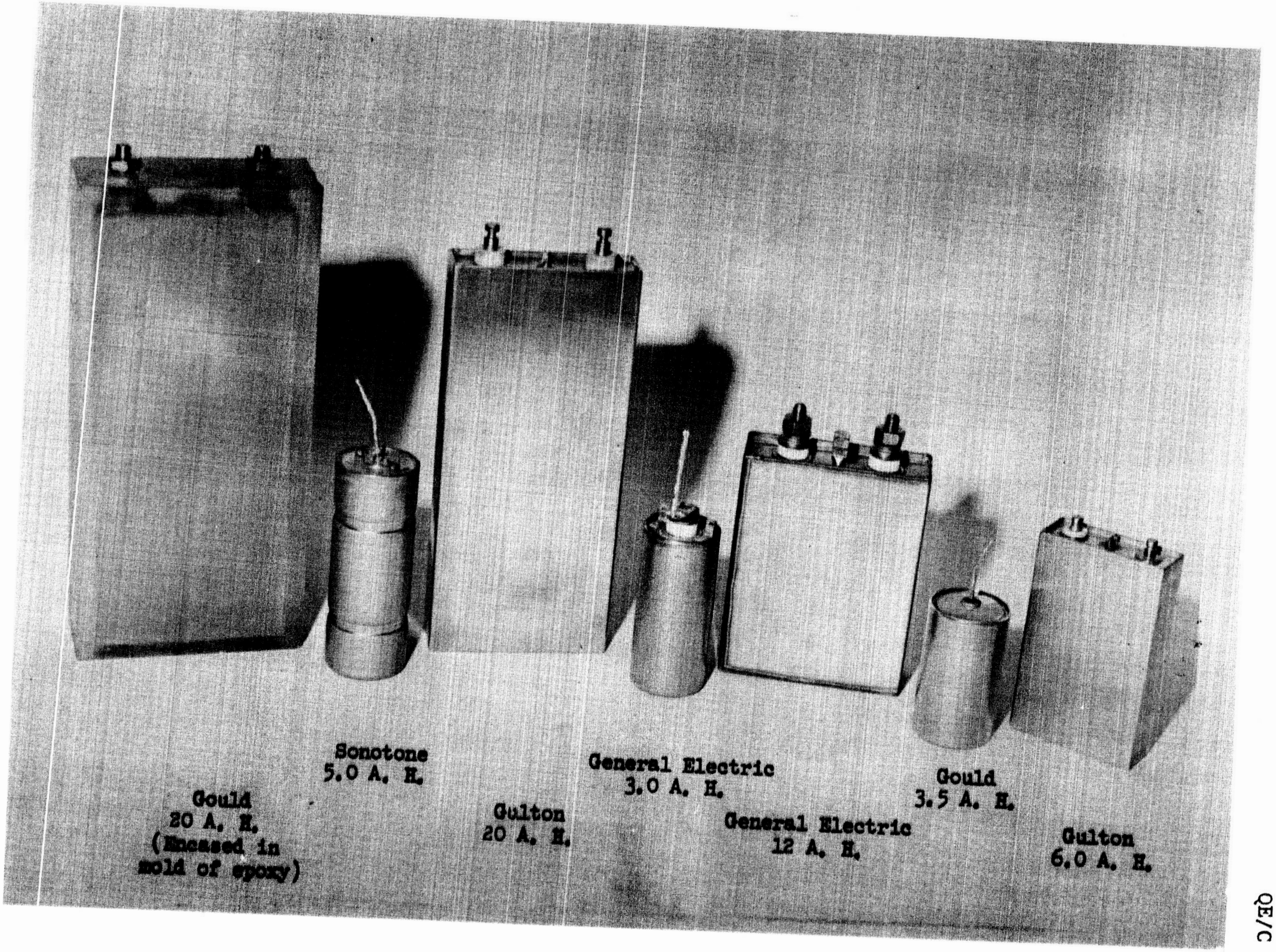
b. <u>20.0 Ampere-hour:</u> The cell container and the cell cover are made of stainless steel. Both terminals are insulated from the cell cover by a ceramic seal and protrude through the cover as solder type terminals.

4. <u>Sonotone Corporation (Sonotone):</u>

a. <u>5.0 Ampere-hour:</u> 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. 3.0 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 the rated capacity in ampere-hours. For example, a cell with a rated capacity of 3.0 ampere-hours, used at the 10-hour rate, would have a discharge or charge current equal to c/10 or 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 Qd is the number of ampere-hours to be removed from the pack on discharge and Qc 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 $I_c \times T_c = I_d \times T_d$ x 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:

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

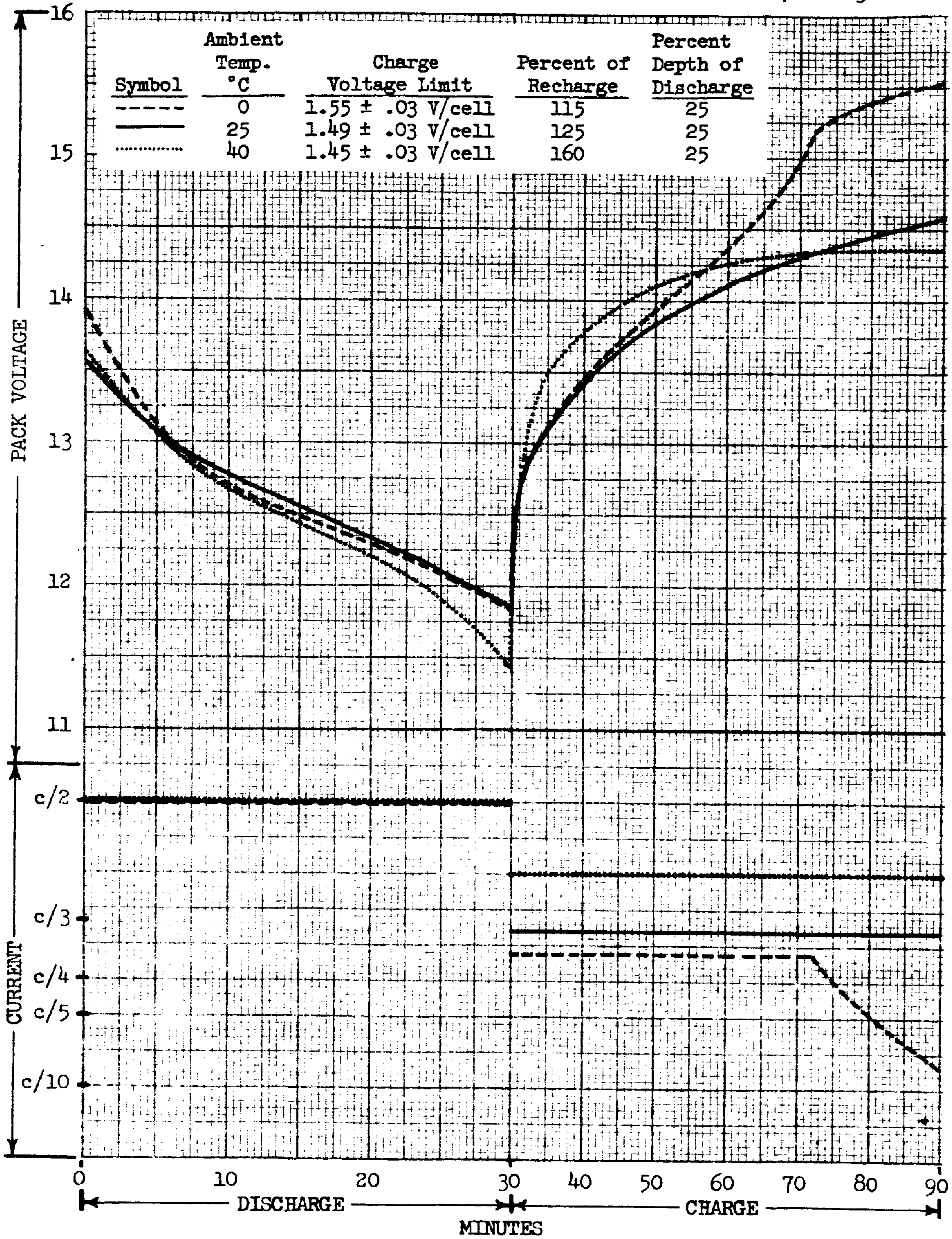
$$= \frac{(0.02 \times 15 \times 3) \times 0.5 \times 1.15}{1}$$

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

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:

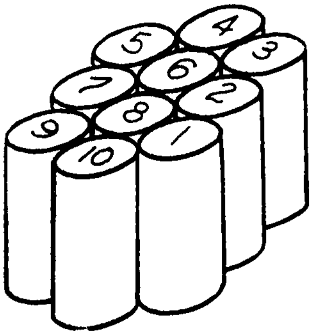
(1) 5.0 Ampere-hour (10-cell Pack): Each cell was wrapped in a double layer of 0.003 inch polyethylene sheet and arranged into oval shaped packs held together with tape, according to diagram (c) of Figure 2. The electrical leads were soldered to the terminals on the top of the cells. The cells are cycling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

2. Temperature Monitoring:

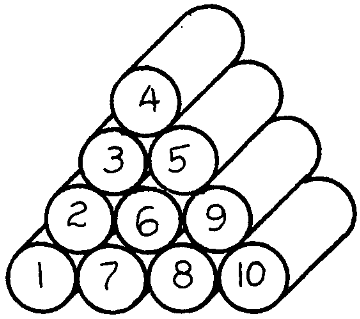
a. A thermocouple (Iron-Constantan, type J) was soldered to the positive terminal of each cell under test.

(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.

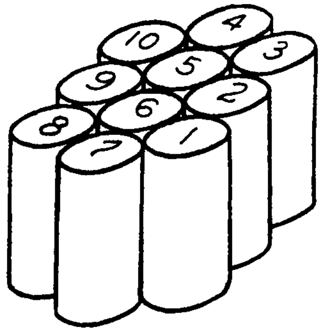
(2) Thermocouple voltages were read simultaneously with cell voltages.



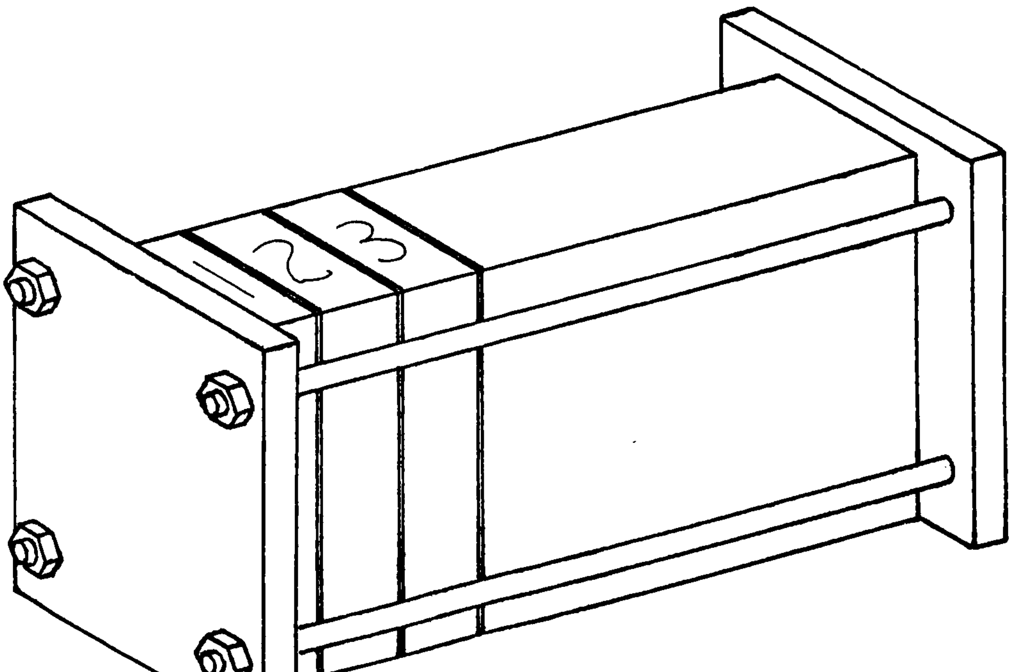
a. G.E. 3.0 ah



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 6(a) through 6(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.)

(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 1965 by the 33 packs which have not failed varies because of different starting times and temporary shutdowns 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 516.6 days to 738.5 days.

2. A total of 51 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).

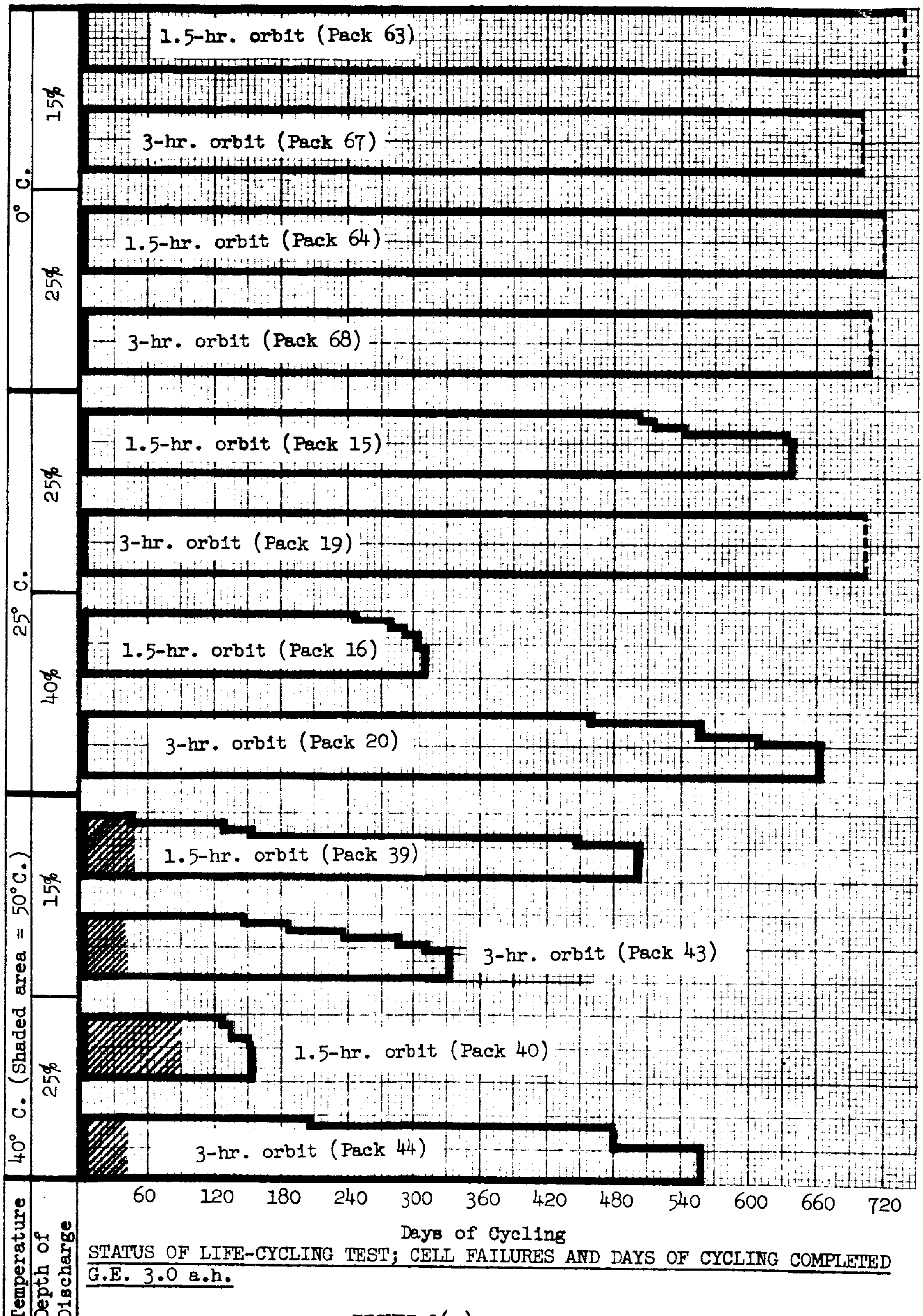
3. The number of cycles and the number of days of continuous cycling completed by each pack are given in Table III. An asterisk indicates that the pack had failed as of the given cycle.

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

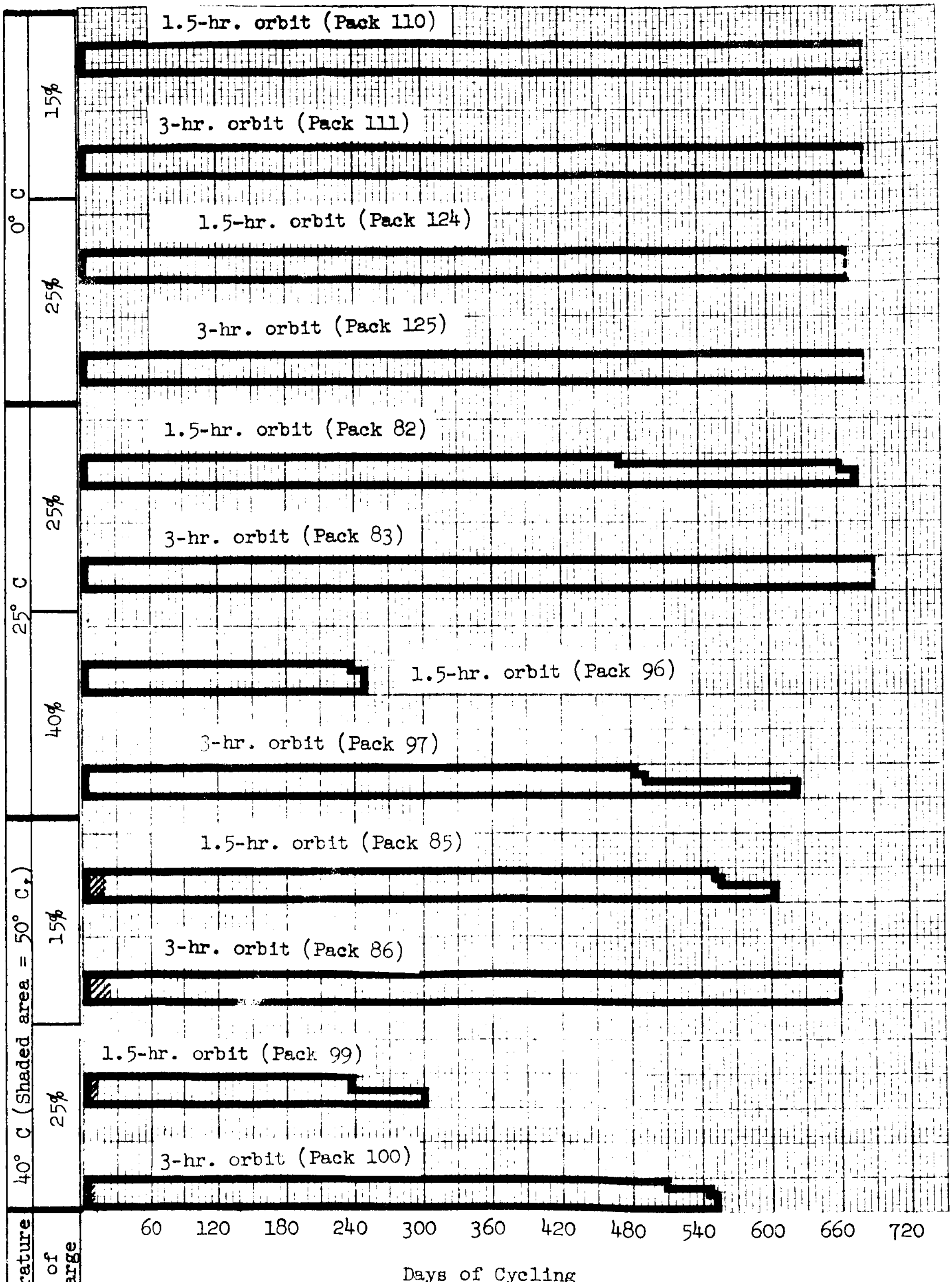
CYCLES AND DAYS OF CYCLING COMPLETED AS OF 31 DECEMBER 1965

Test Temperature	Depth of Discharge	Orbit Period (hours)	G.E. 3 a.h. Pack Number	G.E. 3 a.h. Cycles	G.E. 3 a.h. Days of Cycling	G.E. 12 a.h. Pack Number	G.E. 12 a.h. Cycles	G.E. 12 a.h. Days of Cycling	GOULD 3.5 a.h. Pack Number	GOULD 3.5 a.h. Cycles	GOULD 3.5 a.h. Days of Cycling	GOULD 20 a.h. Pack Number	GOULD 20 a.h. Cycles	GOULD 20 a.h. Days of Cycling	GULTON 6 a.h. Pack Number	GULTON 6 a.h. Cycles	GULTON 6 a.h. Days of Cycling	GULTON 20 a.h. Pack Number	GULTON 20 a.h. Cycles	GULTON 20 a.h. Days of Cycling	SONOTONE 5 a.h. Pack Number	SONOTONE 5 a.h. Cycles	SONOTONE 5 a.h. Days of Cycling
0° C	15%	1.5	63	11816	738.5	110	10963	685.2	51	11533	720.8	84	10909	631.8	61	10146*	634.1	101	3631*	226.9	49	11191	699.4
		3	67	5603	700.4	111	5479	684.9	55	5655	706.9	80	5427	678.4	65	5549	693.6	102	5255	656.9	53	5521	690.1
	25%	1.5	64	11537	721.1	124	10730	670.6	52	11246	702.9	98	10422	651.4	62	10869	679.3	115	2291*	143.2	50	11300	706.3
		3	68	5664	708.0	125	5472	684.0	56	5634	704.3	94	5309	663.6	66	4414*	551.8	116	5097	637.1	54	5539	692.4
25° C	25%	1.5	15	10382*	648.9	82	10878*	679.9	3	4751*	296.9	104	2980*	186.3	13	4021*	251.3	73	7763*	485.2	1	10971	685.7
		3	19	5636	704.5	83	5538	692.3	7	4173*	521.6	105	5227	653.3	17	2885*	360.6	74	1754*	219.3	5	5364	670.5
	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	6672*	417.0
		3	20	5349	668.6	97	5002*	625.3	8	2494*	311.8	119	1793*	224.1	18	1550*	193.8	88	358*	44.8	6	5211*	651.4
50° - 40° C	15%	1.5	39	8109*	506.8	85	9710*	606.9	27	4485*	280.3	112	5213*	325.8	37	6064*	379.0	76	9348*	584.3	25	9328*	583.0
		3	43	2656*	332.0	86	5289	661.1	31	2524*	315.5	108	4273*	534.1	41	1689*	211.1	77	5264	658.0	29	5252	656.5
	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	4487*	560.9	100	4424*	553.0	32	974*	121.8	122	933*	122.9	42	4133*	516.6	91	4480*	560.0	30	4141*	517.6



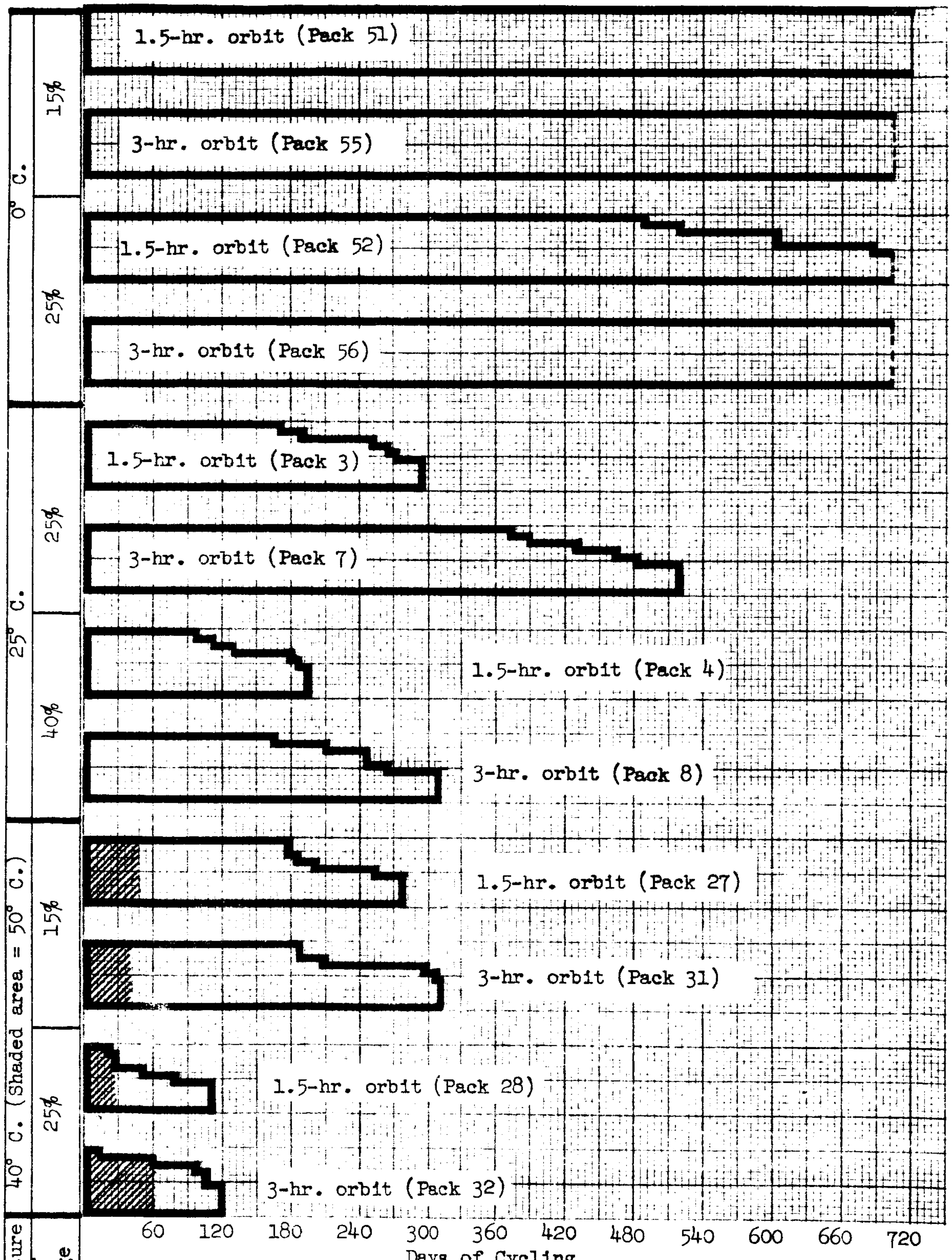
STATUS OF LIFE-CYCLING TEST; CELL FAILURES AND DAYS OF CYCLING COMPLETED G.E. 3.0 a.h.

FIGURE 3(a)



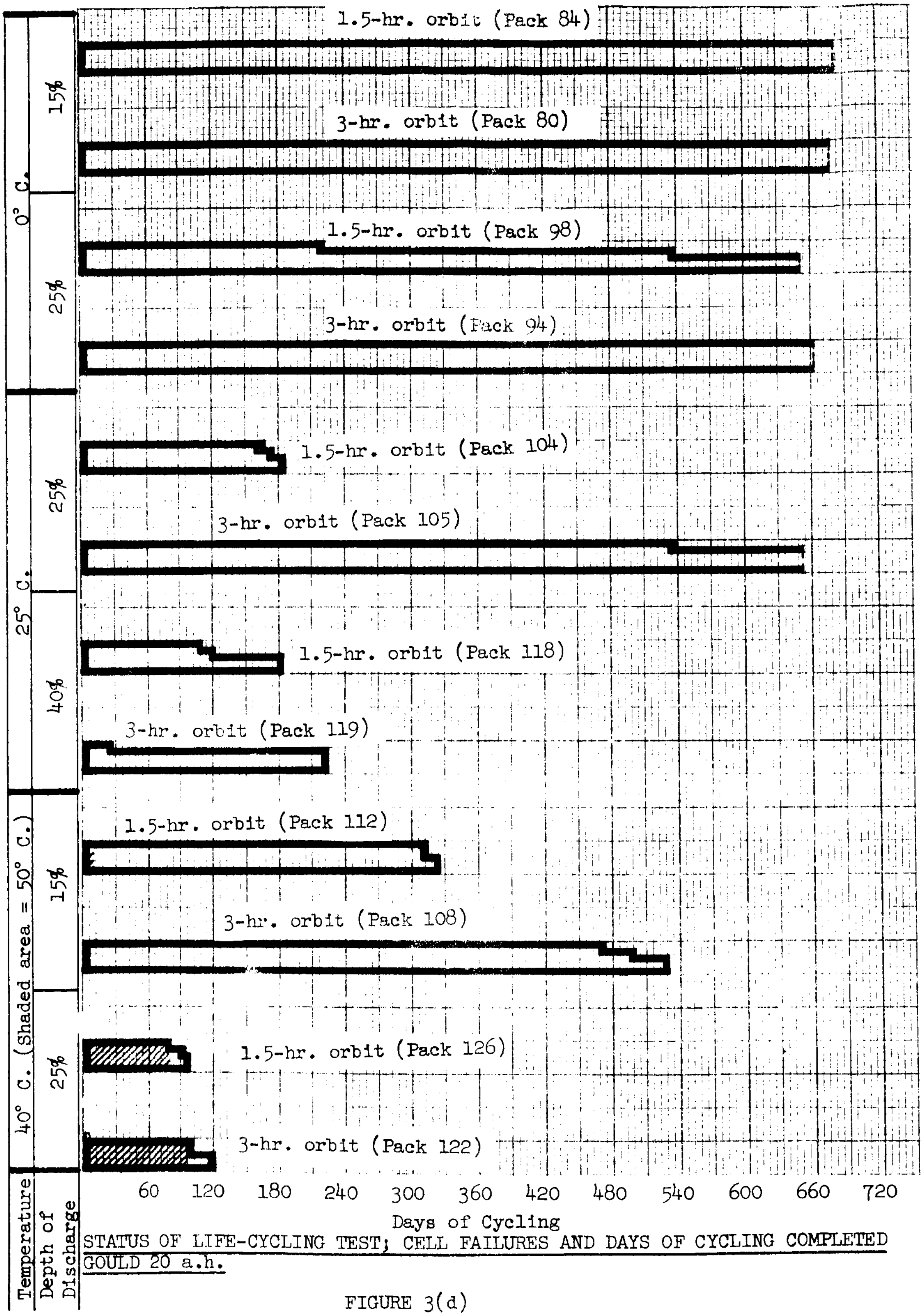
STATUS OF LIFE-CYCLING TEST; CELL FAILURES AND DAYS OF CYCLING COMPLETED G.E. 12 a.h.

FIGURE 3(b)



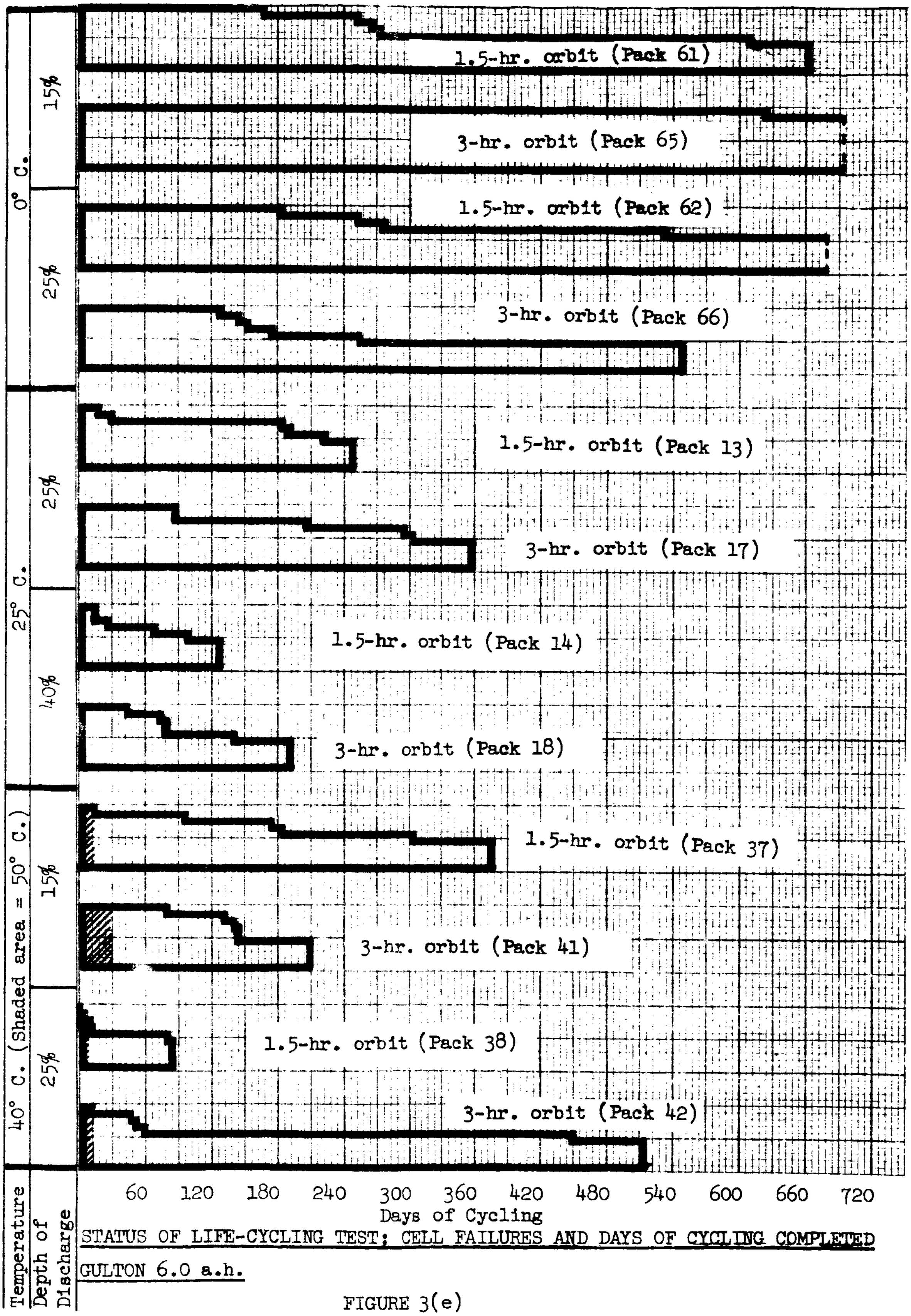
STATUS OF LIFE-CYCLING TEST; CELL FAILURES AND DAYS OF CYCLING COMPLETED
GOULD 3.5 a.h.

FIGURE 3(c)



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

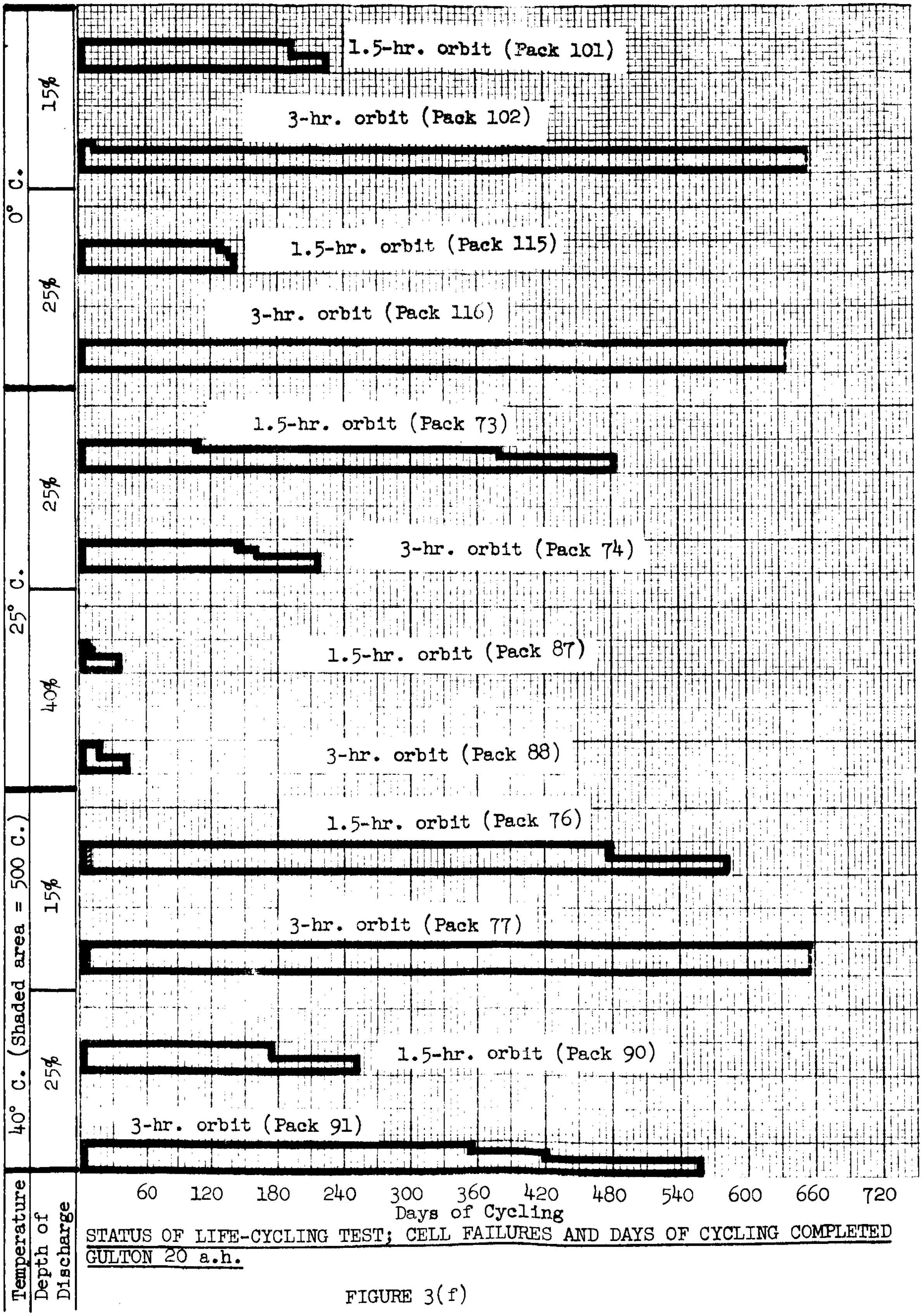
FIGURE 3(d)



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

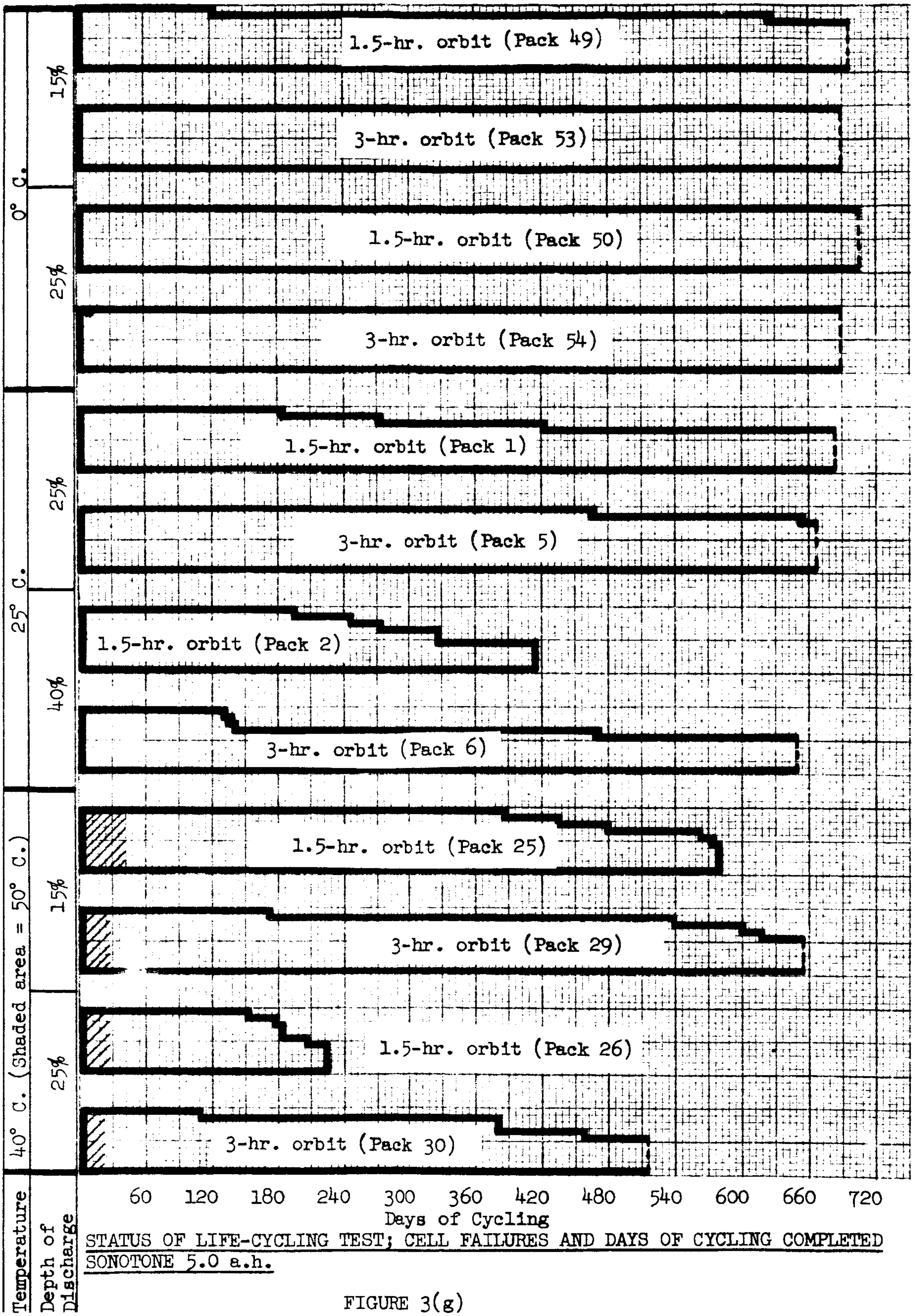
GULTON 6.0 a.h.

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 8(a) through 14(l), 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 10-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 8(a) through 14(l) should be consulted where somewhat greater detail is desired. Pack failures are also indicated by an asterisk, with the horizontal position of the asterisk giving the time of failure. The vertical position of the symbol is of no significance.

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 0.04 volt per cell, over a period of 2 years. The end-of-discharge voltage may drop more than this, especially when a pack approaches failure. The least overall change is seen at 0° C. However, the Gulton 20 a.h. pack at 40° C, 25 percent depth and 3-hour orbit 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 and remained there until the pack failed after almost 19 months of cycling. For a given temperature and cell type, the discharge voltage is generally from 0.02 to 0.08 volts 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 0.0 to 0.1 volt per cell with increase in test temperature from 0° C 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).

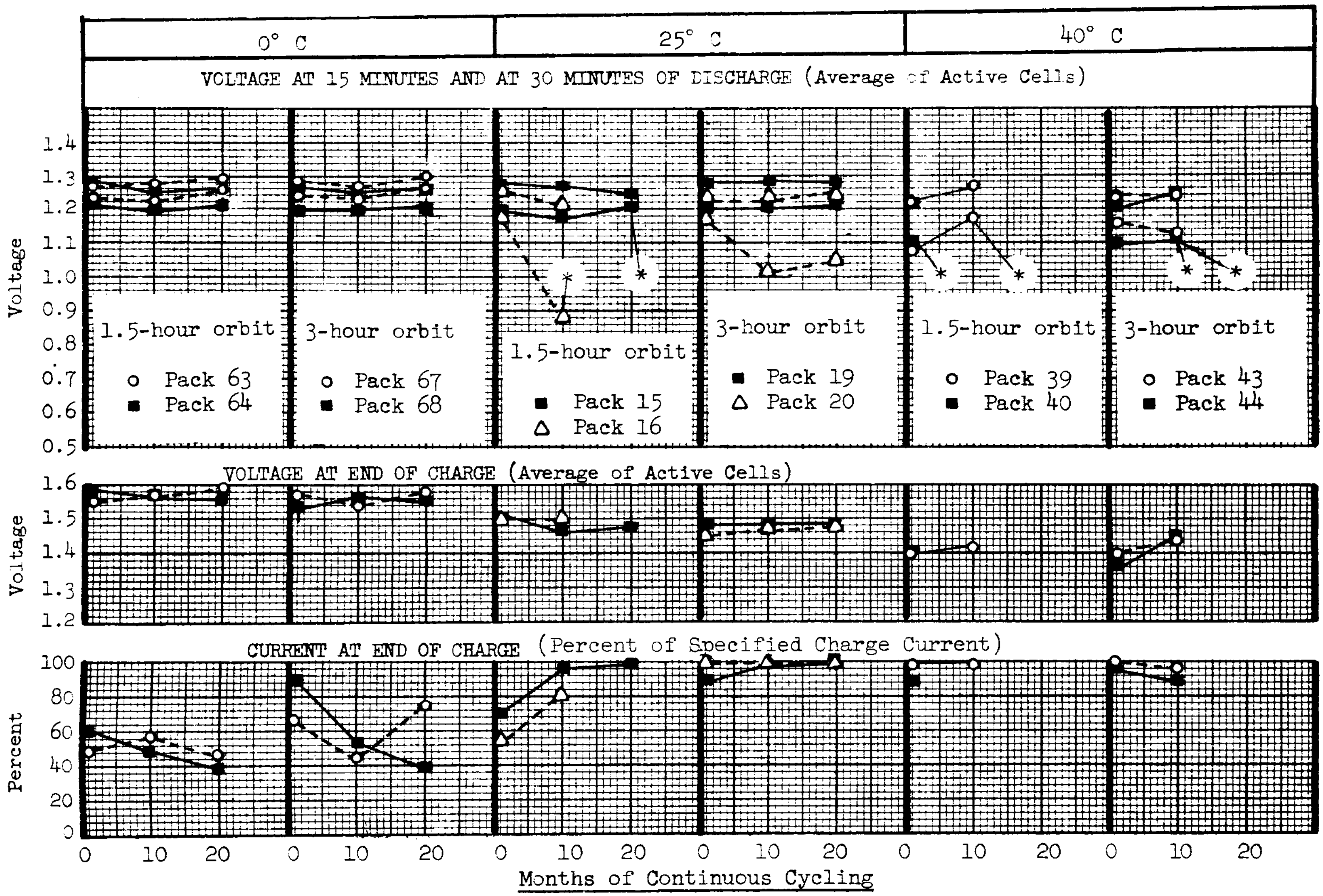
3. End-of-charge current and voltage must be considered simultaneously since the amount by which the current is reduced during the charge portion of a given cycle is determined by the voltage. A tendency towards an increasing end-of-charge voltage will be reflected instead as a decrease in end-of-charge 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.

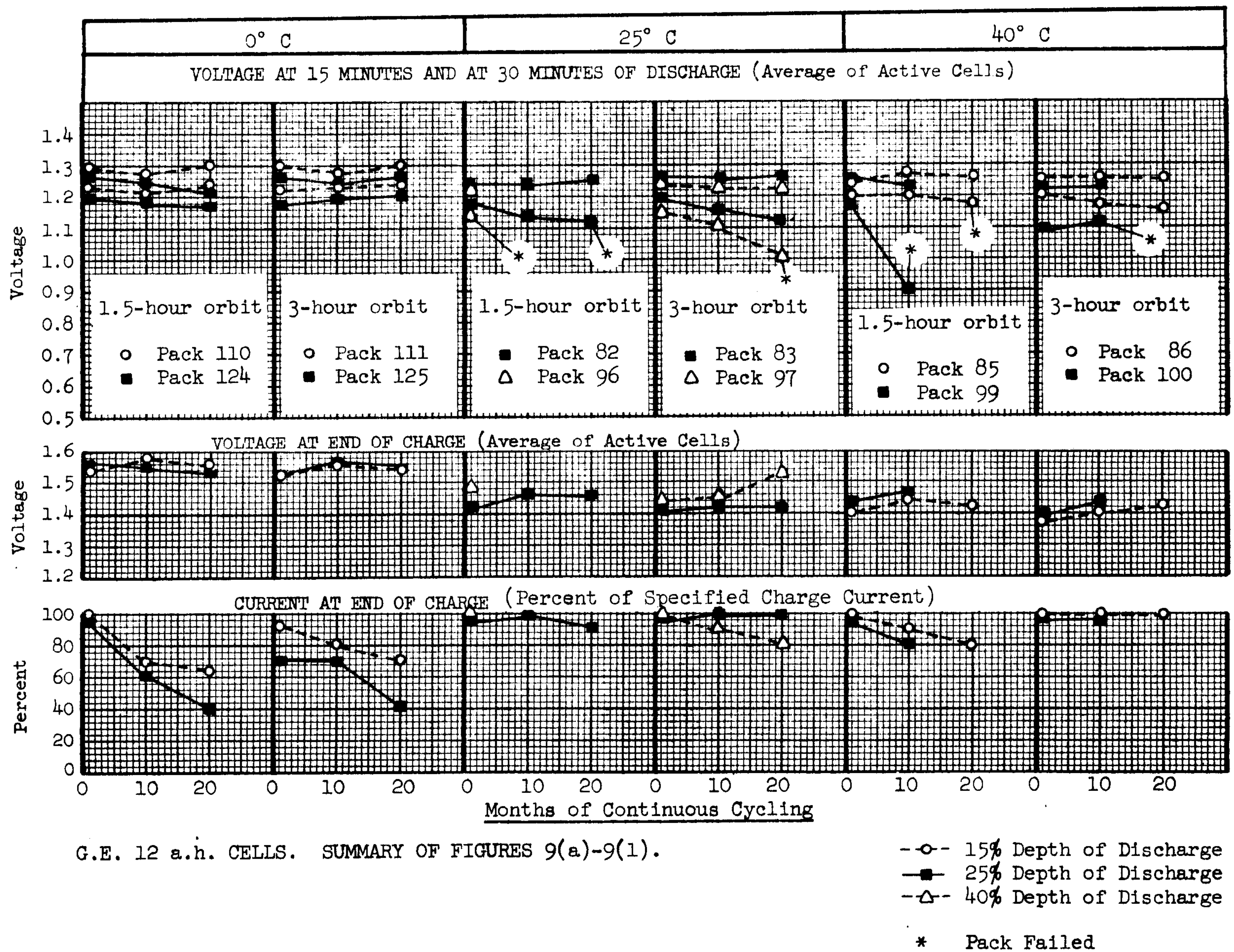
b. In Figures 4(a) through 4(g) the end-of-charge currents are expressed as percent of the specified charge rate. If the voltage limit was not reached, the current is shown as 100 percent. The current values plotted are averages, selected to represent overall trends.

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 although some of the packs did have an increase in the end-of-charge current. This usually occurred after the regular cycling had been interrupted by a capacity check, cell failure, or equipment maintenance. 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 112, 118 and 119 (Gould 20 a.h.), Packs 90 and 102 (Gulton 20 a.h.), and Packs 2, 25, 26 and 54 (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.).



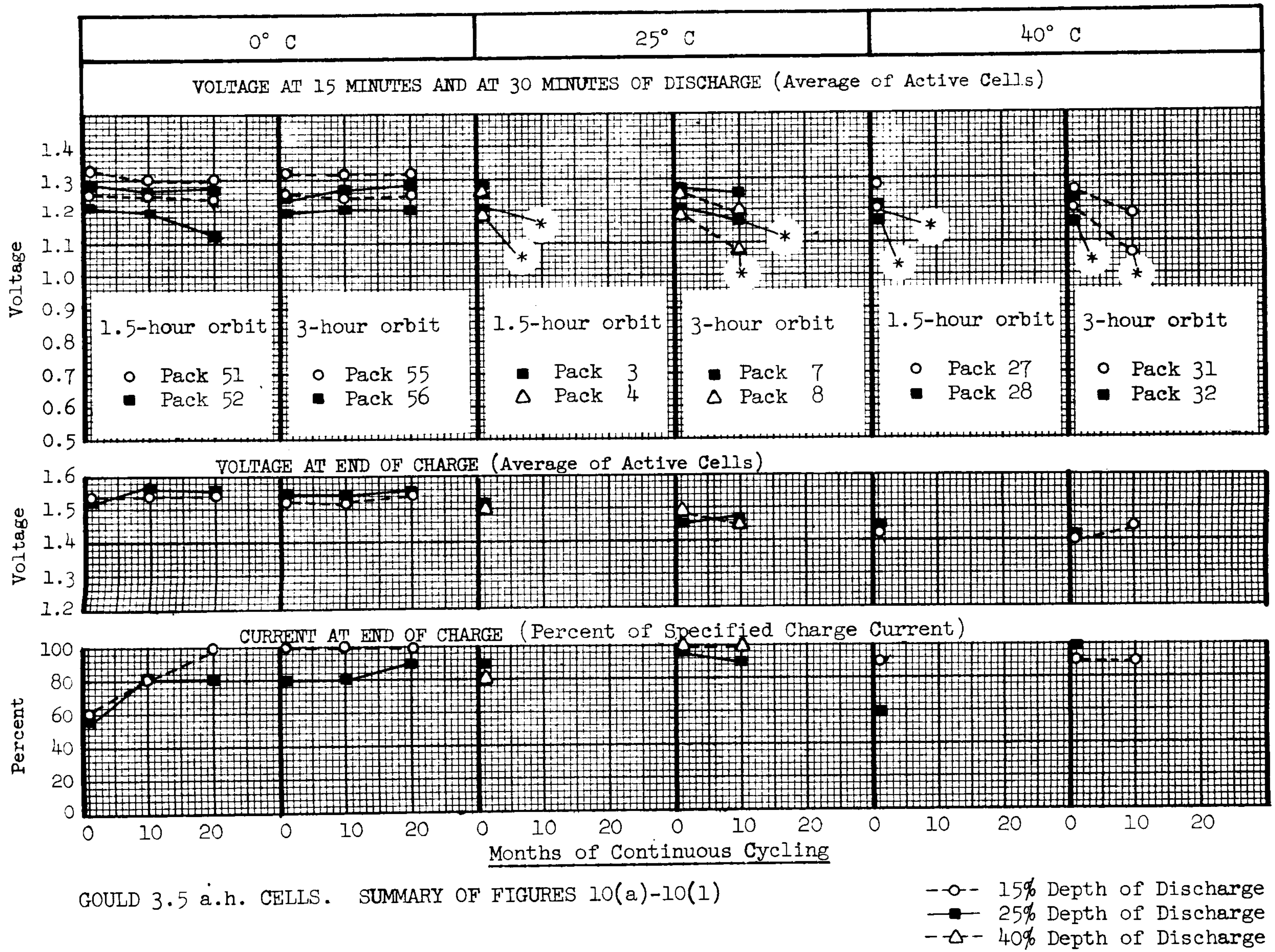
G.E. 3.0 a.h. CELLS. SUMMARY OF FIGURES 8(a)-8(l)

FIGURE 4(a)



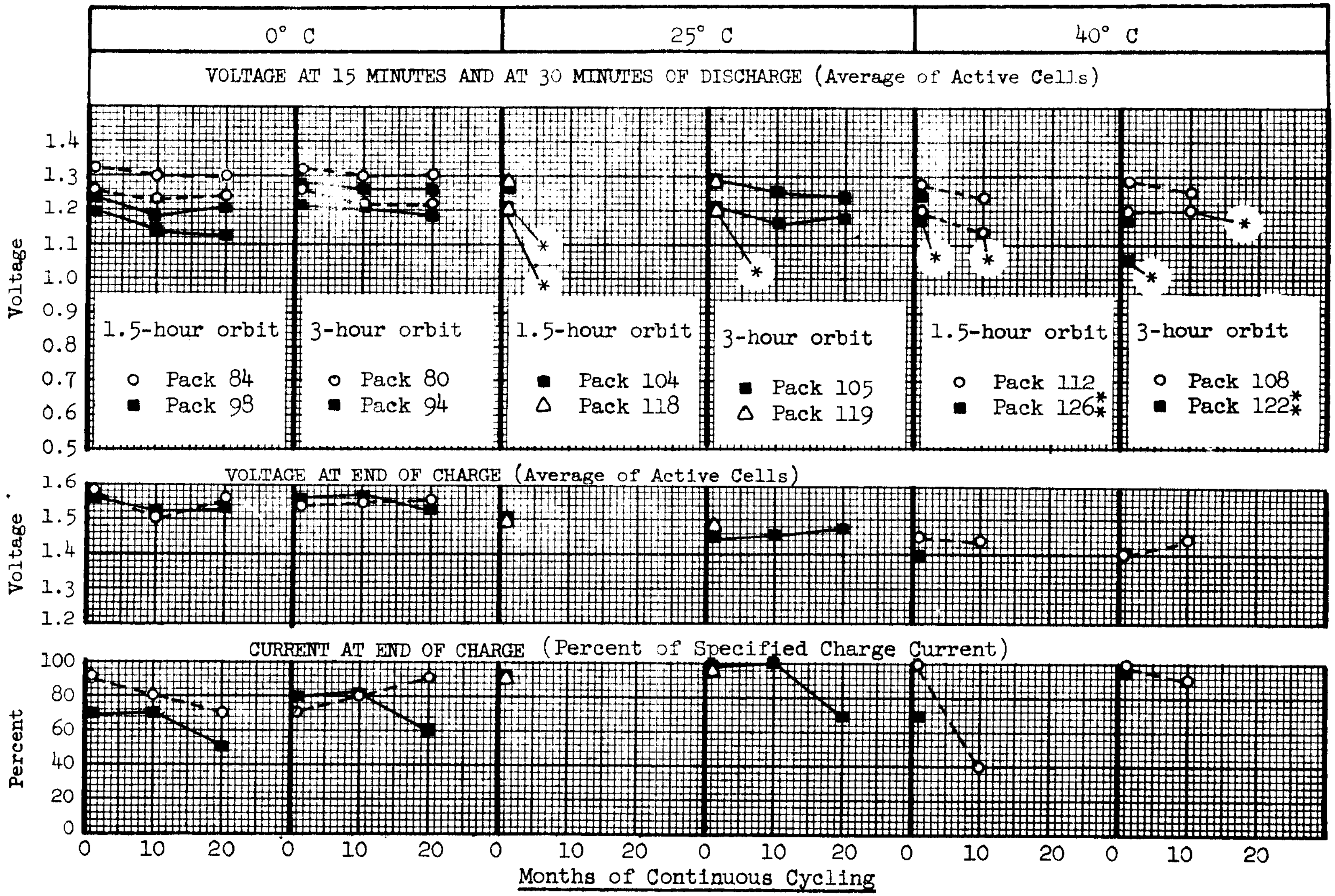
G.E. 12 a.h. CELLS. SUMMARY OF FIGURES 9(a)-9(l).

FIGURE 4(b)



GOULD 3.5 a.h. CELLS. SUMMARY OF FIGURES 10(a)-10(l)

FIGURE 4(c)



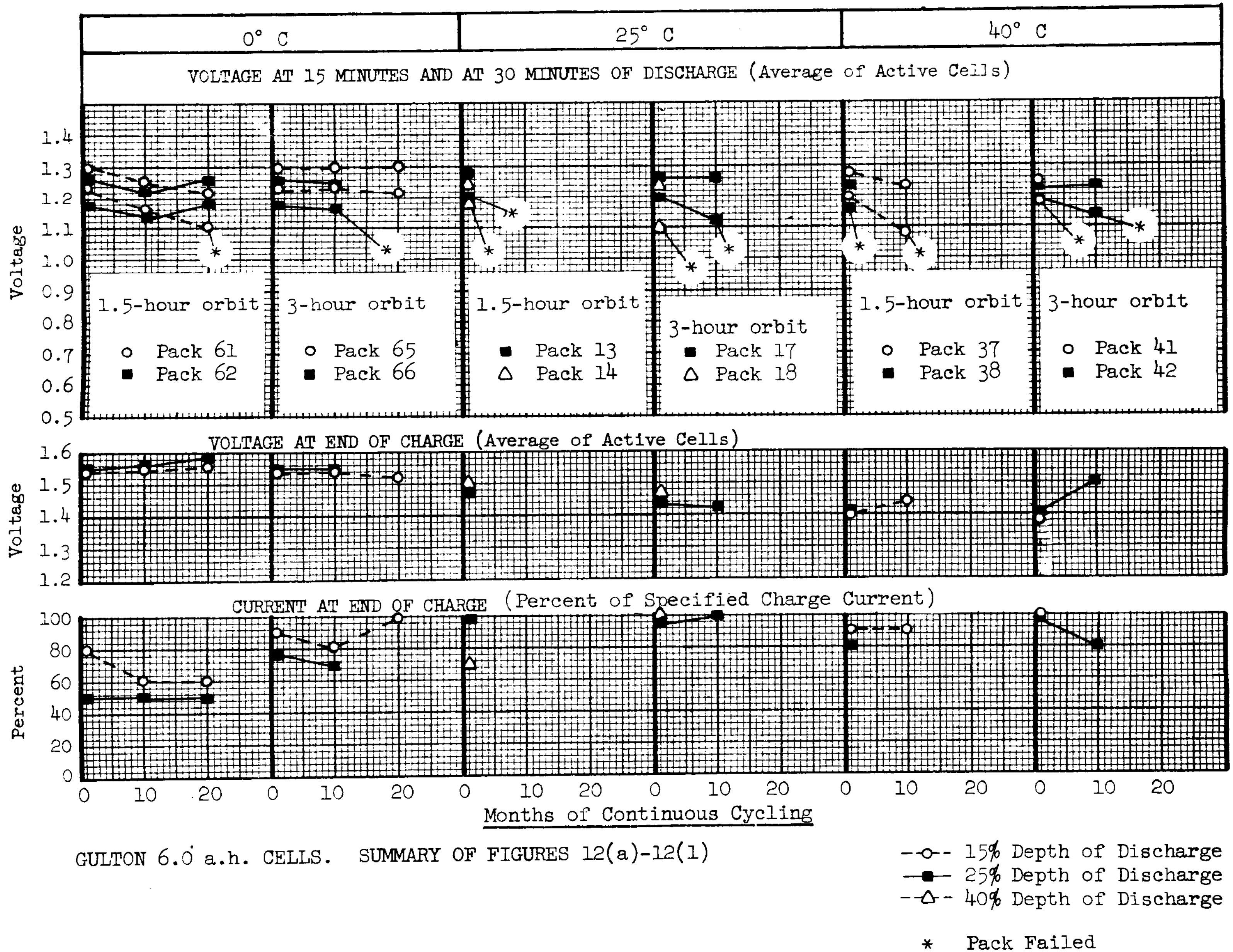
GOULD 20 a.h. CELLS. SUMMARY OF FIGURES 11(a)-11(l)

--○-- 15% Depth of Discharge
—■— 25% Depth of Discharge
--△-- 40% Depth of Discharge

* Pack Failed

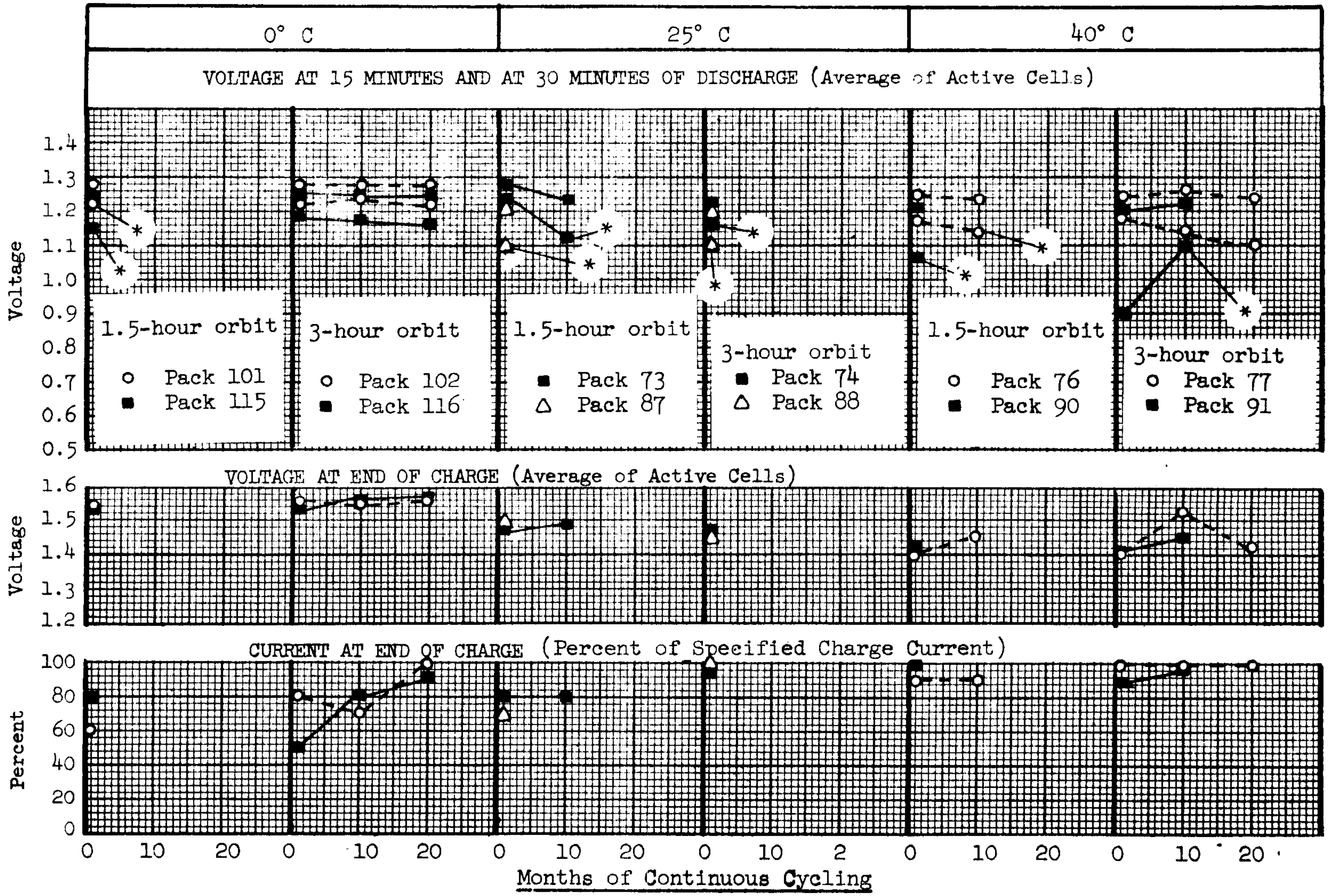
⁑ At 50° C

FIGURE 4(d)



GULTON 6.0 a.h. CELLS. SUMMARY OF FIGURES 12(a)-12(l)

FIGURE 4(e)

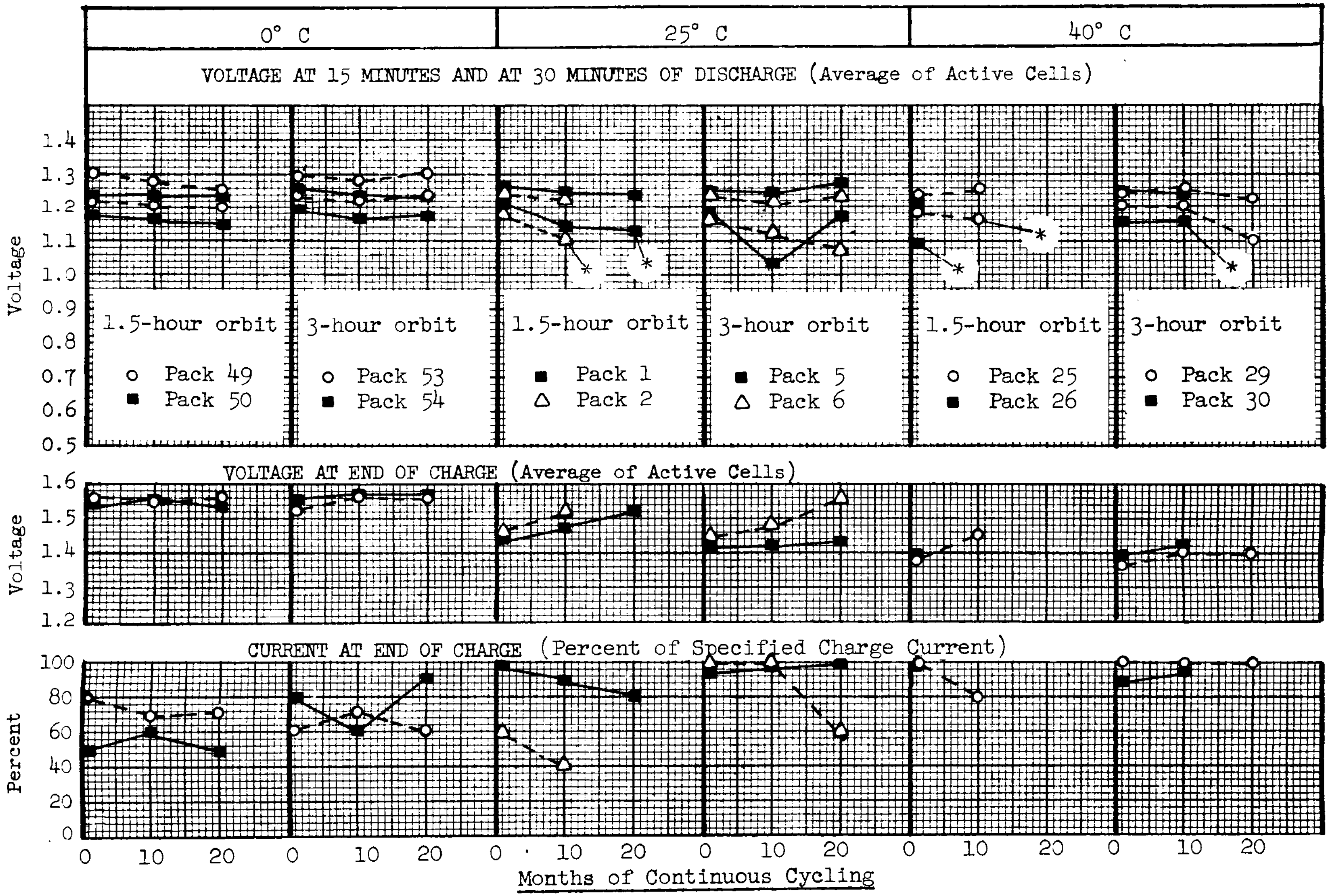


GULTON 20 a.h. CELLS. SUMMARY OF FIGURES 13(a)-13(l)

--o-- 15% Depth of Discharge
—■— 25% Depth of Discharge
--△-- 40% Depth of Discharge

* Pack Failed

FIGURE 4(f)



SONOTONE 5.0 a.h. CELLS. SUMMARY OF FIGURES 14(a)-14(1)

--○-- 15% Depth of Discharge
—■— 25% Depth of Discharge
--△-- 40% Depth of Discharge

* Pack Failed

FIGURE 4(g)

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 December 1965 or the last month of cycling for those packs that failed earlier. Another check had been made of the temperatures 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° C to 10° C above ambient. Generally, for each type, the packs at the 40 percent depth of discharge show temperatures 3° C to 5° C higher than those at 25 percent depth, and at each depth the range for the 1.5-hour orbit is slightly higher than for the 3-hour orbit. A comparison of the two temperature checks revealed that the temperature range had not changed.

3. At 0° C 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 averaged 1° C to 2° C above ambient, with the maximum temperature rise (8° C to 9° C) being shown by the Gould 20 a.h. packs cycling at 1.5 hours. A comparison of the two temperature checks revealed that the temperature range had not changed. The majority of packs in the 40° C environment showed almost no rise in average thermocouple temperature above ambient. This was also true for the three packs which were still cycling at 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° C and 47.3° C respectively. The December 1965 check showed that the March 1964 cell temperatures were typical for this ambient temperature with one exception. The Gould 20 a.h. pack operating at 15 percent depth of discharge and 3-hour orbit had a maximum temperature of 42.7° C in March 1964 but increased to 54.3° C by December 1965.

TABLE IV

TYPICAL RANGE OF PACK TEMPERATURE READINGS

Pack Number	Ambient Temperature °C	Percent Depth of Discharge	Orbit Period (Hours)	Temperatures Discharge Max.	Temperatures Discharge Min.	Temperatures Charge Max.	Temperatures Charge Min.
G.E. 3.0 a.h.							
63	0	15	1.5	4.0	0.6	4.2	0.4
67	0	15	3	2.8	-2.7	4.0	-3.1
64	0	25	1.5	2.2	-1.3	2.8	-1.1
68	0	25	3	3.4	-1.1	2.8	-1.7
15	25	25	1.5	31.4	27.8	31.5	27.5
19	25	25	3	27.9	25.3	28.3	23.6
16	25	40	1.5	36.5	28.3	36.8	28.8
20	25	40	3	35.0	29.5	34.1	27.9
39	40	15	1.5	41.9	39.5	31.9	39.8
43	40	15	3	42.2	40.2	42.0	38.2
40	50	25	1.5	52.3	48.3	52.3	49.5
44	40	25	3	44.7	41.5	43.7	39.6
G.E. 12 a.h.							
110	0	15	1.5	2.8	-2.5	1.4	-2.5
111	0	15	3	3.3	-0.9	3.2	-3.1
124	0	25	1.5	3.2	-3.5	3.1	-0.9
125	0	25	3	4.0	0.2	3.2	-1.1
82	25	25	1.5	30.0	26.0	30.5	27.1
83	25	25	3	32.0	26.0	30.4	23.8
96	25	40	1.5	35.4	29.8	36.4	30.2
97	25	40	3	35.0	27.5	35.8	25.8
85	40	15	1.5	41.6	37.5	40.8	37.6
86	40	15	3	41.9	38.1	41.0	38.1
99	40	25	1.5	47.3	41.4	47.3	40.1
100	40	25	3	44.8	39.6	42.9	39.2

TABLE IV (Contd)

TYPICAL RANGE OF PACK TEMPERATURE READINGS

Pack Number	Ambient Temperature °C	Percent Depth of Discharge	Orbit Period (Hours)	Temperatures Discharge Max.	Temperatures Discharge Min.	Temperatures Charge Max.	Temperatures Charge Min.
			Gould 3.5 a.h.				
51	0	15	1.5	4.3	0.4	4.2	1.1
55	0	15	3	3.5	-0.7	3.0	-2.8
52	0	25	1.5	5.2	0.6	4.4	-0.8
56	0	25	3	4.8	-1.1	4.2	-2.8
3	25	25	1.5	42.1	29.8	41.9	30.2
7	25	25	3	31.6	27.7	32.0	26.7
4	25	40	1.5	41.6	31.5	40.0	31.2
8	25	40	3	40.0	31.5	40.8	27.9
27	40	15	1.5	43.5	40.6	42.9	40.0
31	40	15	3	42.7	39.5	41.6	37.9
28	40	25	1.5	40.0	37.6	40.0	36.2
32	40	25	3	45.4	42.7	44.8	40.0
			Gould 20 a.h.				
84	0	15	1.5	8.8	1.1	8.2	0.8
80	0	15	3	4.0	-2.7	2.0	-1.3
98	0	25	1.5	9.2	-1.3	8.0	-0.9
94	0	25	3	3.0	-3.9	3.1	-1.1
104	25	25	1.5	28.3	27.2	28.5	27.3
105	25	25	3	30.6	25.8	30.0	23.7
118	25	40	1.5	42.9	37.5	42.7	37.9
119	25	40	3	39.6	31.2	37.0	27.9
112	40	15	1.5	41.6	36.0	42.1	36.8
108	40	15	3	54.3	49.3	50.8	48.5
126	50	25	1.5	51.4	49.1	51.0	49.4
122	50	25	3	55.0	49.6	51.4	49.6

TABLE IV (Contd)

TYPICAL RANGE OF PACK TEMPERATURE READINGS

Pack Number	Ambient Temperature °C	Percent Depth of Discharge	Orbit Period (Hours)	Temperatures Discharge Max.	Temperatures Discharge Min.	Temperatures Charge Max.	Temperatures Charge Min.
Gulton 6.0 a.h.							
61	0	15	1.5	3.4	-2.9	3.1	-3.3
65	0	15	3	4.4	1.1	6.0	-1.5
62	0	25	1.5	2.8	-0.3	4.0	-1.2
66	0	25	3	4.8	-0.7	4.0	-0.7
13	25	25	1.5	31.5	26.5	31.8	27.3
17	25	25	3	31.9	26.8	31.4	25.0
14	25	40	1.5	33.3	28.7	36.1	28.5
18	25	40	3	35.6	27.3	36.0	26.8
37	40	15	1.5	45.6	39.3	46.0	37.6
41	40	15	3	44.6	40.8	44.6	40.0
38	40	25	1.5	44.8	40.9	45.9	41.0
42	40	25	3	40.8	37.9	41.7	38.0
Gulton 20 a.h.							
101	0	15	1.5	3.2	-1.9	4.0	-0.7
102	0	15	3	3.2	-4.1	1.2	-2.8
115	0	25	1.5	4.8	-0.7	5.4	2.8
116	0	25	3	3.3	-2.8	2.8	-3.3
73	25	25	1.5	30.3	27.3	32.5	26.2
74	25	25	3	31.2	26.0	31.8	27.3
87	25	40	1.5	42.9	38.0	44.2	38.1
88	25	40	3	36.2	25.4	38.0	26.2
76	40	15	1.5	41.9	40.0	42.0	39.6
77	40	15	3	41.9	38.1	42.0	37.7
90	40	25	1.5	42.7	38.8	42.9	38.1
91	40	25	3	43.5	39.5	45.8	41.4

TABLE IV (Contd)

TYPICAL RANGE OF PACK TEMPERATURE READINGS

Pack Number	Ambient Temperature °C	Percent Depth of Discharge	Orbit Period (Hours)	Temperatures Discharge Max.	Min.	Charge Max.	Min.
			Sonotone 5.0 a.h.				
49	0	15	1.5	2.0	-2.3	3.2	-1.9
53	0	15	3	6.0	1.3	6.0	-0.8
50	0	25	1.5	3.3	-0.7	2.8	-0.3
54	0	25	3	4.0	-2.9	1.2	-3.9
1	25	25	1.5	39.6	34.5	39.1	34.1
5	25	25	3	34.2	29.1	34.3	28.3
2	25	40	1.5	38.1	27.3	38.1	32.7
6	25	40	3	36.0	29.6	37.0	29.3
25	40	15	1.5	45.8	38.0	46.0	38.4
29	40	15	3	43.9	41.2	44.1	40.0
26	40	25	1.5	48.9	39.3	45.0	37.9
30	40	25	3	44.6	41.2	44.8	41.0

E. Cell Failures:

1. Cell failures are discussed below, with detailed results of the failure analyses shown in Tables Va through Vg and Figures 5(a) through 5(g).

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 (+), 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 two exceptions, this condition was found only among cells tested at 50°-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) Ceramic 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 (Ⓣ), 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 (Ⓢ).

(15) Blisters: Raised areas of active material, which have pulled away from the grid (+). Typically, they ranged from pinhead size to 3/8 inch 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 (Ⓧ). 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). Shorts between the plates may result at the center of the core (Ⓒ).

4. Discussion of Failures:

a. General Observations:

(1) Most of the cell failures occurred at the higher ambient temperatures. Of the total of 281 failures, 33 were at 0° C, 117 at 25° C and 131 at 50°-40° C. The relatively small number of failures at 0° C is more pronounced on certain individual cell types. For example, of the total of 60 failures of Gould 3.5 a.h. cells, only four were at 0° C.

(2) In general, for a given cell type and temperature, failures occurred earlier at the greater depth of discharge although there were exceptions as shown in Figures 3(a) through 3(g). The

1.5-hour orbit was likewise more sever than the 3-hour orbit although there were some exceptions. This comparison of the number of failures at each orbit is shown, as a function of both the number of cycles and the number of calendar days completed by the cells, in Figures 5(a) through 5(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, except those occurring during the month of December 1965, were analyzed by a representative of the manufacturer.

(a) 3.0 a.h. Cells: There were 41 cell failures of which 25 were at the 50°-40° C ambient condition (one at 50° C before dropping temperature to 40° C) and 16 were at 25° C. These are shown in Table Va. Figure 5(a) shows that the cell failures can be grouped into those which failed before 350 days of cycling and those which failed after 450 days of cycling.

1. At 50°-40° C, burned tabs were present in the 17 early failures. This condition accounted for 10 failures on the 1.5-hour orbit and seven on the 3-hour orbit. All of the cell failures after 287 days of cycling on the 3-hour orbit and after 451 days of cycling on the 1.5-hour orbit showed separator deterioration usually accompanied by migration. Although it is not indicated in Table Va, the plates of several cells were exposed at the edge of the roll, apparently due to improper alignment of the seapartors.

2. At 25° C, 15 of the 16 failed cells showed signs of migration. Burned tabs was the cause of failure of the sixteenth cell and contributed to that of one of the other fifteen

cells. The cells of the 3-hour orbit period which failed after 463 days of cycling, and the cells of the 1.5-hour orbit period which failed after 504 days of cycling showed separator deterioration and blistering of the positive plates. At this temperature, each orbit period had one of the two burned tab failures.

(b) 12 a.h. Cells: There were 18 failures, of which nine were at 40° C and nine were at 25° C. These are shown in Table Vb. Twice as many failures occurred at the 1.5-hour orbit than at the 3-hour orbit as shown in Figure 5(b).

1. At 40° C, eight of the nine cells showed separator deterioration. Migration was also present in seven of these same cells and in the ninth failed cell. High pressures were prevalent in the cells of both the 1.5-hour and 3-hour orbit periods which failed after 521 days of cycling.

2. At 25° C, the nine failed cells showed migration. Those cells which failed after 470 days of cycling showed separator deterioration. Most of the migration in cells of the 1.5-hour orbit resulted in shorting penetration.

(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 60 cell failures of which 29 were at the 50°-40° C ambient condition (three at 50° C before dropping temperature to 40° C), 26 were at 25° C and five were at 0° C. These are shown in Table Vc. At 40° C and 25° C, the cells cycled on the 1.5-hour orbit period ran about the same number of successful cycles as those cycled on the 3-hour orbit period. This is shown in Figure 5(c).

1. Migration was common after 100 days at 50°-40° C, after 168 days at 25° C, and after 491 days at 0° C.

2. At 40° C and 25° C, separator deterioration became common after about 180 days of cycling, and after 491 days of cycling at 0° C.

3. At 40° C and 25° C, weight losses of 1.1 to 7.1 grams occurred in 39 of the cell failures. No weight loss was observed at 0° C.

4. At 40° C and 25° C, one or more weak welds were present on 25 cell failures, whereas none were observed on the cells cycling at 0° C.

5. At 40° C and 25° C, the distribution of failure conditions was quite similar for both orbit periods.

(b) 20 a.h. Cells: There were 24 cell failures of which 12 were at 50°-40° C ambient condition (one at 50° C before dropping temperature to 40° C), 10 were at 25° C, and two were at 0° C. These are shown in Table Vd. At 40° C or 25° C, the cells cycled on the 1.5-hour orbit period ran about the same number of successful cycles as those cycled on the 3-hour orbit period. This is shown in Figure 5(d).

1. Nearly all of the cells developed high pressure, as evidenced by the release of gas when analyzing cells for causes 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. At 40° C and 25° C, migration was present in eight of the 11 failed cells in the 3-hour orbit, and was present in the two failed cells in the 1.5-hour orbit at 0° C.

4. The majority of the 24 cells failed rather suddenly, with little or no indication on previous cycles.

5. Separator deterioration was common at 40° C but was infrequent at 25° C and 0° C.

(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 65 cell failures of which 24 were at 50°-40° C ambient condition (four at 50° C before dropping temperature to 40° C), 24 were at 25° C and 17 were at 0° C. These are shown in Table Ve. At 40° C and 25° C, the cells cycled on the 1.5-hour orbit period ran about the same number of successful cycles as those cycled on the 3-hour orbit period. However, at 0° C, cell failures occurred on both the 1.5-hour orbit period and the 3-hour orbit period at about the same number of days of cycling. This is shown in Figure 5(e).

1. At the higher temperatures, 40° C and 25° C, approximately 34 percent of the failed cells showed weight losses of 2.3 to 12.0 grams.

2. A ceramic short was exhibited by 59 percent of the failures at 0° C, by 75 percent of the failures at 25° C, and by 83 percent of the failures at 40° C ambient conditions.

3. Separator deterioration was rare, probably because 43 of the 65 cell failures occurred before completion of 200 days of cycling.

4. High pressure bulge was common among cells cycling at 0° C in the 1.5-hour and 3-hour orbit periods, and at 25° C in the 1.5-hour orbit period.

(b) 20 a.h. Cells: There were 32 cell failures of which 10 were at 50°-40° C ambient conditions, 15 were at 25° C, and seven were at 0° C. These are shown in Table Vf. At each cycling temperature, the cells cycled on the 1.5-hour orbit period ran about the same number of successful cycles as those cycled on the 3-hour orbit period. This is shown in Figure 5(f).

1. Eighteen of the cells showed weight losses of 6.8 to 26.9 grams.

2. Seven cells had ceramic shorts.

3. Nineteen cells showed evidence of high pressure.

4. Six cells were shorted as a result of concaved sides due to high 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.

5. Separator deterioration was common at 40° C but was infrequent at 25° C and 0° C.

6. Migration was common at 40° C.

(4) Sonotone: All failures of Sonotone cells were analyzed by a representative of the manufacturer except those failures occurring during the month of December 1965.

(a) 5.0 a.h. Cells: There were 41 cell failures of which 22 were at 50°-40° C ambient condition, 17 were at 25° C, and two were at 0° C. These are shown in Table Vg. At each cycling temperature, the cells cycled on the 1.5-hour orbit period ran about the same number of successful cycles as those on the 3-hour orbit period. This is shown in Figure 5(g).

1. Many of these cells had exposed grid wires protruding through the separator at the center of the core.

2. Excessive scoring of the cases produced pressure points on the plates of many cells. This resulted in 11 shorted cells, one of which had the plate material broken beneath the scoring ring.

3. Nineteen of the 41 cell failures had weak welds due primarily to insufficient cleaning of the area prior to welding.

4. Twenty-nine of the 39 failures at 40° C and 25° C showed deteriorated separators.

5. Twenty of the 39 failures at 40° C and 25° C had carbonate deposits around the glass to metal seal indicating leakage although there was no appreciable weight loss.

LIST OF SYMBOLS USED IN TABLES Va THROUGH Vg

End-of-charge Voltage:
- H - High
- L - Low
- S - Shorted
- O - Open Circuited
- N - Normal

Deposits:
- T - Terminal
- S - Seam

High Pressure:
- B - Bulged
- G - Gas Present

Concave Sides:
- X - Present
- Ⓧ - Caused Short

Weak Weld:
- P - Tab to Plate
- C - Tab to Case
- T - Tab to Terminal

Loosened Active Material:
- + - Present

Extraneous Active Material:
- X - Present
- Ⓧ - Caused Short

Pierced Separator:
- Ⓦ - Grid Wire Short
- Ⓣ - Tab to Plate Short

Excess Scoring:
- X - Present
- Ⓧ - Caused Short

Burned Positive Tab:
- X - Present
- b - Broken
- ⓑ - Caused Short

Short Separator:
- X - Present
- Ⓧ - Caused Short

Ceramic Short:
- Ⓧ - Present

Migration:
- X - General
- P - Small Area Penetration
- Ⓟ - Shorting Penetration
- + - Positive Plate
- Ⓣ - Shorting Around Tab
- Ⓢ - Shorting Around Scoring

Blisters:
- + - Present
- ⊕ - Caused Short

Separator Deterioration:
- X - General
- Ⓧ - Permitted Shorting
- C - Center of Core
- Ⓒ - Permitted Shorting

TABLE Va

G.E. 3.0 a.h. CELLS. DATA ON CELL FAILURES THROUGH 31 DECEMBER 1965

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	Migration	Blisters	Loosened Active Material	Extraneous Active Material	Burned Positive Tab	Short Separator	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%	15	7	432	8065	504	L			X	+					X	
25%	15	8	414	8254	516	L			X	+					X	
25%	15	5	479	8714	545	N		T	X	+					X	
25%	15	10	267	10123	633	N			(P)	+					X	
25%	15	4	485	10382	649	L			(P)	+					X	
25%	15	9	447	10382	649	L			(P)	+					X	
25° C; 3-hour orbit																
40%	20	5	421	3704	463	L			X	+					X	
40%	20	2	433	4485	561	L			(P)	+			X		X	
40%	20	6	711	4485	561	L		T	(P)	+					X	
40%	20	3	710	4889	611	S		T	(P)	+					X	

* Additional Notes:
1. Short circuit between plates, no obvious cause.

TABLE Va (Contd)

G.E. 3.0 a.h. CELLS. DATA ON CELL FAILURES THROUGH 31 DECEMBER 1965

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	Migration	Blisters	Loosened Active Material	Extraneous Active Material	Burned Positive Tab	Short Separator	Separator Deterioration	Additional Notes*
					50°-40° C; 1.5-hour orbit											
15%	39	2	541	779	49	H		T					X	(X)		1
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			+					
25%	40	5	49	2446	153	H						X	X			
25%	40	10	45	2461	154	H						X				
25%	40	2	466	2509	157	H		T					X			2
25%	40	6	441	2509	157	L							X	(X)		
15%	39	7	549	2532	158	H							X			
15%	39	1	527	7213	451	N		T	X				X		X	
15%	39	5	534	8109	507	N	3.5		X				X		X	
15%	39	8	550	8109	507	N			P						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			P				b	X	X	
15%	43	7	436	2515	314	O							b		X	3
15%	43	10	435	2656	332	O			P				b		X	
25%	44	8	366	3848	481	H			P	+					X	
25%	44	1	459	3854	482	S		T	P						X	
25%	44	3	77	3854	482	N			X						X	
25%	44	2	3120	4487	561	H		T	P	+	+				X	
25%	44	10	296	4487	561	L		T	(P)		+				X	

* Additional Notes:

1. Failed while pack was cycling at 50° C.
2. Tabs were found shorted together when cell was opened.
3. Short circuit between plates due to improper separator placement.

TABLE Vb

G.E. 12 a.h. CELLS. DATA ON CELL FAILURES THROUGH 31 DECEMBER 1965

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	Migration	Blisters	Separator Deterioration	Pierced Separator
0° C; 1.5-hour and 3-hour orbits (No Failures)												
25° C; 1.5-hour orbit												
40%	96	3	445	3822	239	L			(P)			
40%	96	2	446	4020	251	L			(P)			
40%	96	4	442	4020	251	L			(P)			
25%	82	2	430	7527	470	N			X		(X)	(W)
25%	82	5	397	10624	664	N			(P)		(X)	
25%	82	1	437	10878	680	N	T		(P)		X	
25° C; 3-hour orbit												
40%	97	2	438	3894	487	L	T		P		X	
40%	97	3	435	3946	493	N		G	X	+	X	
40%	97	4	434	5002	625	N		G	X		X	
50°-40° C; 1.5-hour orbit												
25%	99	3	429	3841	240	L	T		P			
25%	99	2	432	3841	240	L			X		X	
25%	99	1	440	4835	303	L			X		X	
15%	85	4	428	8888	556	L		B	X		X	
15%	85	3	448	8947	559	L		B	X		X	
15%	85	2	455	9710	607	N		G	X		X	
50°-40° C; 3-hour orbit												
25%	100	3	427	4170	521	S		B		+	(X)	
25%	100	2	431	4358	548	S		B	X		(X)	
25%	100	1	436	4424	553	S			X		(X)	

TABLE Vc

GOULD 3.5 a.h. CELLS. DATA ON CELL FAILURES THROUGH 31 DECEMBER 1965

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	Pierced Separator	Migration	Blisters	Loosened Active Material	Extraneous Active Material	Weak Weld	Separator Deterioration	Additional Notes*
						0° C; 1.5-hour orbit											
25%	52	8	116	7858	491	L			G		X					X	
25%	52	10	194	8367	523	N			G		P,(T)						
25%	52	7	108	9724	608	H					X		+			X	
25%	52	9	118	9724	608	L					X		+			X	
25%	52	3	55	10994	687	S		T			X		+	(X)		X	
						0° C; 3-hour orbit (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		(T)					P		
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			X				C	X	
40%	8	2	41	2494	312	L	1.7	T			X				P	X	
40%	8	9	130	2494	312	L	2.1	T			+					X	
25%	7	2	49	3007	376	L	2.7	T			X				P	X	
25%	7	1	37	3130	391	N	1.1	T			P		+		P	X	1
25%	7	6	109	3483	435	L	2.0	T			P				P	X	
25%	7	5	104	3736	467	S	1.1	T			P				P	X	
25%	7	7	131	3884	486	N	1.7	T			P		+			X	
25%	7	3	62	4173	522	N	1.4	T			P				P	X	

* Additional Notes:
1. Glass seal broken.

TABLE Vc (Contd)

GOULD 3.5 a.h. CELLS. DATA ON CELL FAILURES THROUGH 31 DECEMBER 1965

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	Pierced Separator	Migration	Blisters	Loosened Active Material	Extraneous Active Material	Weak Weld	Separator Deterioration	Additional Notes*
					50°-40° C; 1.5-hour orbit												
25%	28	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					(P)				C		
25%	28	9	163	1811	113	L		T			(P)				C		
15%	27	3	13	2901	181	L	1.5	T					+			X	
15%	27	8	195	2901	181	N	3.6	T					+			(C)	
15%	27	7	103	2998	187	N			B					(X)			
15%	27	10	200	3270	204	N	2.5	T			(P)				C	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			(T)				C		
25%	32	7	132	875	109		4.4	T	(B)								4
25%	32	9	149	974	122	H	1.1	T						(X)	P,C		
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			X			(X)	P	X	
15%	31	8	R162	2477	310	H	2.4	T			P				C	X	
15%	31	1	72	2517	315	L	1.8	T						(X)	P	X	
15%	31	6	143	2517	315	L			G		X			(X)	P,T	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 off.

TABLE Vd

GOULD 20 a.h. CELLS. DATA ON CELL FAILURES THROUGH 31 DECEMBER 1965

Depth of Discharge	Pack Number	Cell Position in Pack	Cell Serial Number	Cycles Completed	Days of Cycling Completed	End-of-charge Voltage	High Pressure	Pierced Separator	Migration	Blisters	Loosened Active Material	Extraneous Active Material	Separator Deterioration	Additional Notes*
				0° C; 1.5-hour orbit										
25%	98	5	77	3556	222	L			X				X	
25%	98	1	47	8619	539	L	B		X		+		X	1
				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	(W)				X		
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								2
40%	119	2	80	1793	224	N	G		X	+				
40%	119	3	86	1793	224	N	G		X	+				
25%	105	1	40	4306	538	L	G		(P)	+			X	
				50°-40° C; 1.5-hour orbit										
25%	126	3	9	1273	80	L	G	(W)						3
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)	
15%	112	5	38	5213	326	L		(T)		+			(X)	

* Additional Notes:

1. Short through separator at bottom of plates where tape holds plates together.
2. Short circuit between plates, near edge, no obvious cause.
3. Failed while pack was cycling at 50° C.

TABLE Vd (Contd)

GOULD 20 a.h. CELLS. DATA ON CELL FAILURES THROUGH 31 DECEMBER 1965

Depth of Discharge	Pack Number	Cell Position in Pack	Cell Serial Number	Cycles Completed	Days of Cycling Completed	End-of-charge Voltage	High Pressure	Pierced Separator	Migration	Blisters	Loosened Active Material	Extraneous Active Material	Separator Deterioration	Additional Notes*
				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	+				
15%	108	4	R99	3796	475	L			(P)				X	
15%	108	2	81	4003	500	S	G			+			X	1
15%	108	3	82	4233	529	S	G	(T)	X	+	+		X	

* Additional Notes:

1. Several shorts caused by small pieces of metal between plates.

TABLE Ve

GULTON 6.0 a.h CELLS. DATA ON CELL FAILURES THROUGH 31 DECEMBER 1965

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)		+		
25%	62	7	2227	8590	537	L			B			(X)	X	+		
15%	61	3	1636	9760	610	L	2.7		B	X		(X)	X	+	X	2
15%	61	1	1616	10146	634	H	6.0	T		(X)			X		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%	66	4	1591	4414	552	N		T	B	(X)		(X)	P			
15%	65	4	1234	5012	626	L		T	G	X	(T)		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	3203	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	

* Additional Notes:
1. Broken ceramic at seal.
2. Rough place on positive plate shorted through separator.

TABLE Ve (Contd)

GULTON 6.0 a.h. CELLS. DATA ON CELL FAILURES THROUGH 31 DECEMBER 1965

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*
					25° C; 3-hour orbit											
40%	18	6	1826	365	46	N	3.0			X		⊗				
40%	18	3	1615	608	76	N	5.1	T	B							
40%	18	7	1827	643	80	H			B			⊗				
40%	18	9	2228	643	80	H						⊗				
25%	17	3	1832	721	90	H			B			⊗			⊗	
25%	17	5	1862	721	90	H						⊗				
40%	18	5	1562	1145	143	L						⊗				
40%	18	1	1233	1550	194	L						⊗		+		
25%	17	10	2348	1698	211	L						⊗	X	+		
25%	17	1	1757	2375	297	L						⊗				
25%	17	2	1598	2449	306	L						⊗	P	+		
25%	17	9	2347	2885	361	L			B			⊗		+		
					50°-40° C; 1.5-hour orbit											
25%	38	8	1454	37	2	S						⊗				1
25%	38	6	1815	114	7	L	3.5					⊗				1
25%	38	9	1853	187	12	N	4.0	T				⊗				
25%	38	3	1627	225	14	H	3.5									2
15%	37	3	1764	238	15	L	4.0					⊗				1
25%	38	5	2405	1333	83	N				⊗						
25%	38	2	1626	1377	86	L			B			⊗				
15%	37	8	1784	1566	98	L	10.5					⊗				
15%	37	4	1802	2819	176	L						⊗		+		
15%	37	10	2333	2981	186	N						⊗		+		
15%	37	7	1769	4897	306	N	1.0					⊗		+	X	
15%	37	6	1814	6064	379	H		T				⊗	X	+	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 Ve (Contd)

GULTON 6.0 a.h. CELLS. DATA ON CELL FAILURES THROUGH 31 DECEMBER 1965

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*
					50°-40° C; 3-hour orbit											
25%	42	8	2309	96	12	N						(X)				
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)				
25%	42	6	2340	3619	452	N	8.2	T,S					P		X	
25%	42	4	2334	4133	517	L	8.8	T				(X)	X	+	(X)	1

* Additional Notes:
1. Ceramic cracked around terminal.

TABLE Vf

GULTON 20 a.h. CELLS. DATA ON CELL FAILURES THROUGH 31 DECEMBER 1965

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)					1
					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)				2
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					3
25%	73	1	387	6120	383	L	13.2		B			X	+	(X)	
25%	73	4	465	7763	485	L		T		X	(X)	X	+	(X)	
					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			

* Additional Notes:

1. End of negative plates pushed into positive bus.
2. Burned spots on separator near top of plates.
3. Broken ceramic at negative seal.

TABLE Vf (Contd)

GULTON 20 a.h. CELLS. DATA ON CELL FAILURES THROUGH 31 DECEMBER 1965

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	Extraneous Active Material	Separator Deterioration	Additional Notes*
				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				+			1
25%	90	3	378	4045	253	S					(X)				X	
15%	76	2	453	7697	481	S		T						(X)	(X)	2
15%	76	4	431	7698	481	S			B,G			(P)			(X)	
15%	76	3	455	9348	584	S			B,G			(P)	+		(X)	1
				50°-40° C; 3-hour orbit												
25%	91	4	395	2862	358	S	6.8	T			(X)	X			(X)	3
25%	91	3	412	3385	423	S			B			X			(X)	
25%	91	1	489	4480	560	S		T	G	X		(P)	+		(X)	
25%	91	2	447	4480	560	S		T	B	X		(P)	+		(X)	

* Additional Notes:

1. Small short circuit between plates; no obvious cause.
2. Broken ceramic at negative seal.
3. Broken ceramic on both terminals.

TABLE Vg

SONOTONE 5.0 a.h. CELLS. DATA ON CELL FAILURES THROUGH 31 DECEMBER 1965

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	Pierced Separator	Migration	Extraneous Active Material	Weak Weld	Excess Scoring	Separator Deterioration	Additional Notes*
					0° C; 1.5-hour orbit											
15%	49	9	6887	2010	126	L			B		(T)		P			
15%	49	3	4370	10073	630	S					X	X		(X)		
					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	(W)			P			
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	
40%	2	6	3630	5262	329	N		T	B	(T)	X		P		X	
40%	2	7	3631	5262	329	L				(W)	X		P	X	X	3
40%	2	1	3611	6671	417	N		T	B		X			X	(X)	
25%	1	6	4878	7782	486	N		T			X			(X)	(X)	
					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				(W)		(X)	P			
25%	5	2	4351	3771	471	H		T			X			(X)	X	
40%	6	9	6875	3798	475	N			B		X			X	(X)	
40%	6	7	6882	4608	576	N					T		P	(X)	X	
40%	6	6	6880	5211	651	N					X		P	X	(X)	
25%	5	3	4354	5272	659	N			G		X		P	X	X	

* Additional Notes:

1. Foreign particle shorted adjacent plates through separator.
2. Defect (hole) in separator.
3. Separator torn at start of core exposing positive and negative plates.

TABLE Vg (Contd)

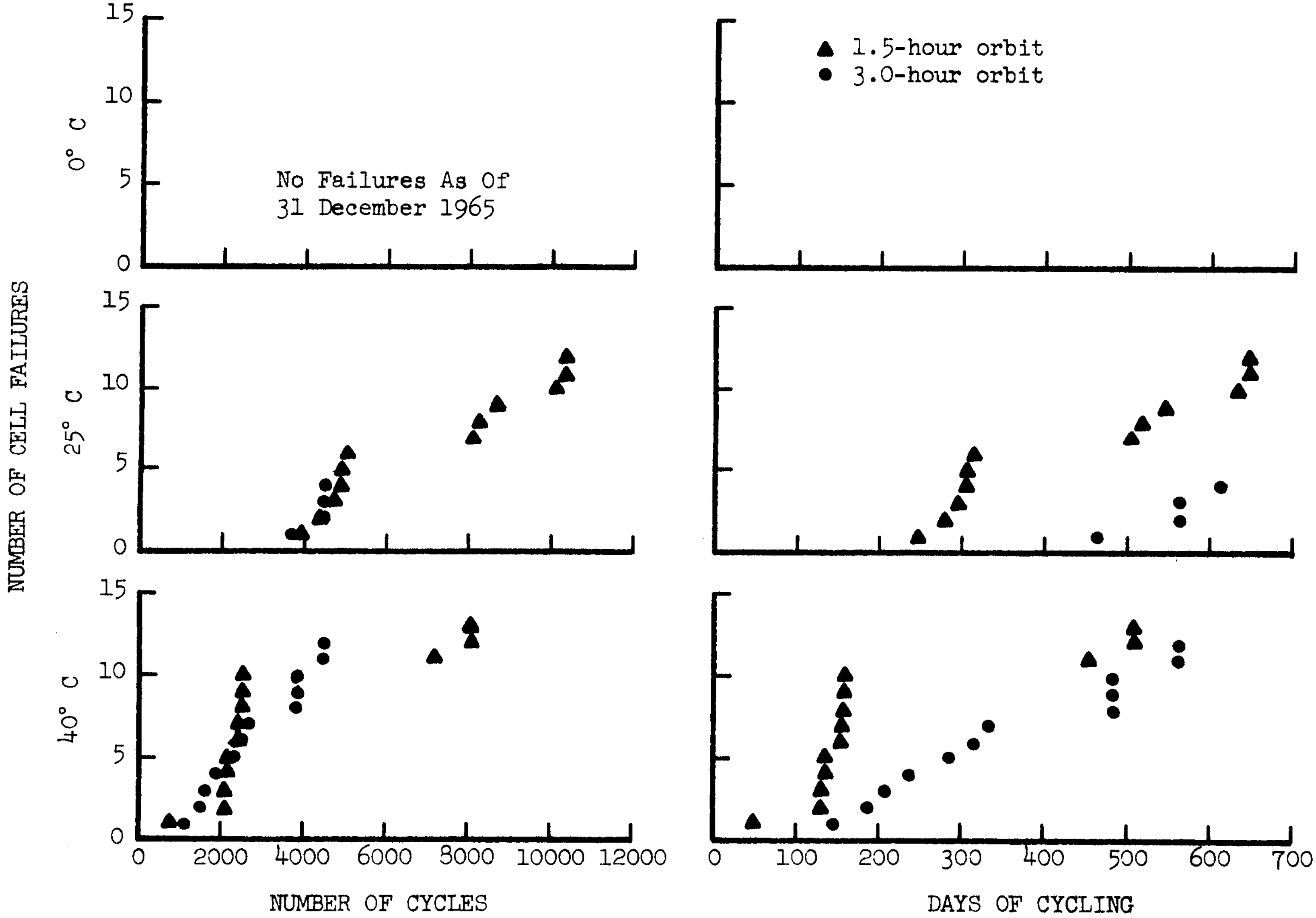
SONOTONE 5.0 a.h. CELLS. DATA ON CELL FAILURES THROUGH 31 DECEMBER 1965

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	Pierced Separator	Migration	Extraneous Active Material	Weak Weld	Excess Scoring	Separator Deterioration	Additional Notes*
					50°-40° C; 1.5-hour orbit											
25%	26	1	4323	2487	155	S				(W)					X	
25%	26	9	6773	2902	181	S			G		(T)		P		X	
25%	26	6	7224	2993	187	N		T	B		X		P		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	
15%	25	5	4852	6348	397	H					P			(X)	(C)	
15%	25	4	4364	7052	441	N		T	B		X			(X)	(X)	
15%	25	1	4317	7758	485	L		T			X			X	(X)	
15%	25	3	4350	9070	567	N		T		(W)					(X)	1
15%	25	6	6850	9220	576	N		T				(X)				1
15%	25	2	4347	9328	583	L		T			X		P		X	
					50°-40° C; 3-hour orbit											
25%	30	7	3657	855	107	S							P		(X)	2
15%	29	1	3626	1418	177	S					(S)		P			
25%	30	4	3643	3068	384	L					(T)		P	(X)	(X)	
25%	30	9	809	3068	384	L		T		(W)	(T)			(X)	X	
25%	30	8	3658	3684	461	L	1.3	T			X			(X)	(X)	
25%	30	1	3617	4141	518	S		T		(T)					(X)	
25%	30	10	7230	4141	518	L		T			X				(X)	
15%	29	8	4327	4340	543	N		T						(X)	(X)	
15%	29	7	810	4835	604	L		T		(W)			P			
15%	29	9	4340	4964	621	N			G		X		P	X	(X)	

* Additional Notes:

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

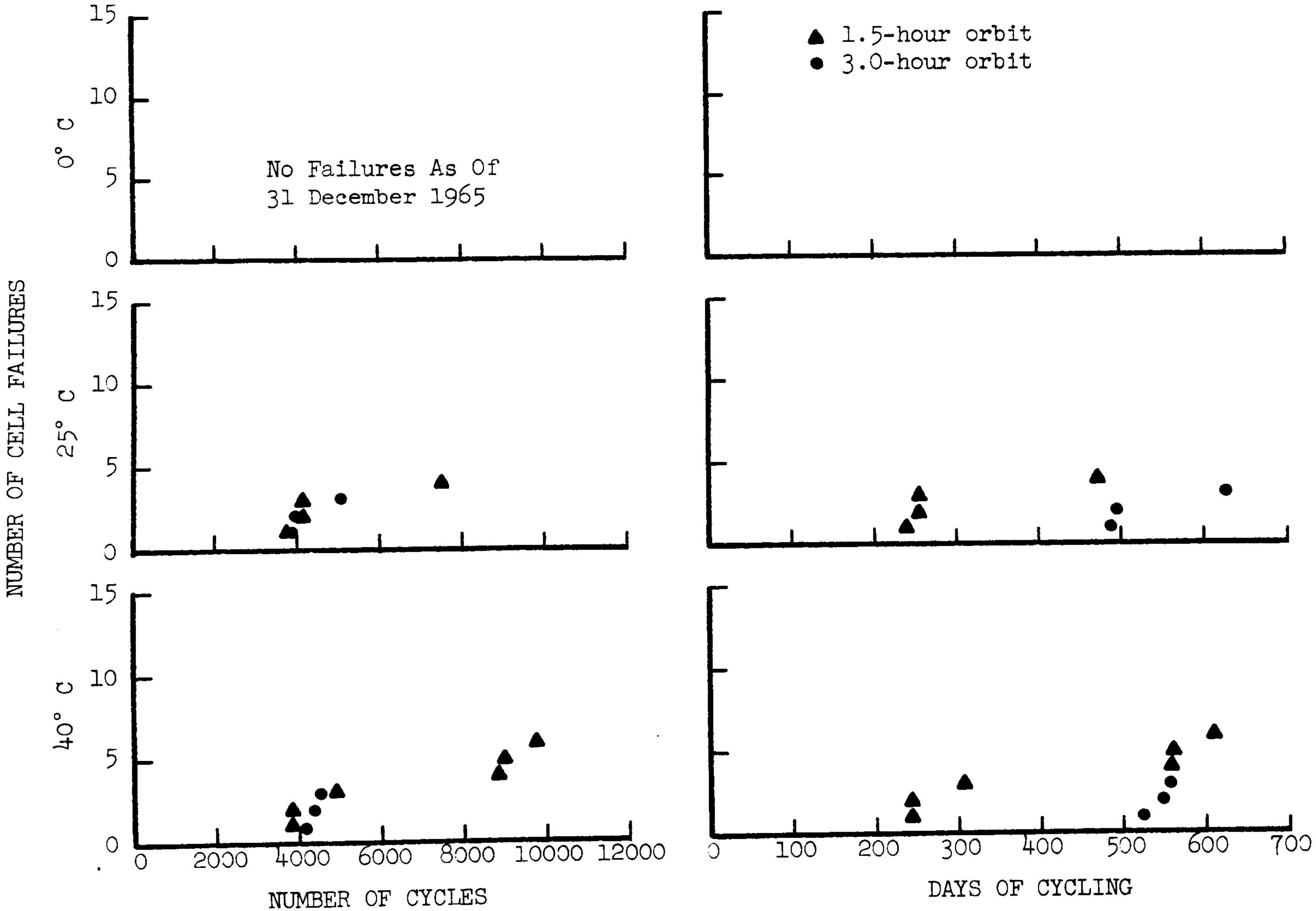
G.E. 3.0 a.h.



CELL FAILURES AS A FUNCTION OF NUMBER OF CYCLES AND CALENDAR DAYS OF TESTING

FIGURE 5(a)

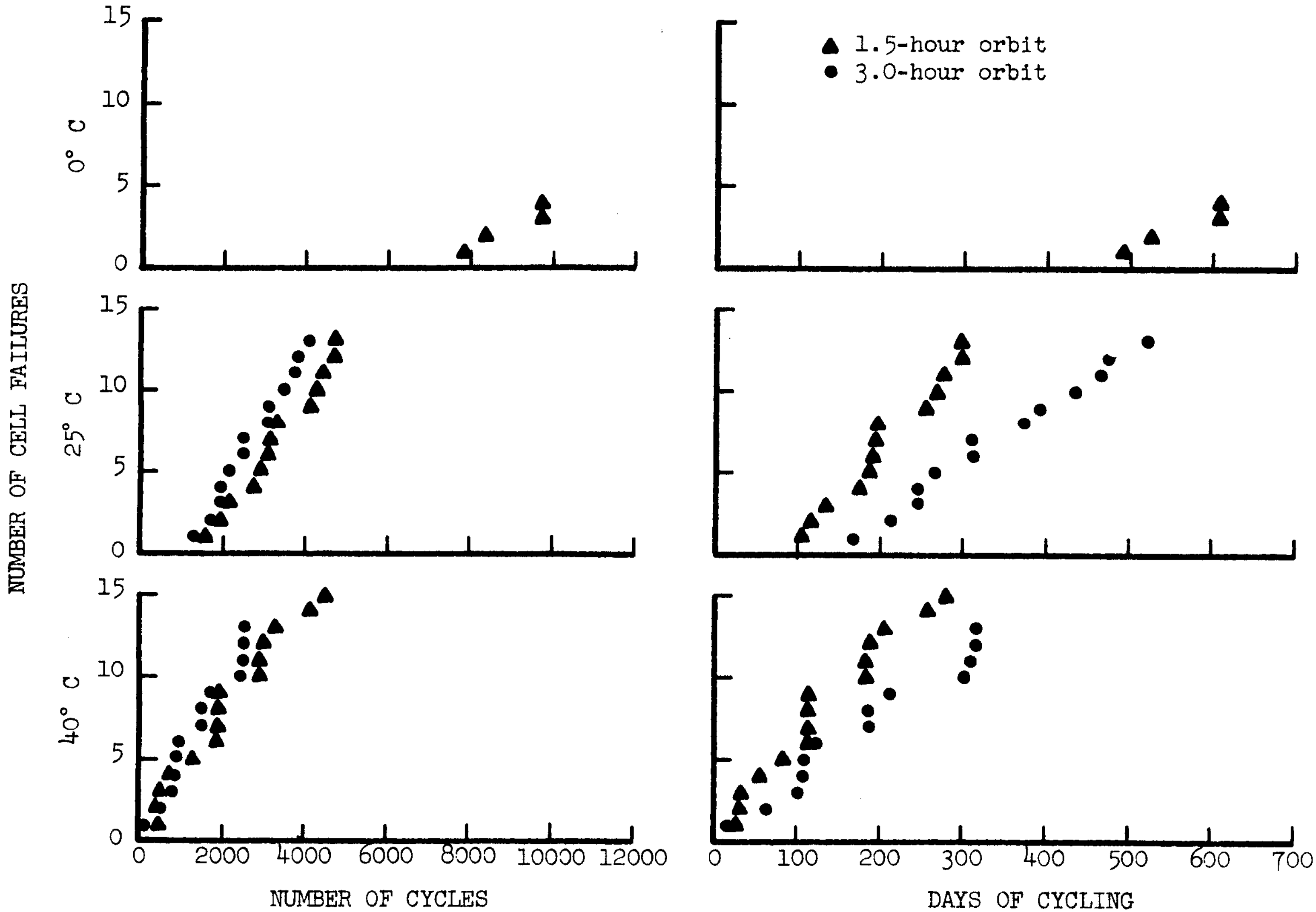
G.E. 12 a.h.



CELL FAILURES AS A FUNCTION OF NUMBER OF CYCLES AND CALENDAR DAYS OF TESTING

FIGURE 5(b)

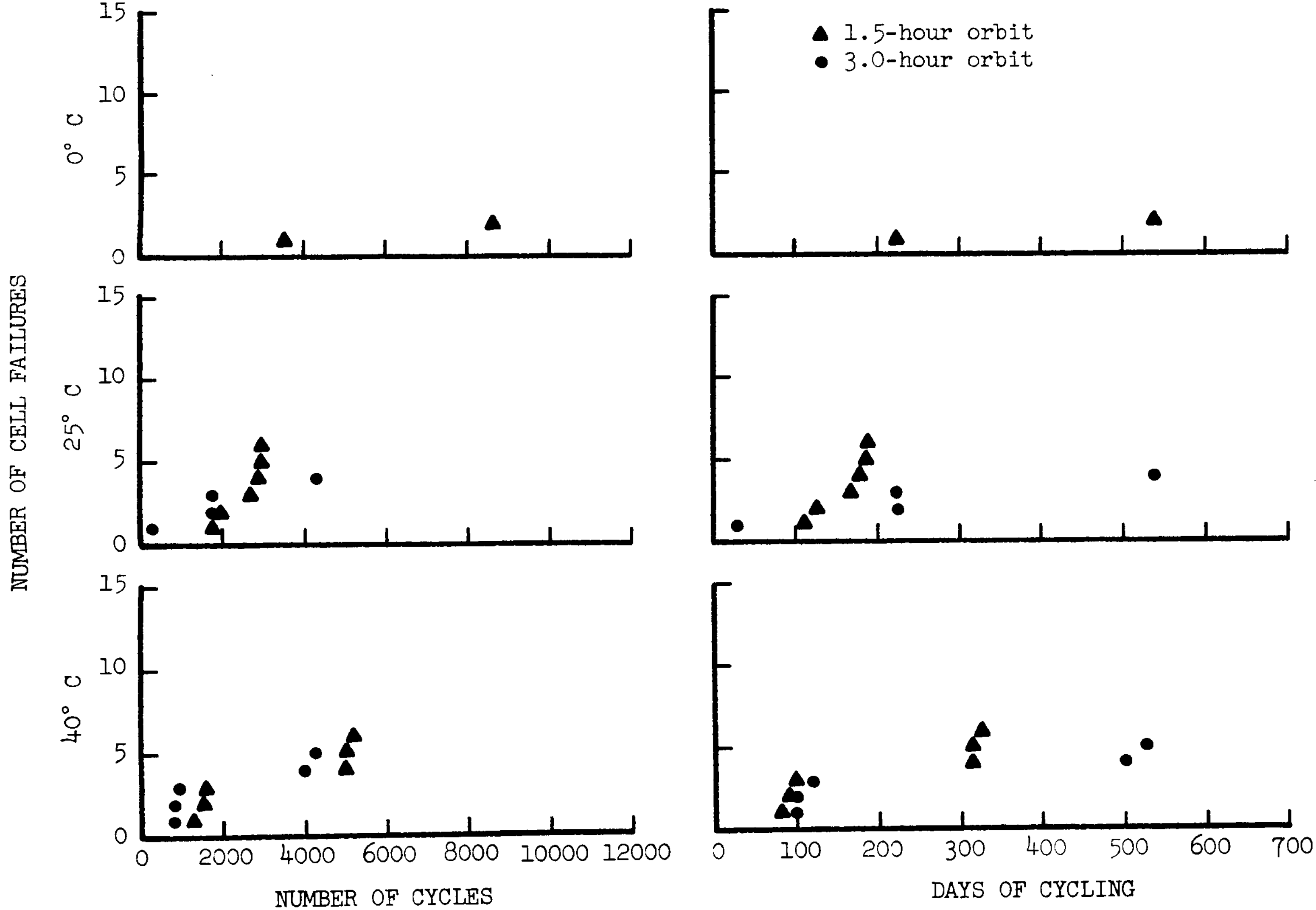
GOULD 3.5 a.h.



CELL FAILURES AS A FUNCTION OF NUMBER OF CYCLES AND CALENDAR DAYS OF TESTING

FIGURE 5(c)

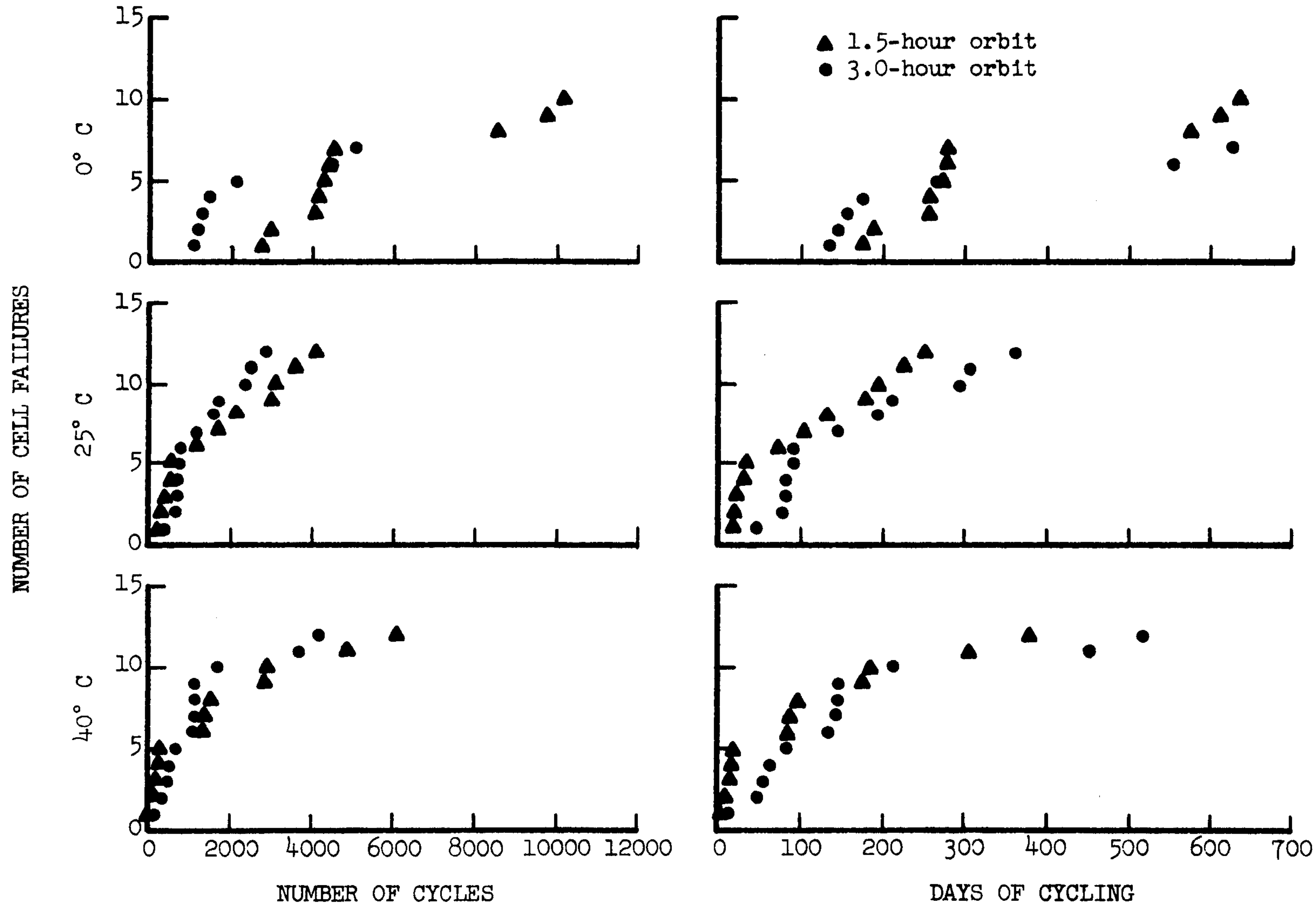
GOULD 20 a.h.



CELL FAILURES AS A FUNCTION OF NUMBER OF CYCLES AND CALENDAR DAYS OF TESTING

FIGURE 5(d)

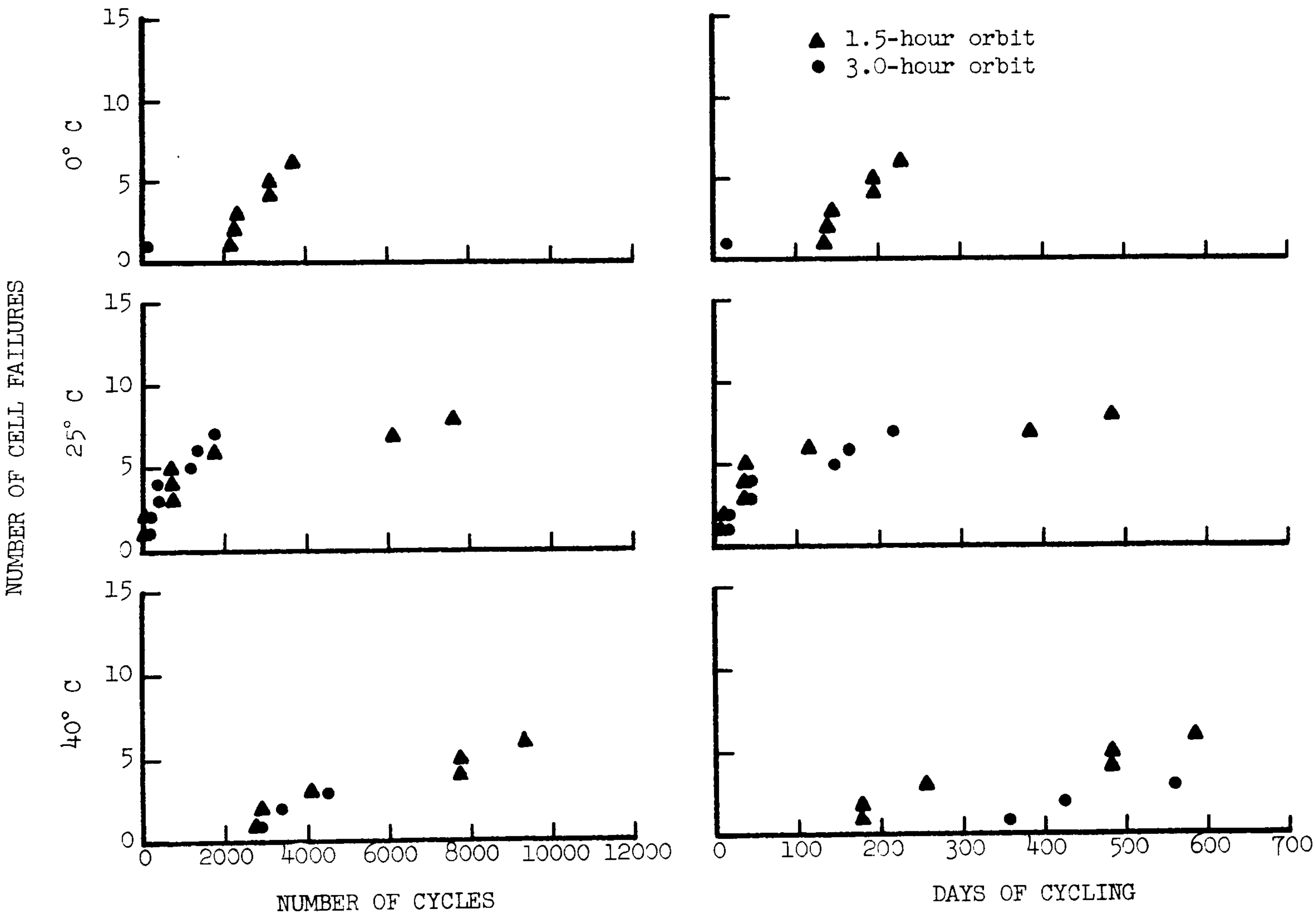
GULTON 6.0 a.h.



CELL FAILURES AS A FUNCTION OF NUMBER OF CYCLES AND CALENDAR DAYS OF TESTING

FIGURE 5(e)

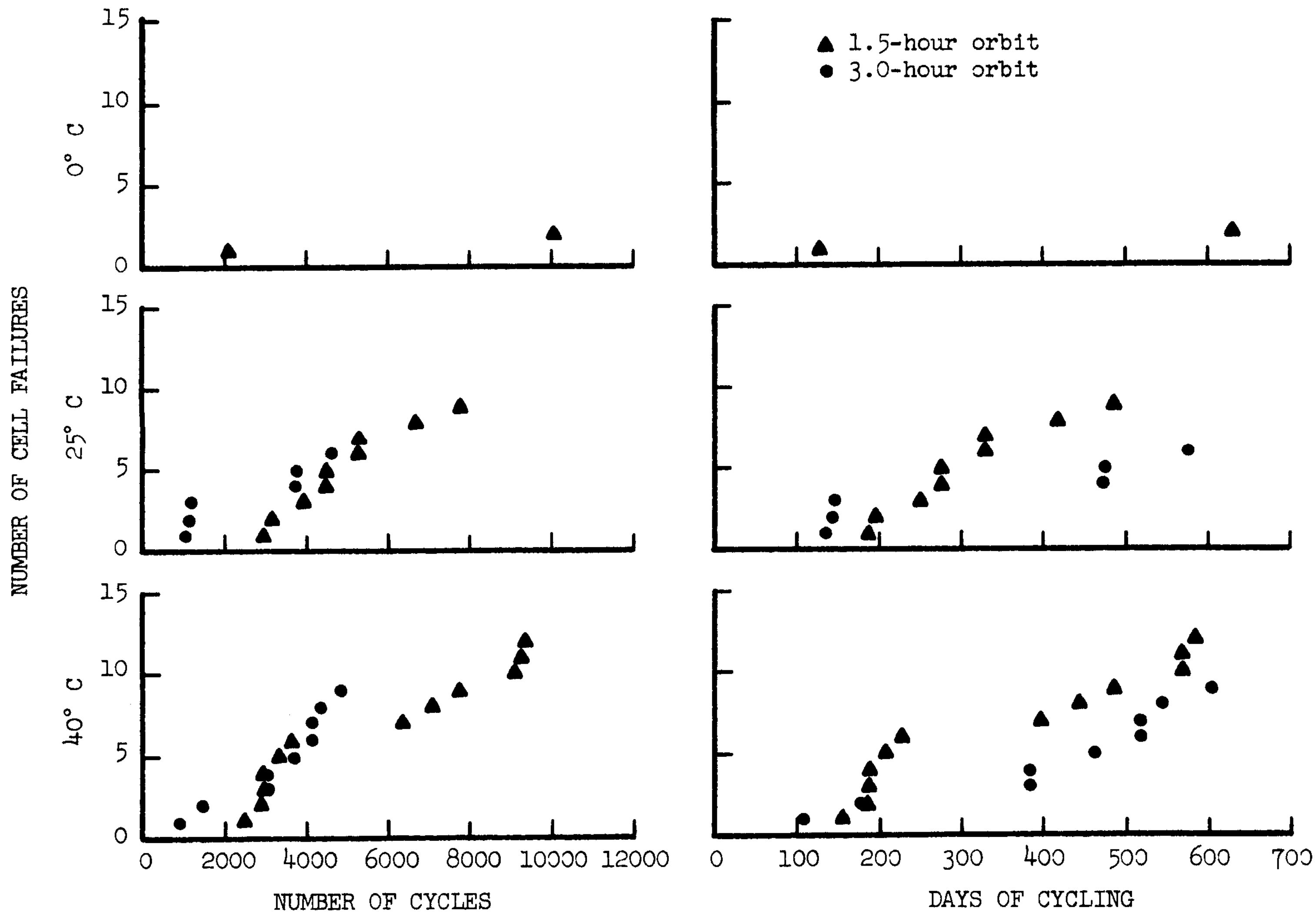
GULTON 20 a.h.



CELL FAILURES AS A FUNCTION OF NUMBER OF CYCLES AND CALENDAR DAYS OF TESTING

FIGURE 5(f)

SONOTONE 5.0 a.h.



CELL FAILURES AS A FUNCTION OF NUMBER OF CYCLES AND CALENDAR DAYS OF TESTING

FIGURE 5(g)

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 6(a) through 6(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° C, 25° C, and 50° C may be obtained from Figures 6(a) through 6(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 Tables VIIIa through VIIIg, 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° C and 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 of the third capacity check (after 264 days of cycling) and the preconditioning capacity. (For detailed explanation of preconditioning capacity and capacity checks see paragraph III.G.) Because of pack failures after the third capacity check on some cell types, this type of comparison is not practical on those types after this capacity check. 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 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. At 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.

c. In general the capacity at 40° C and 25° C continues to drop throughout the life of the cells whereas at 0° C the capacity remains about the same as shown in Figures 6(a) through 6(g). Sometimes the capacity of a pack is lowered by one cell. For example, Pack 105 (Gould 20 a.h., 25° C, 25 percent depth of discharge, and 3-hour orbit period) delivered about 100 percent of its rated capacity after 440 days of cycling but only 53 percent after 528 days. However, after removal of the failed cell, the pack again delivered about 100 percent of its rated capacity, in ampere-hours, at the capacity check following 616 days of cycling.

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	After 264 Days of Cycling		Number of Packs	Preconditioning	After 264 Days of Cycling		Number of Packs	Preconditioning	After 264 Days of Cycling	
		Percent of Rated	Percent of Rated	Percent of Preconditioning		Percent of Rated	Percent of Rated	Percent of Preconditioning		Percent of Rated	Percent of Rated	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	101.8	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

TEMPERATURE		50° - 40° C				25° C				0° C			
DEPTH OF DISCHARGE		25%		15%		40%		25%		25%		15%	
ORBIT PERIOD		1.5	3	1.5	3	1.5	3	1.5	3	1.5	3	1.5	3
PACK NUMBER		40	44	39	43	16	20	15	19	64	68	63	67
PRECONDITIONING CAPACITY		1.80	1.60	1.65	1.77	4.08	3.78	4.00	3.93	3.50	3.50	3.48	3.63
PRECONDITIONING CAPACITY AT 40°		2.50	2.00	2.43	2.63								
88 Days	Disch #1	0.73	1.17	2.10	2.20	2.37	2.98	3.38	3.78	3.30	3.25	3.15	3.25
	Disch #2	0.88	1.35	1.92	1.98	2.75	3.00	3.28	3.70	3.33	3.35	3.18	3.12
176 Days	Disch #1	0.88	1.05	1.40	1.58	1.83	2.03	2.82	3.48	3.70	3.53	3.10	3.40
	Disch #2	0.86	1.19	1.53	1.61	2.10	2.35	2.93	3.48	3.53	3.35	3.12	3.25
264 Days	Disch #1	*	1.08	0.95	1.53	1.35	1.68	2.17	3.05	3.30	3.30	2.90	3.53
	Disch #2		1.15	1.25	1.65	1.33	2.07	2.33	3.15	3.37	3.40	3.05	3.27
352 Days	Disch #1		0.98	0.85	*	*	1.20	1.70	2.70	3.28	3.20	2.88	2.90
	Disch #2		1.10	1.17			1.83	1.95	3.00	3.35	3.27	3.03	2.97
440 Days	Disch #1		0.95	0.50			1.47	1.30	2.67	3.23	2.73	2.97	0.65
	Disch #2		0.95	0.70			2.00	1.47	2.78	3.42	3.25	3.05	3.25
528 Days	Disch #1		0.83	*			1.43	0.78	2.40	2.93	2.58	2.70	2.95
	Disch #2		0.88				1.62	1.15	2.48	3.27	2.93	2.90	2.93
616 Days	Disch #1		*				1.37	0.83	2.22	3.02	2.63	3.30	
	Disch #2						1.47	1.10	2.29	3.12	2.87	3.25	
704 Days	Disch #1						1.17	*	2.12			3.50	
	Disch #2						1.20		2.20			3.08	
792 Days	Disch #1												
	Disch #2												
880 Days	Disch #1												
	Disch #2												

* Pack Failed.

TABLE VIIIb

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

TEMPERATURE		50° - 40° C				25° C				0° C			
DEPTH OF DISCHARGE		25%		15%		40%		25%		25%		15%	
ORBIT PERIOD		1.5	3	1.5	3	1.5	3	1.5	3	1.5	3	1.5	3
PACK NUMBER		99	100	85	86	96	97	82	83	124	125	110	111
PRECONDITIONING CAPACITY		6.90	7.00	6.80	7.10	14.8	14.9	15.2	15.2	14.2	14.6	13.9	14.2
PRECONDITIONING CAPACITY AT 40°		6.00	9.80	8.20	8.20								
88 Days	Disch #1	3.40	2.90	4.80	6.30	5.00	5.00	8.00	11.7	13.2	11.8	10.8	11.7
	Disch #2	4.90	3.80	5.00	5.90	6.00	5.60	7.80	11.5	13.5	13.0	12.7	13.2
176 Days	Disch #1	4.50	4.70	4.70	2.80	6.16	5.19	4.57	7.70	12.4	10.6	9.88	10.3
	Disch #2	5.20	4.70	4.70	3.70	7.65	5.86	5.55	8.20	12.9	12.1	10.4	10.7
264 Days	Disch #1	3.90	3.15	4.26	2.70	*	5.70	3.90	4.90	11.8	11.0	12.0	10.3
	Disch #2	4.40	5.70	5.00	4.00		7.90	5.50	6.13	12.8	11.9	13.0	11.0
352 Days	Disch #1	*	4.10	4.10	2.70		6.50	4.00	4.10	10.4	10.8	12.1	11.0
	Disch #2		5.10	4.90	3.50		8.20	5.40	5.20	11.4	12.2	12.5	12.1
440 Days	Disch #1		3.50	3.90	2.10		5.90	5.40	3.50	10.5	13.0	14.1	13.6
	Disch #2		4.00	5.00	2.90		6.80	5.70	4.80	11.5	12.9	14.1	12.9
528 Days	Disch #1		3.20	1.80	2.30		5.10	4.40	3.60	10.8	11.4	13.2	11.1
	Disch #2		4.00	1.90	2.10		5.50	5.00	4.40	11.7	11.7	13.7	12.0
616 Days	Disch #1		*	2.10	1.90		5.60	4.10	3.80	9.70	10.7	12.9	10.9
	Disch #2			4.30	4.40		5.70	4.90	5.10	10.8	11.2	14.3	11.4
704 Days	Disch #1			*			*	*					
	Disch #2												
792 Days	Disch #1												
	Disch #2												
880 Days	Disch #1												
	Disch #2												

* Pack Failed.

TABLE VIIIc

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

TEMPERATURE		50° - 40° C				25° C				0° C			
DEPTH OF DISCHARGE		25%		15%		40%		25%		25%		15%	
ORBIT PERIOD		1.5	3	1.5	3	1.5	3	1.5	3	1.5	3	1.5	3
PACK NUMBER		28	32	27	31	4	8	3	7	52	56	51	55
PRECONDITIONING CAPACITY		1.55	1.55	1.52	1.60	3.94	4.29	4.00	4.32	3.33	3.50	3.62	3.27
PRECONDITIONING CAPACITY AT 40°		2.07	1.66	2.63	1.31								
88 Days	Disch #1	1.90	0.82	2.07	1.66	3.30	3.63	2.51	3.94	3.73	3.82	3.97	3.06
	Disch #2	2.86	1.49	1.93	1.75	3.38	3.65	3.82	4.03	3.85	3.91	4.00	3.59
176 Days	Disch #1	*	*	1.72	1.66	2.07	3.30	1.46	3.79	3.35	3.18	3.06	2.83
	Disch #2			1.95	1.98	2.77	3.35	2.92	3.76	3.53	3.53	3.33	3.15
264 Days	Disch #1			0.64	1.49	*	2.54	1.20	3.41	2.51	3.24	2.83	3.21
	Disch #2			1.90	2.16		3.03	2.25	3.53	3.18	3.65	3.41	3.38
352 Days	Disch #1			*	*		*	*	1.63	1.23	3.21	2.71	2.60
	Disch #2								2.77	3.30	3.41	3.21	3.33
440 Days	Disch #1								1.23	2.19	3.00	2.65	2.63
	Disch #2								2.28	3.24	3.38	3.35	3.27
528 Days	Disch #1								2.10	1.08	2.51	2.19	2.48
	Disch #2								2.51	2.80	3.30	3.15	3.03
616 Days	Disch #1								*	2.33	3.12	1.55	2.36
	Disch #2									2.65	3.27	3.47	2.77
704 Days	Disch #1											1.34	
	Disch #2											3.00	
792 Days	Disch #1												
	Disch #2												
880 Days	Disch #1												
	Disch #2												

* Pack Failed.

TABLE VIIId

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

TEMPERATURE		50° - 40° C				25° C				0° C			
DEPTH OF DISCHARGE		25%		15%		40%		25%		25%		15%	
ORBIT PERIOD		1.5	3	1.5	3	1.5	3	1.5	3	1.5	3	1.5	3
PACK NUMBER		126	122	112	108	118	119	104	105	98	94	84	80
PRECONDITIONING CAPACITY		9.00	9.33	9.67	9.50	24.7	24.8	25.0	23.3	23.0	23.0	22.5	23.0
PRECONDITIONING CAPACITY AT 40°		13.9	7.50	6.83	9.67								
88 Days	Disch #1	15.0	4.67	15.7	11.8	23.0	17.5	11.8	22.2	19.0	15.0	25.7	18.7
	Disch #2	15.2	8.17	12.2	9.83	23.3	24.7	18.5	23.5	21.2	17.5	27.7	23.2
176 Days	Disch #1	*	*	15.2	14.2	15.0	21.7	12.2	19.3	7.60	13.3	24.2	20.0
	Disch #2			15.3	14.8	19.5	19.5	14.0	22.2	15.2	25.0	26.5	21.5
264 Days	Disch #1			3.50	14.2	*	14.5	*	19.7	14.8	16.3	23.0	17.0
	Disch #2			12.5	16.8		21.0		21.3	18.7	18.2	24.2	20.3
352 Days	Disch #1			9.09	14.8		*		19.2	17.2	16.7	22.8	25.8
	Disch #2			12.4	15.2				21.2	16.7	18.8	24.7	20.0
440 Days	Disch #1			*	12.2				15.8	14.1	14.8	17.5	16.3
	Disch #2				12.3				20.7	17.5	16.8	21.7	19.7
528 Days	Disch #1				*				9.00	12.3	14.8	19.5	15.5
	Disch #2								10.5	13.5	17.0	22.3	18.3
616 Days	Disch #1								20.5	9.83	14.0	19.2	14.7
	Disch #2								17.2	13.5	15.8	19.8	16.7
704 Days	Disch #1												
	Disch #2												
792 Days	Disch #1												
	Disch #2												
880 Days	Disch #1												
	Disch #2												

* Pack Failed.

TABLE VIIIe

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

TEMPERATURE		50° - 40° C				25° C				0° C			
DEPTH OF DISCHARGE		25%		15%		40%		25%		25%		15%	
ORBIT PERIOD		1.5	3	1.5	3	1.5	3	1.5	3	1.5	3	1.5	3
PACK NUMBER		38	42	37	41	14	18	13	17	62	66	61	65
PRECONDITIONING CAPACITY		2.65	2.60	2.75	2.75	6.40	4.55	5.80	5.80	5.00	4.25	5.00	4.50
PRECONDITIONING CAPACITY AT 40°		2.90	3.80	3.60	4.55								
88 Days	Disch #1	1.30	1.60	0.80	1.80	2.65	4.15	2.34	1.70	1.40	2.80	5.10	4.65
	Disch #2	1.55	2.15	1.70	2.05	3.45	4.95	2.75	3.65	4.75	5.00	5.10	5.45
176 Days	Disch #1	*	1.85	2.95	1.20	*	2.10	1.60	2.95	2.60	1.50	4.65	5.00
	Disch #2		2.10	2.20	1.63		3.16	2.85	3.45	3.30	3.50	5.40	5.35
264 Days	Disch #1		1.82	0.80	*		*	2.10	2.00	3.15	1.50	3.70	4.75
	Disch #2		2.35	1.85				2.70	2.50	4.35	2.50	4.45	5.15
352 Days	Disch #1		1.60	1.15				*	2.05	2.65	2.40	2.25	5.04
	Disch #2		1.85	2.00					2.30	3.55	3.80	3.15	4.50
440 Days	Disch #1		1.45	*					*	2.30	2.20	1.35	4.10
	Disch #2		1.50							3.30	3.90	2.60	4.50
528 Days	Disch #1		1.25							2.75	2.30	0.90	4.20
	Disch #2		1.30							3.30	3.45	2.15	5.15
616 Days	Disch #1		*							3.45	*	1.70	3.90
	Disch #2									3.95		1.75	4.20
704 Days	Disch #1											*	
	Disch #2												
792 Days	Disch #1												
	Disch #2												
880 Days	Disch #1												
	Disch #2												

* Pack Failed.

TABLE VIIIf

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

TEMPERATURE		50° - 40° C				25° C				0° C			
DEPTH OF DISCHARGE		25%		15%		40%		25%		25%		15%	
ORBIT PERIOD		1.5	3	1.5	3	1.5	3	1.5	3	1.5	3	1.5	3
PACK NUMBER		90	91	76	77	87	88	73	74	115	116	101	102
PRECONDITIONING CAPACITY		9.00	9.17	10.3	9.50	23.3	19.8	23.3	20.3	17.7	21.7	17.2	16.7
PRECONDITIONING CAPACITY AT 40°		11.3	10.3	13.8	12.7								
88 Days	Disch #1	4.50	4.50	6.00	5.67	*	*	5.67	4.00	4.83	20.1	12.5	18.8
	Disch #2	6.00	6.67	6.50	7.33			7.17	6.17	11.2	20.7	12.2	18.3
176 Days	Disch #1	9.17	4.83	3.67	3.67			6.60	4.83	*	20.8	3.00	21.0
	Disch #2	10.3	6.67	4.83	5.33			9.50	7.17		21.8	5.67	25.2
264 Days	Disch #1	7.33	6.17	3.93	3.17			5.33	*		17.7	*	20.2
	Disch #2	9.33	7.67	5.50	4.83			7.83			19.3		20.3
352 Days	Disch #1	*	5.67	3.50	3.83			5.67			8.67		8.33
	Disch #2		6.83	4.67	5.33			8.67			17.5		19.5
440 Days	Disch #1		5.83	2.67	3.00			5.50			14.2		15.5
	Disch #2		7.17	5.00	4.67			8.83			15.2		17.3
528 Days	Disch #1		5.00	3.97	3.33			*			13.2		17.0
	Disch #2		5.50	5.17	5.00						15.8		16.7
616 Days	Disch #1		*	*	3.33						13.2		13.5
	Disch #2				5.17						13.5		15.0
704 Days	Disch #1												
	Disch #2												
792 Days	Disch #1												
	Disch #2												
880 Days	Disch #1												
	Disch #2												

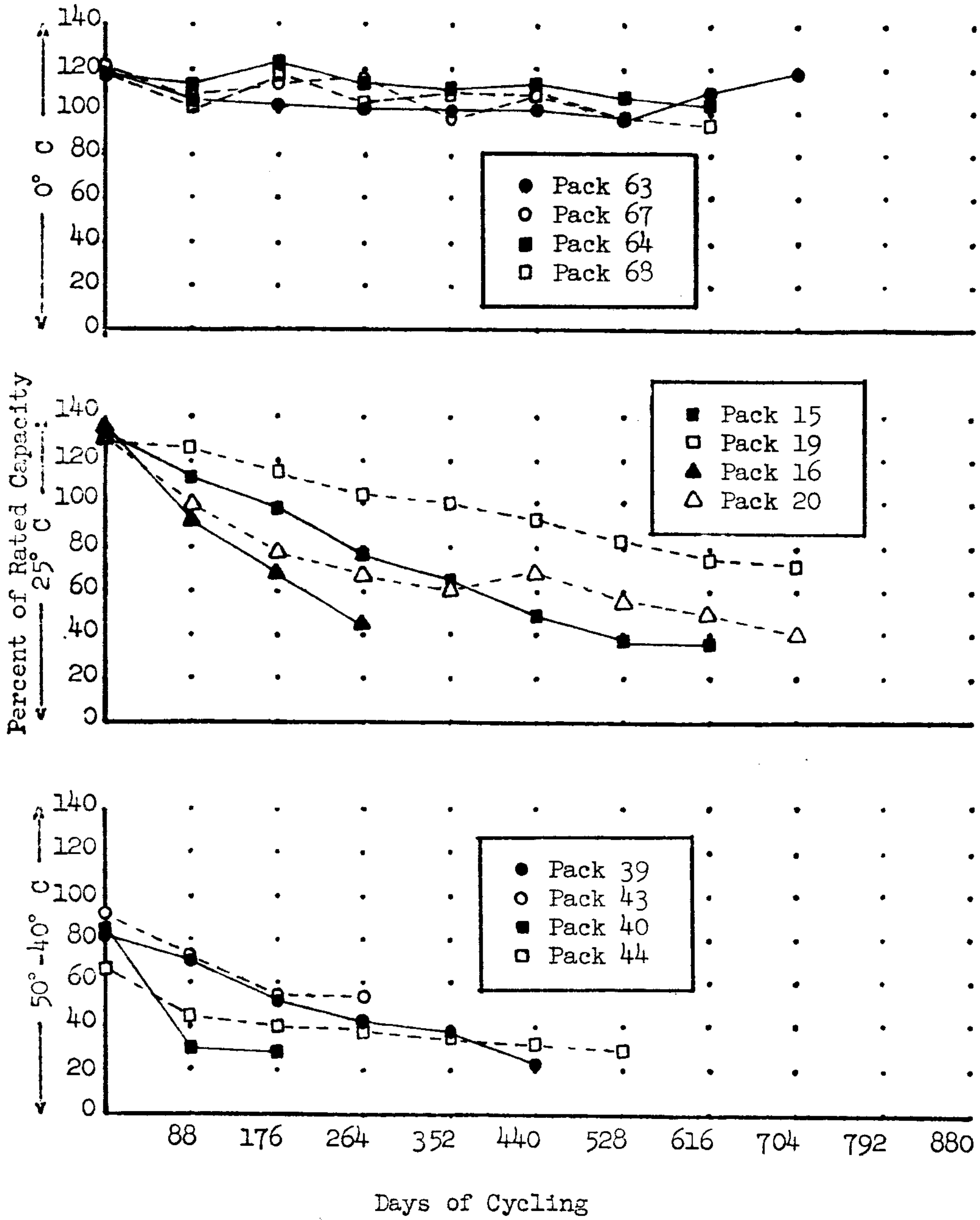
* Pack Failed.

TABLE VIIIg

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

TEMPERATURE		50° - 40° C				25° C				0° C			
DEPTH OF DISCHARGE		25%		15%		40%		25%		25%		15%	
ORBIT PERIOD		1.5	3	1.5	3	1.5	3	1.5	3	1.5	3	1.5	3
PACK NUMBER		26	30	25	29	2	6	1	5	50	54	49	53
PRECONDITIONING CAPACITY		3.17	3.75	3.08	3.33	6.42	5.83	5.42	5.71	5.04	4.92	5.45	5.67
PRECONDITIONING CAPACITY AT 40°		3.17	3.50	3.63	4.92								
88 Days	Disch #1	1.63	1.63	1.92	1.92	3.79	3.04	3.25	4.17	4.58	3.63	3.67	5.75
	Disch #2	2.75	1.88	2.25	2.75	4.38	4.50	3.67	4.58	4.96	3.96	5.54	5.79
176 Days	Disch #1	2.93	2.17	1.38	1.38	3.38	2.50	1.92	2.42	4.25	3.50	5.08	5.38
	Disch #2	2.67	2.88	1.83	2.38	4.17	3.29	2.33	3.04	4.58	3.96	5.50	5.67
264 Days	Disch #1	*	1.54	2.04	1.17	2.46	2.42	2.21	1.29	3.83	3.42	4.79	5.21
	Disch #2		2.38	2.04	2.42	3.25	3.25	2.88	2.04	4.25	4.13	4.96	5.42
352 Days	Disch #1		1.13	0.96	1.25	2.12	2.71	1.67	1.67	3.17	3.33	4.46	4.65
	Disch #2		1.67	1.17	2.08	3.00	2.92	2.79	2.13	3.79	3.96	4.79	5.33
440 Days	Disch #1		1.08	0.75	1.04	*	2.21	1.38	1.42	3.29	3.17	3.21	4.75
	Disch #2		1.21	1.17	1.96		2.33	2.21	2.13	3.67	3.75	4.71	5.50
528 Days	Disch #1		*	0.71	1.04		2.33	1.79	1.38	2.92	3.00	2.92	4.75
	Disch #2			1.54	1.29		1.92	2.58	2.08	3.67	3.29	4.50	5.54
616 Days	Disch #1			0.58	1.79		2.00	1.25	1.54	2.79	3.04	4.21	5.00
	Disch #2			0.83	1.54		1.83	2.80	2.21	3.46	3.38	4.54	4.96
704 Days	Disch #1			*			2.08	1.54					
	Disch #2						2.13	2.46					
792 Days	Disch #1						*						
	Disch #2												
880 Days	Disch #1												
	Disch #2												

* Pack Failed.



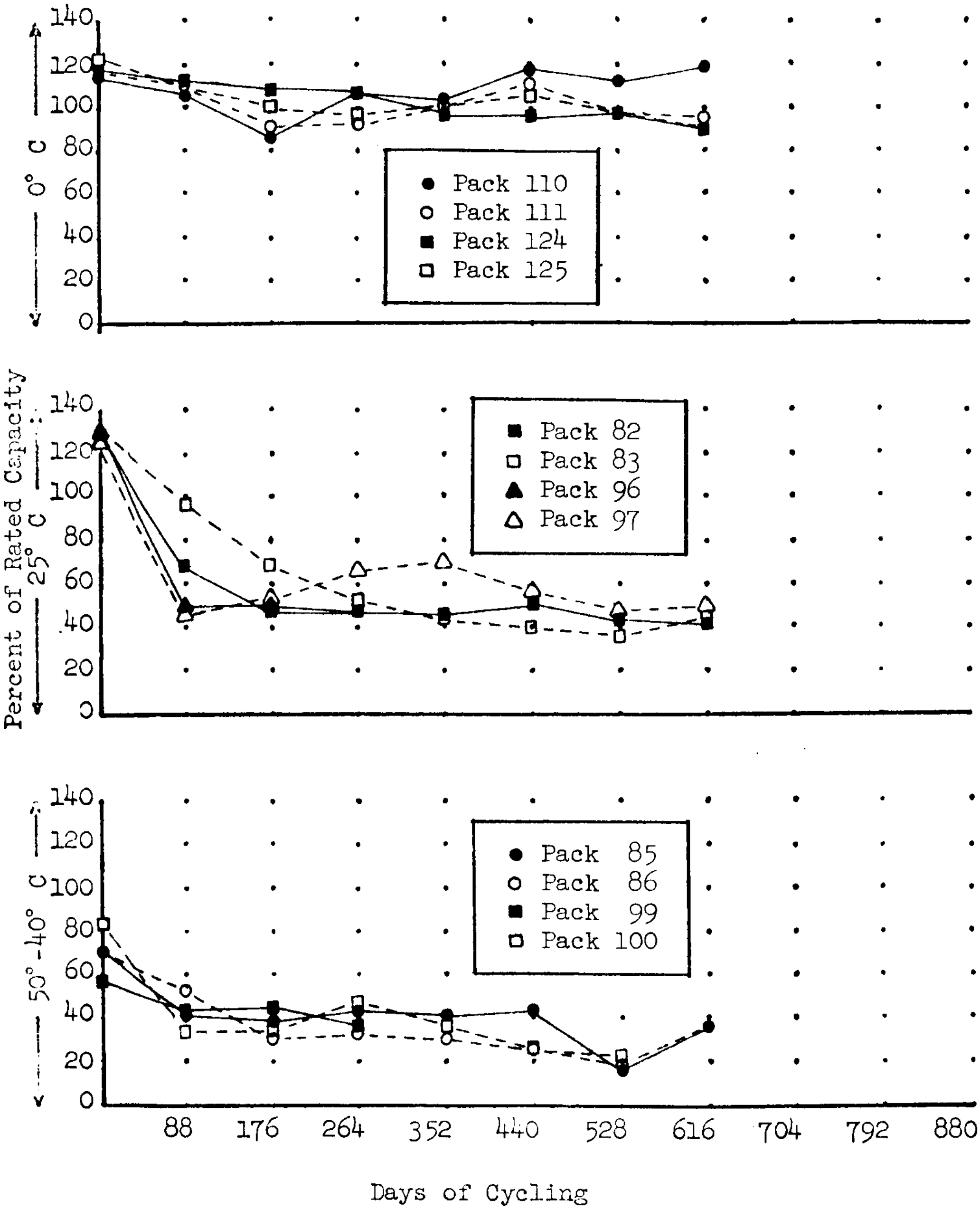
G. E. 3.0 a.h.

PRECONDITIONING AND CAPACITY CHECK CYCLES

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

1.5 hr. period	3.0 hr. period	Depth of Discharge
—●—	--○--	15%
—■—	--□--	25%
—▲—	--△--	40%

FIGURE 6(a)



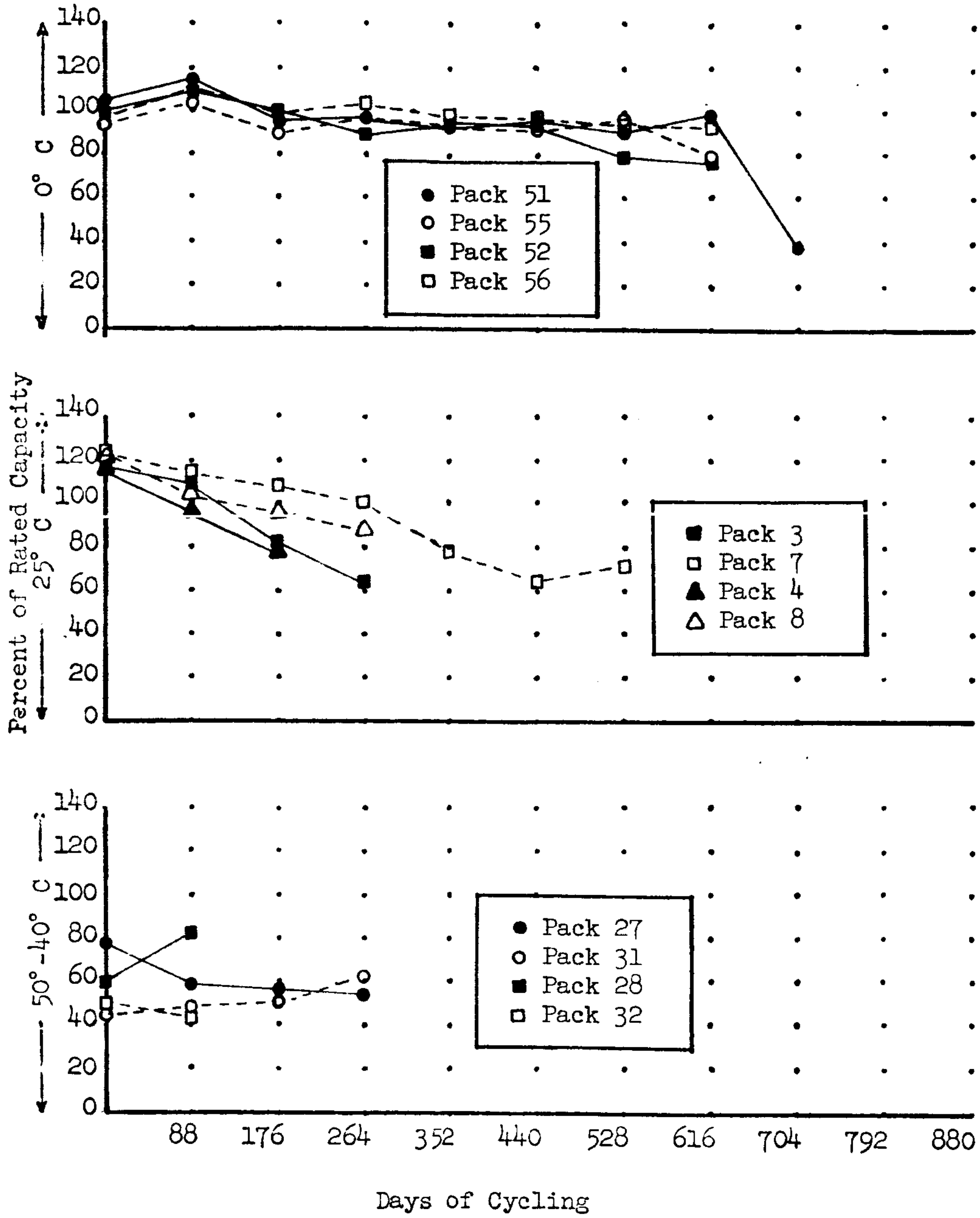
G.E. 12 a.h.

PRECONDITIONING AND CAPACITY CHECK CYCLES

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

1.5 hr. period	3.0 hr. period	Depth of Discharge
—●—	--○--	15%
—■—	--□--	25%
—▲—	--△--	40%

FIGURE 6(b)



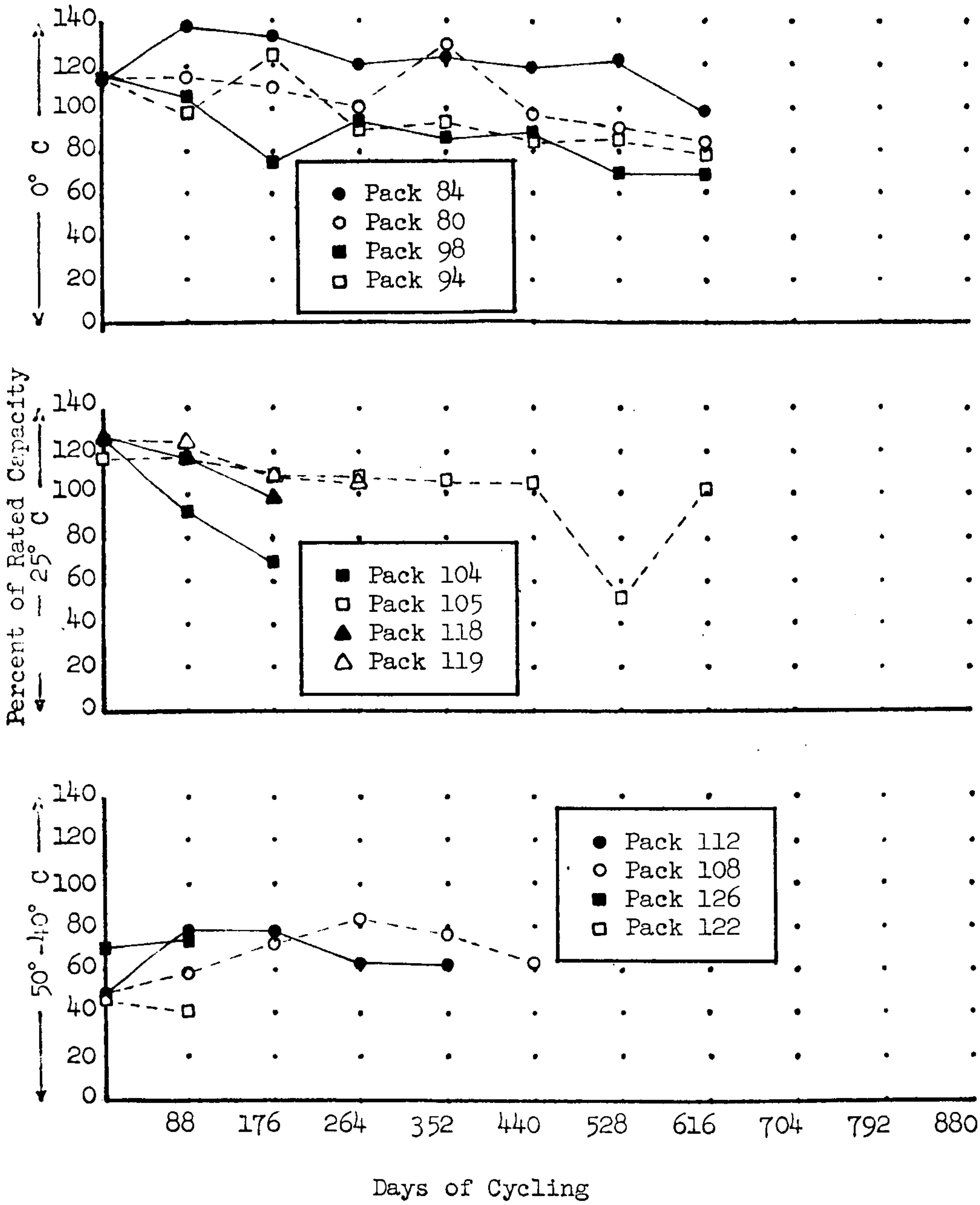
Gould 3.5 a.h.

PRECONDITIONING AND CAPACITY CHECK CYCLES

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

1.5 hr. period	3.0 hr. period	Depth of Discharge
—●—	– –○– –	15%
—■—	– –□– –	25%
—▲—	– –△– –	40%

FIGURE 6(c)



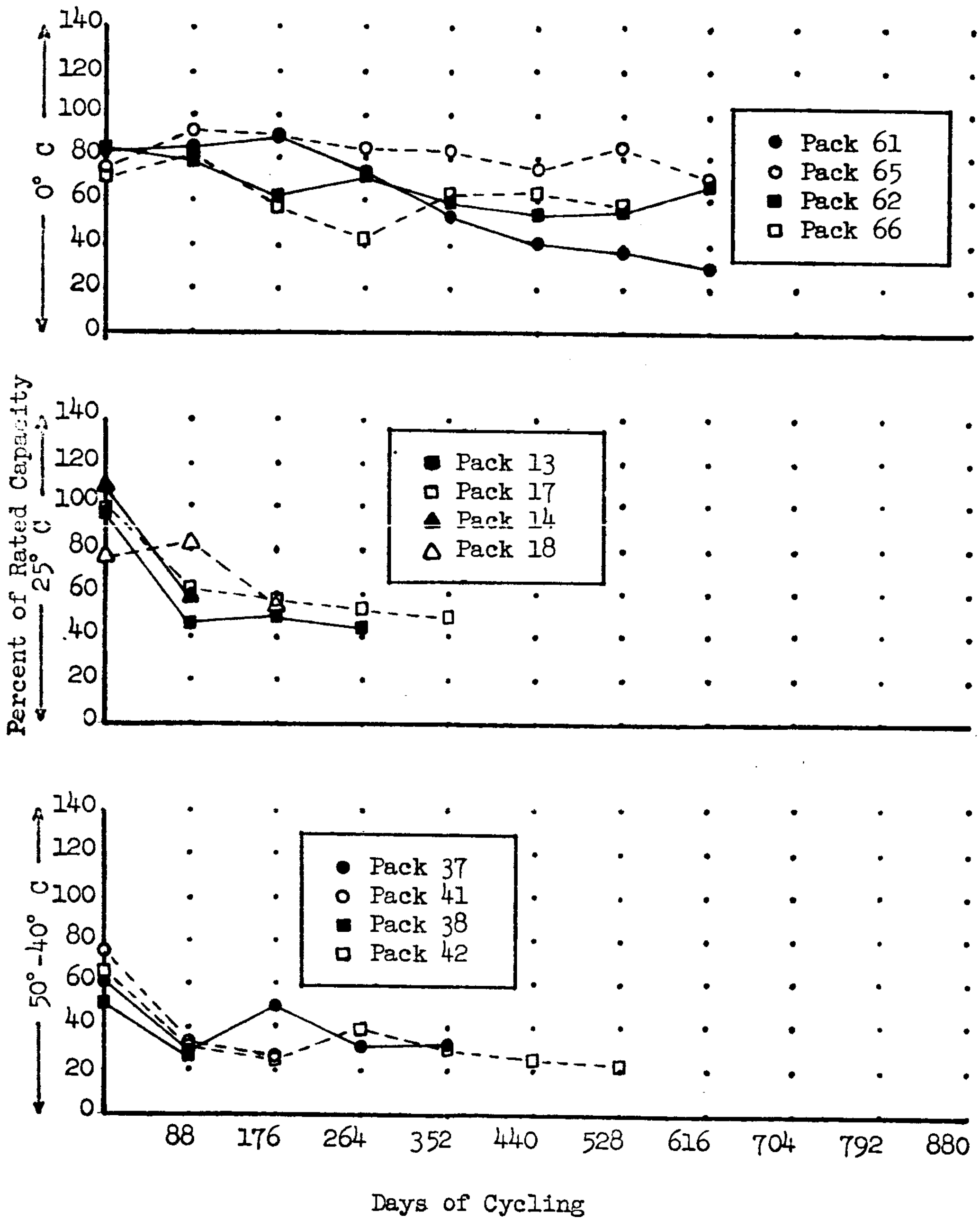
Gould 20 a.h.

PRECONDITIONING AND CAPACITY CHECK CYCLES

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

1.5 hr. period	3.0 hr. period	Depth of Discharge
—●—	– –○– –	15%
—■—	– –□– –	25%
—▲—	– –△– –	40%

FIGURE 6(d)



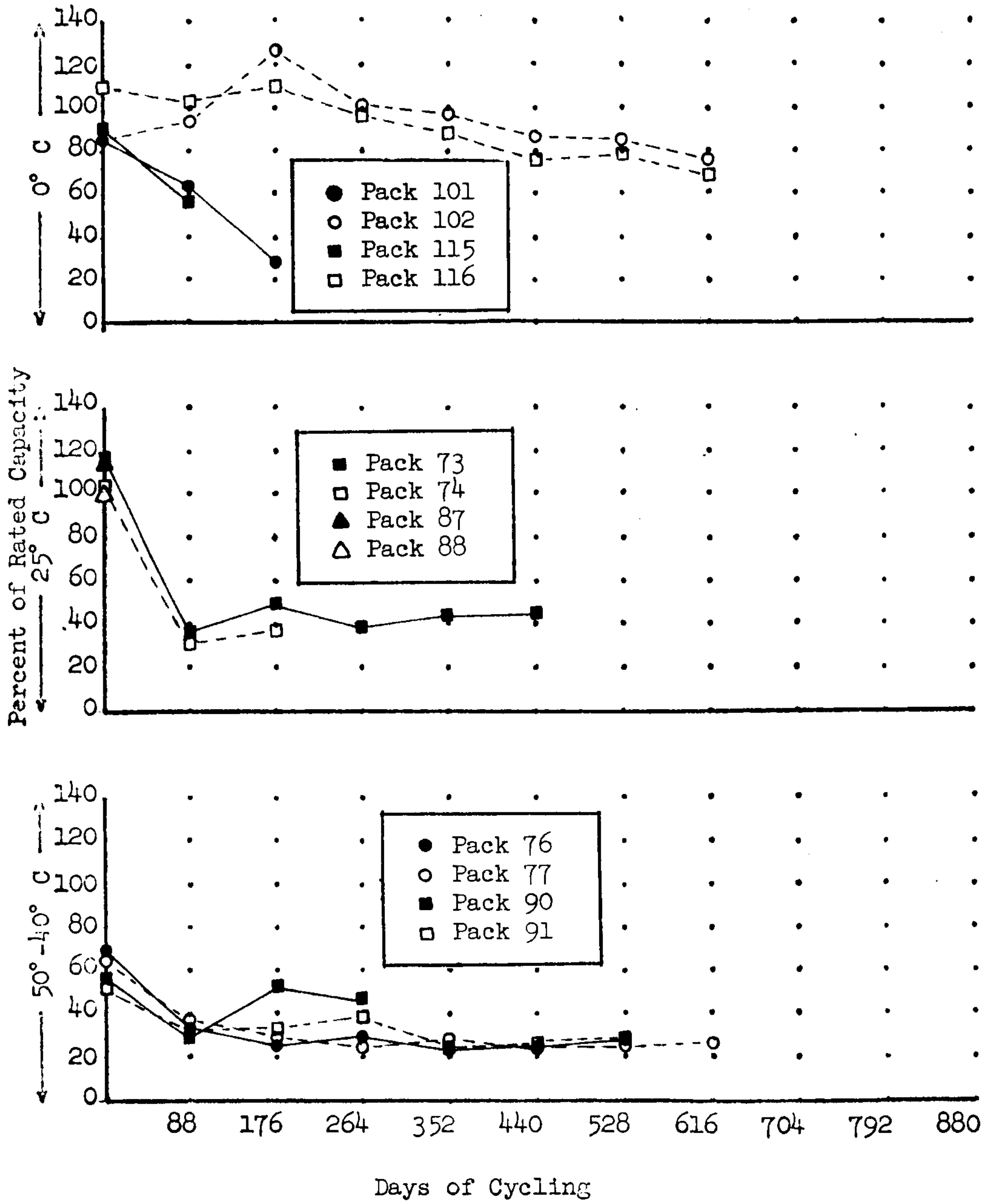
Gulton 6.0 a.h.

PRECONDITIONING AND CAPACITY CHECK CYCLES

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

1.5 hr. period	3.0 hr. period	Depth of Discharge
—●—	--○--	15%
—■—	--□--	25%
—▲—	--△--	40%

FIGURE 6(e)



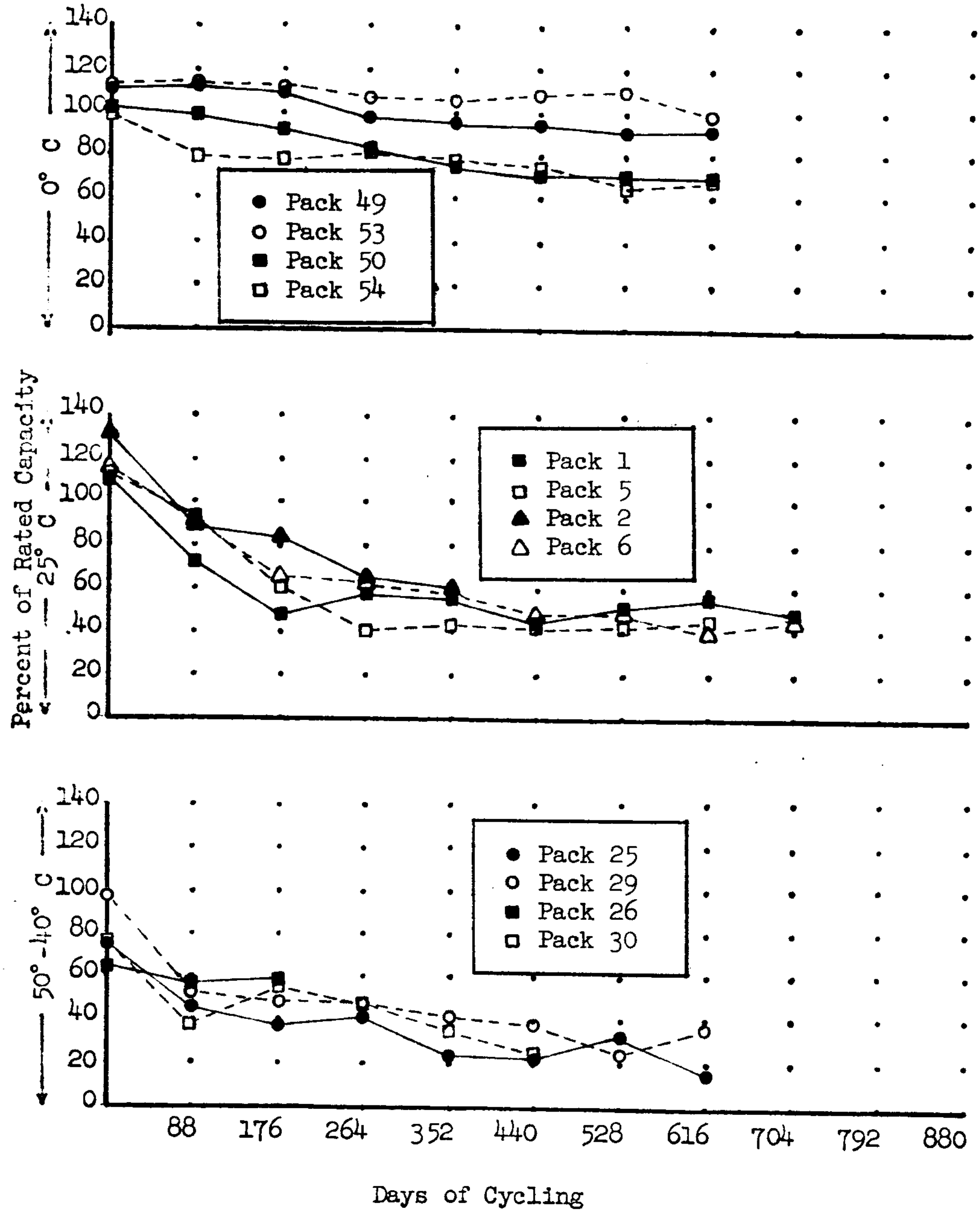
Gulton 20 a.h.

PRECONDITIONING AND CAPACITY CHECK CYCLES

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

1.5 hr. period	3.0 hr. period	Depth of Discharge
—●—	--○--	15%
—■—	--□--	25%
—▲—	--△--	40%

FIGURE 6(f)



Sonotone 5.0 a.h.

PRECONDITIONING AND CAPACITY CHECK CYCLES

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

1.5 hr. period	3.0 hr. period	Depth of Discharge
—●—	--○--	15%
—■—	--□--	25%
—▲—	--△--	40%

FIGURE 6(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.

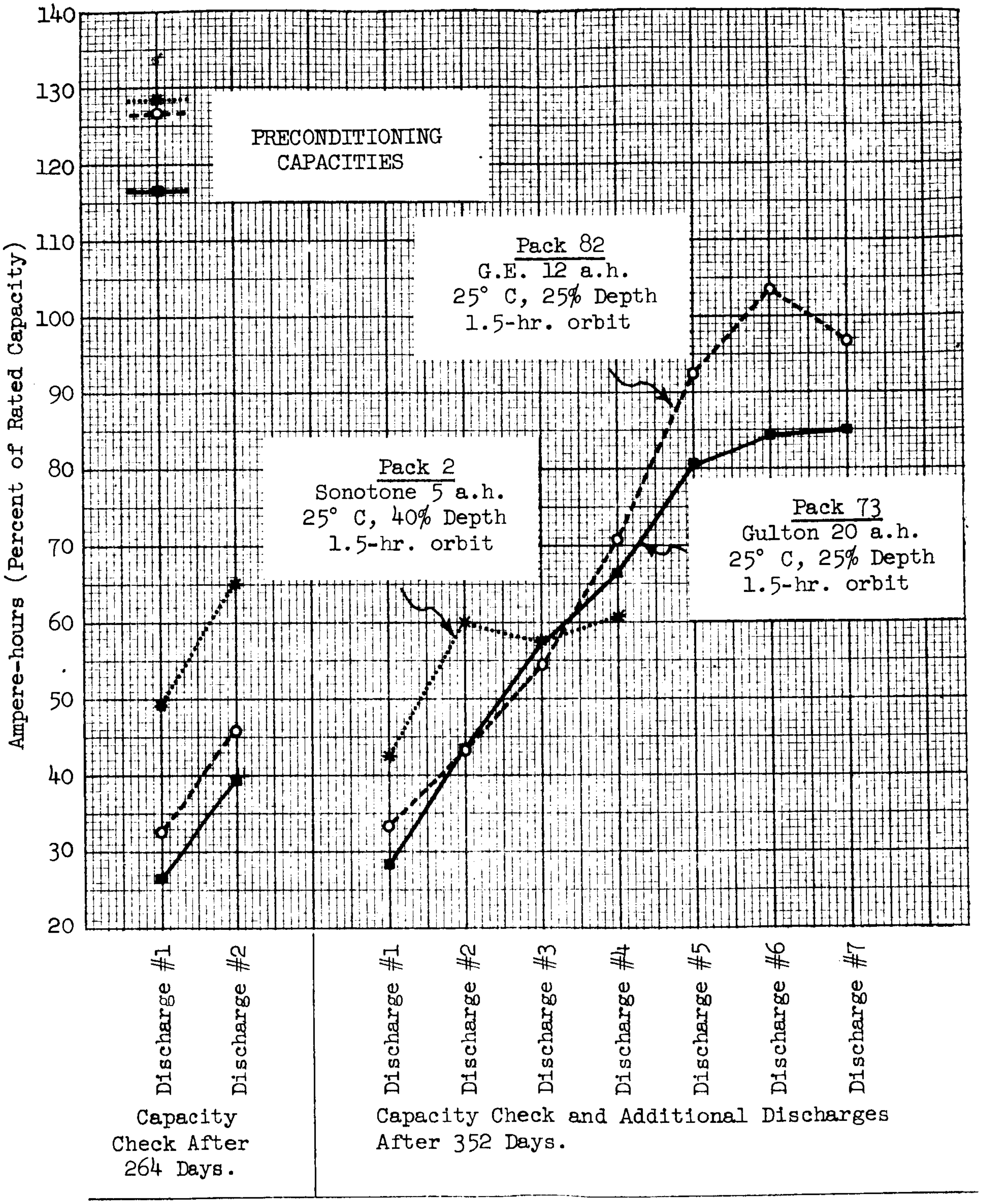
b. The first discharge of the capacity check and the subsequent 16-hour charge at c/10 are designed to break the memory effect and otherwise prepare the packs for a truer capacity measurement on the second discharge. Nonetheless, after the first 88 days some packs showed a considerable loss of capacity 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 7. 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.

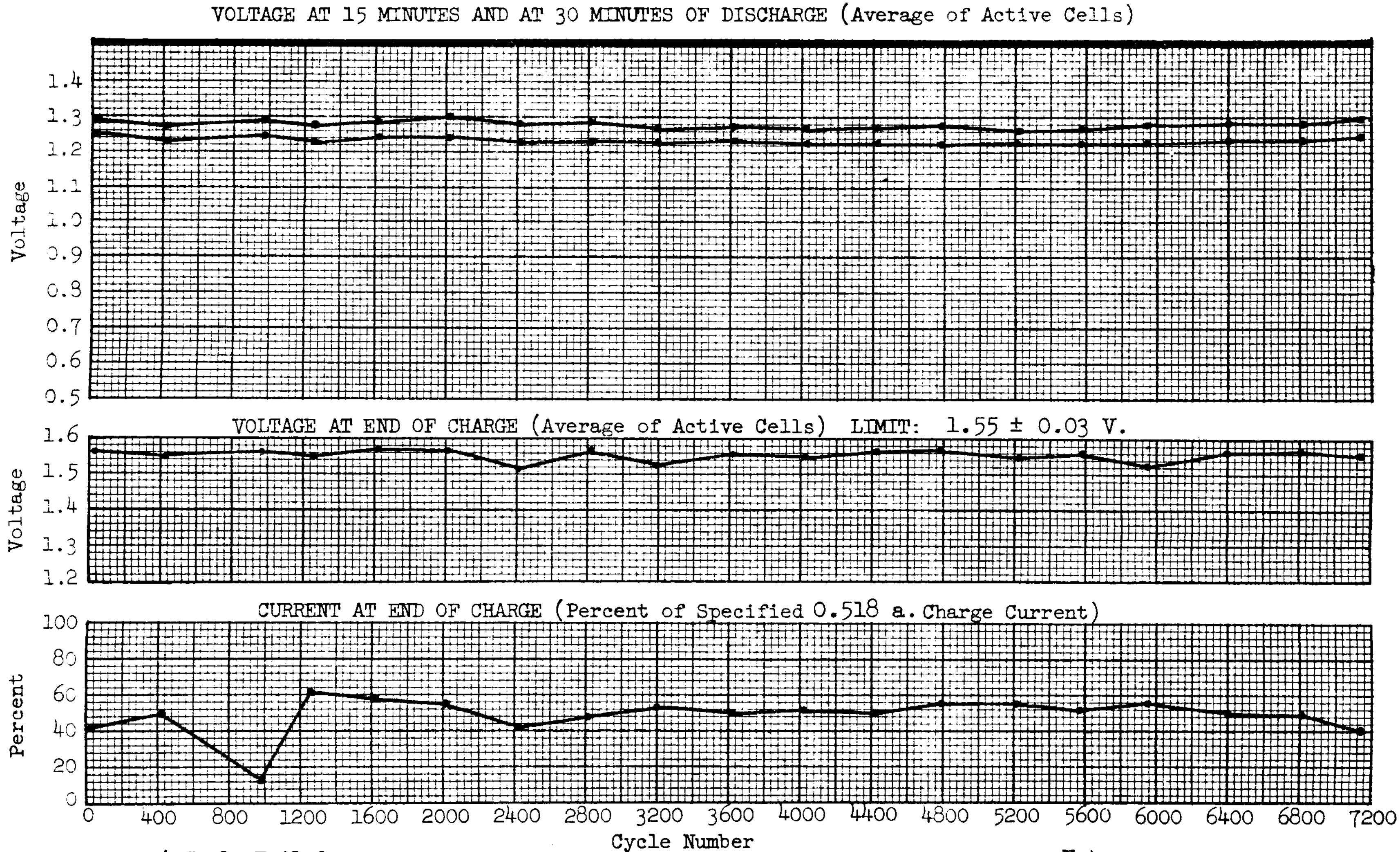
e. The capacity checks of the same three packs, following 440 days of cycling, showed that the capacities obtained were far below those of the fourth discharge immediately following the capacity check after 352 days of cycling. However, the capacities of the capacity check following 440 days of cycling were comparable to those following 264 and 352 days of cycling. The capacity of Pack 82 (G.E. 12 a.h.) after 264, 352 and 440 days of cycling was 46, 43 and 48 percent respectively of the rated capacity whereas its capacity on the fourth discharge following the capacity check after 352 days of cycling was 104 percent of the rated capacity. Likewise, the capacity of Pack 73 (Gulton 20 a.h.) after 264, 352 and 440 days of cycling was 40, 43 and 44 percent respectively of the rated capacity whereas its capacity on the fourth discharge following the capacity check after 352 days of cycling was 85 percent of the rated capacity. This indicates that the capacity of the cells cannot be maintained after their return to the cycling mode. Since Pack 2 (Sonotone 5.0 a.h.) failed after 417 days of cycling, no capacity check following 440 days of cycling could be made for comparison.

f. On the Sonotone cells the maximum percent of rated capacity (60 percent) was obtained on the second discharge after 352 days of cycling; subsequent discharges showed no gain in capacity, indicating a permanent loss of capacity. On the General Electric and Gulton cells (both types use SAFT plates) six discharges after 352 days of cycling were required to obtain the maximum percent of rated capacity (104 and 85 percent respectively) indicating that this loss was due to the memory effect. 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. Contracts to study this phenomenon have been let by the National Aeronautics and Space Administration.



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

FIGURE 7



Cell Number	Cycle Failed

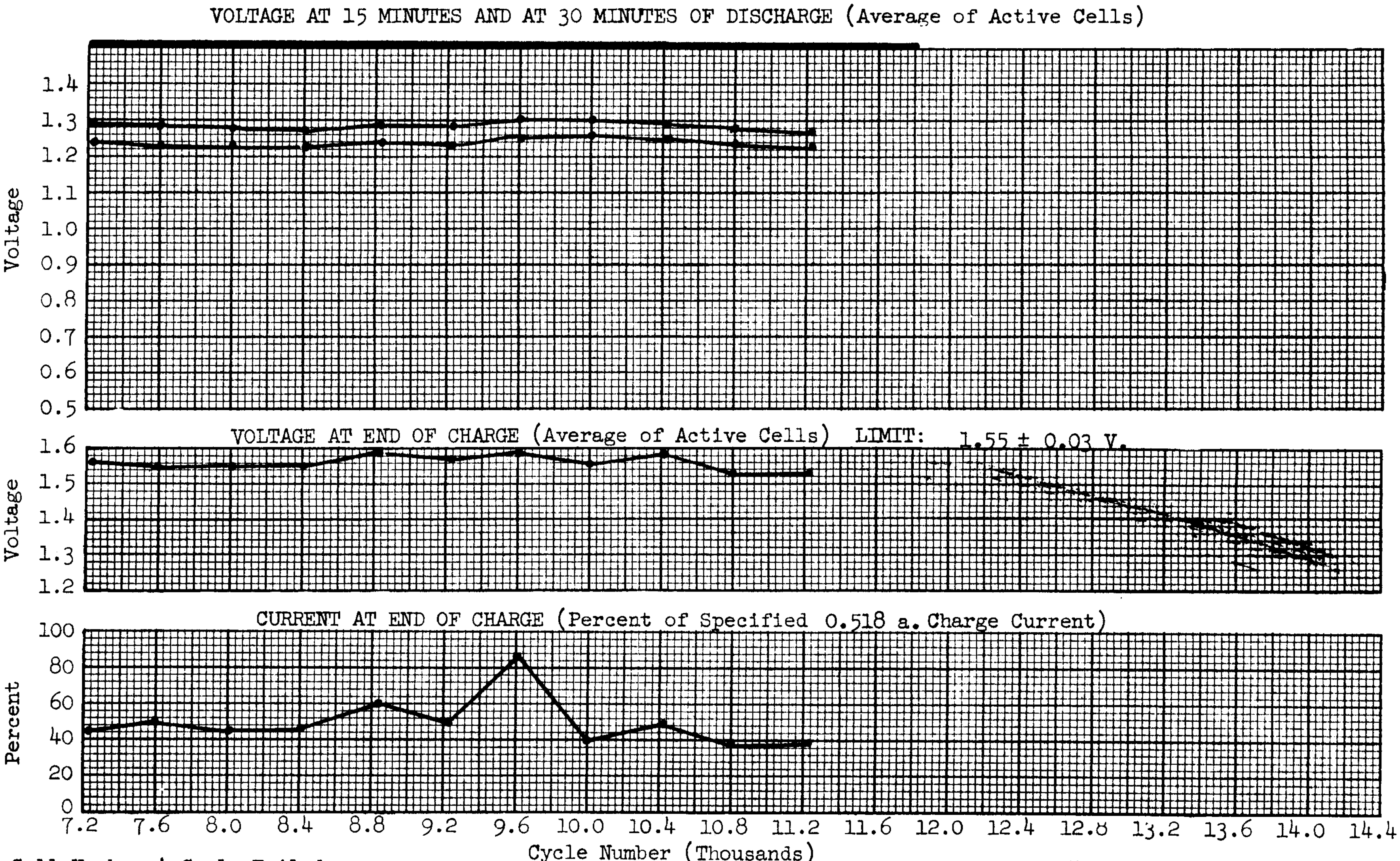
G.E. 3.0 a.h. (Pack 63)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

Status: Continued

Notes

1. Cycles 1546, 2944, 4100, 5607, 7057: Capacity Check.

FIGURE 8(a)



Cell Number	Cycle Failed

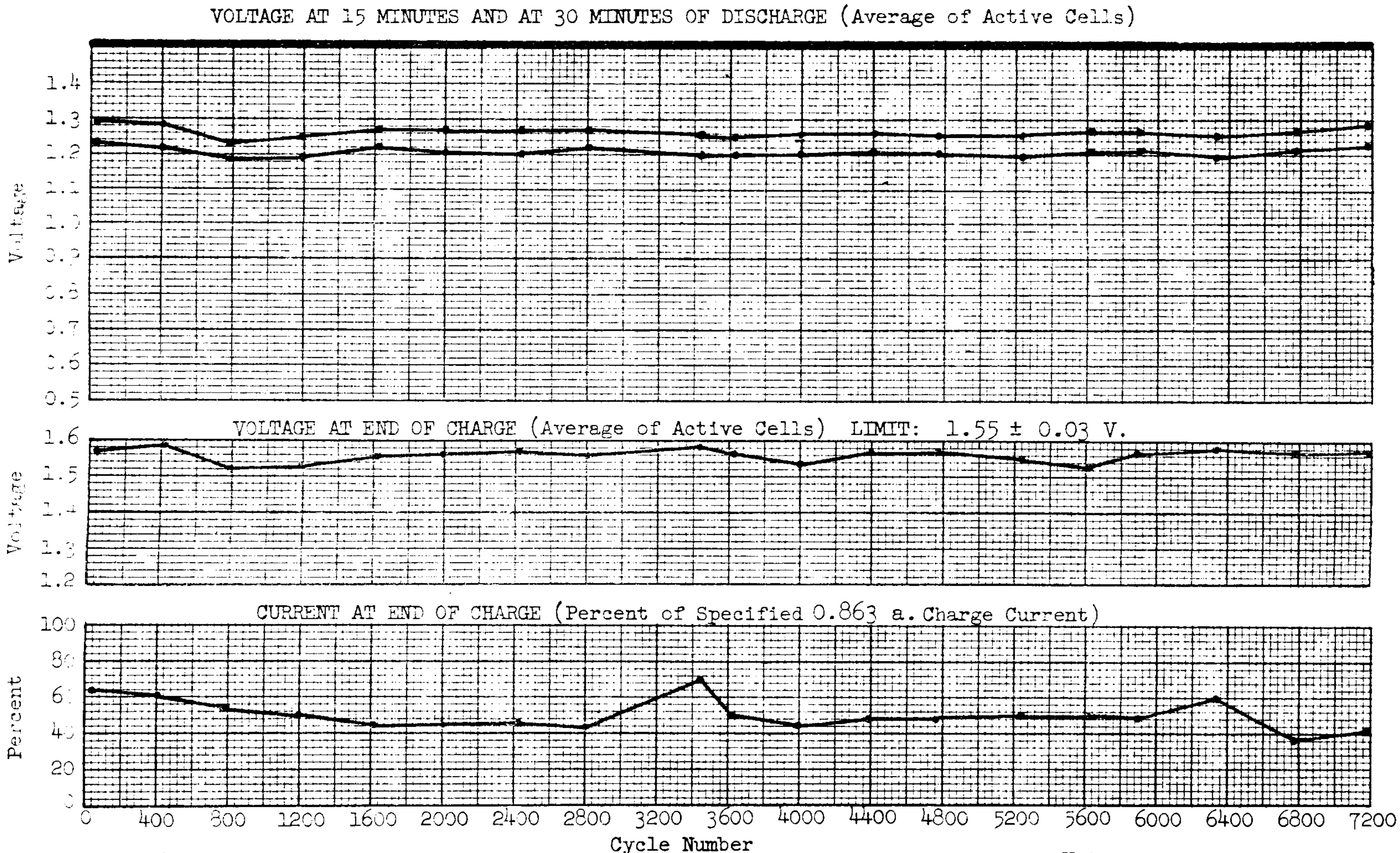
G.E. 3.0 a.h. (Pack 63)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

Status: 10 cells cycling after 11816 cycles.

Notes

1. Cycles 8881, 9835, 11282: Capacity Check.

FIGURE 8(a) (Contd)



Cell Number	Cycle Failed

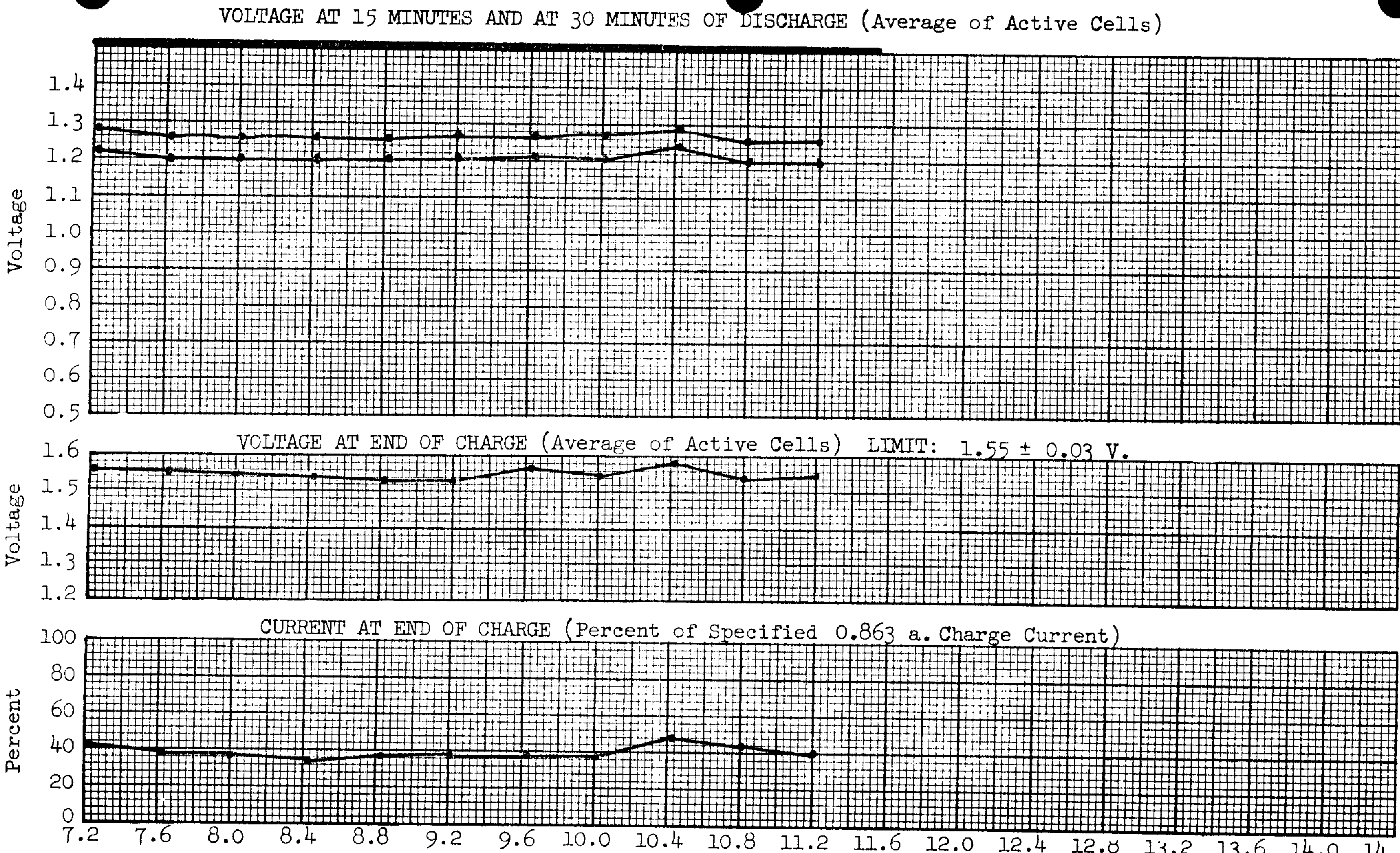
G.E. 3.0 a.h. (Pack 64)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: Continued

Notes

1. Cycles 1442, 2841, 4045, 5472, 7012: Capacity Check.

FIGURE 8(b)



Cell Number	Cycle Failed

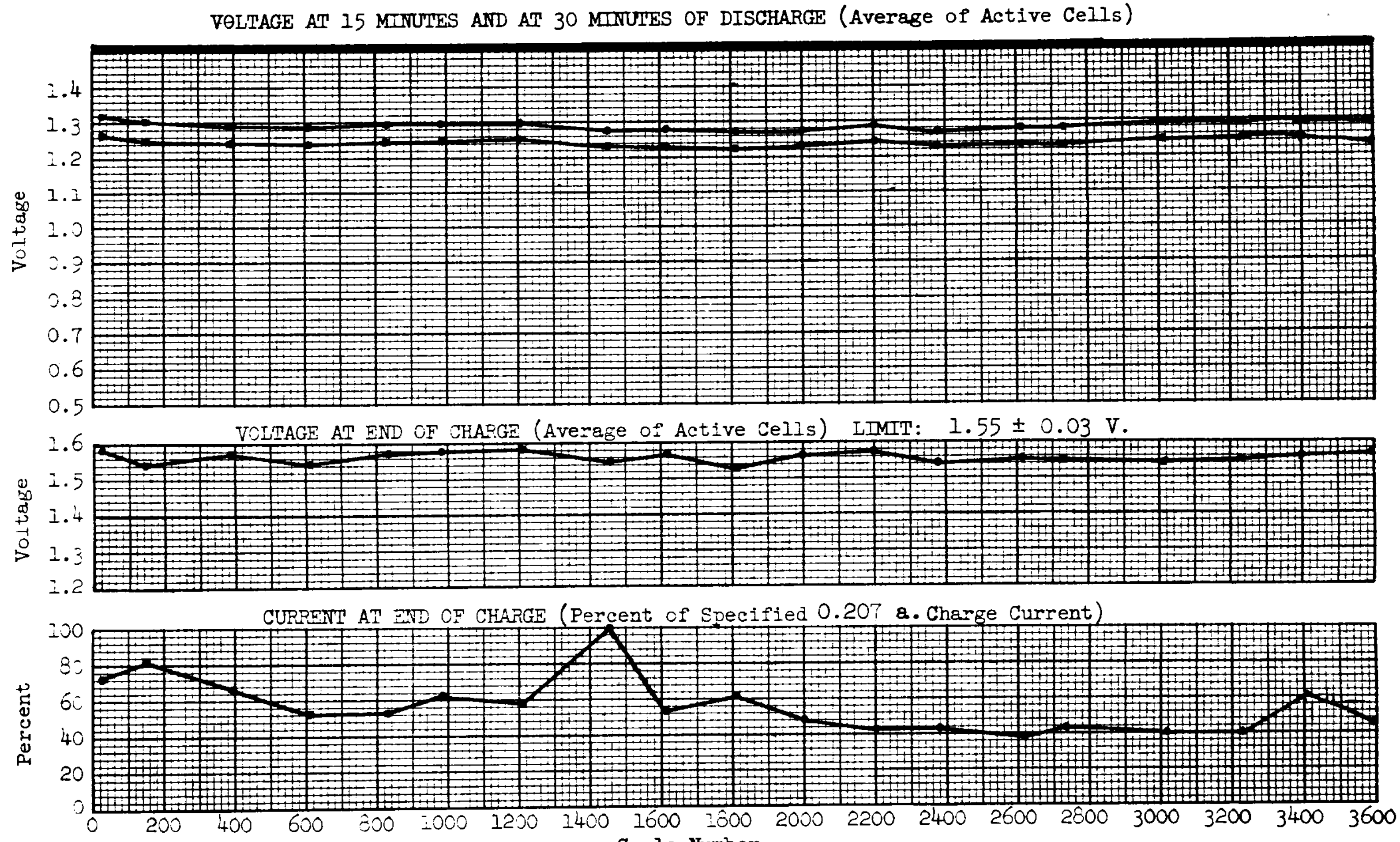
G.E. 3.0 a.h. (Pack 64)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: 10 cells cycling after 11537 cycles.

Notes

1. Cycles 8743, 10096: Capacity Check.

FIGURE 8(b) (Contd)



Cell Number	Cycle Failed

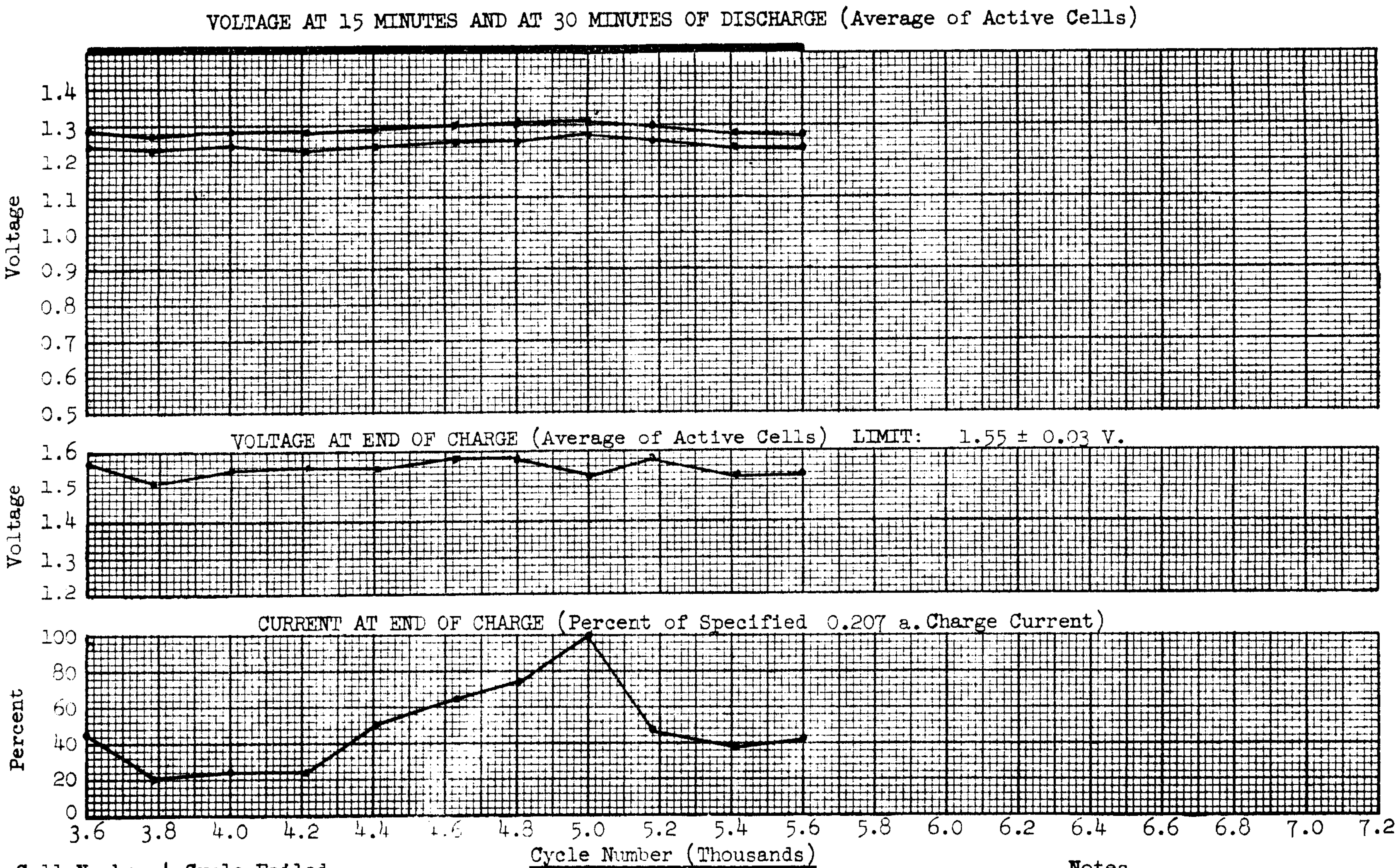
G.E. 3.0 a.h. (Pack 67)
Test Temperature: 0° C
Orbit Period: 3 hours
Depth of Discharge: 15%

Status: Continued

Notes

1. Cycles 719, 1374, 2015, 2762, 3504: Capacity Check.

FIGURE 8(c)



Cell Number	Cycle Failed

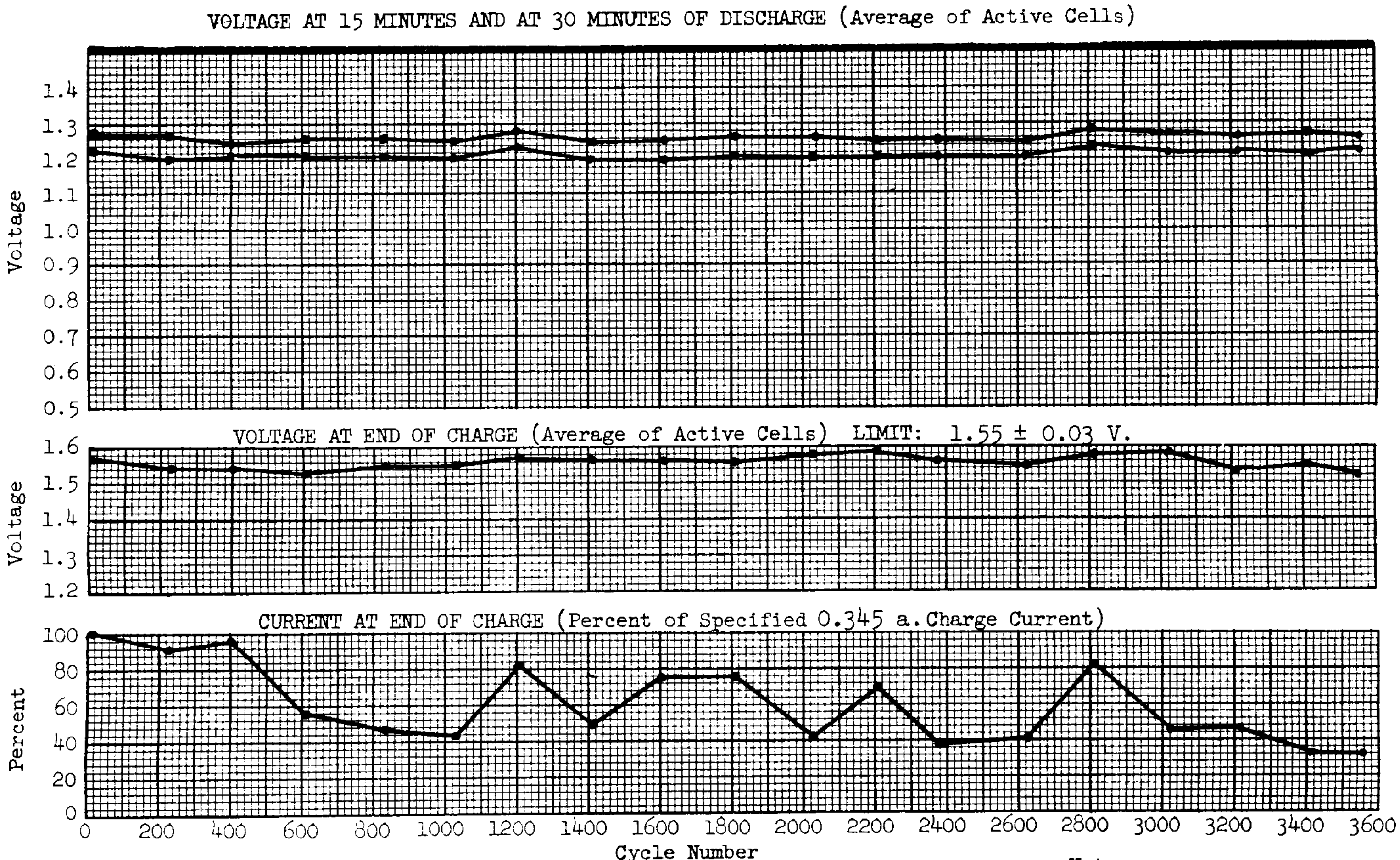
G.E. 3.0 a.h. (Pack 67)
Test Temperature: 0° C
Orbit Period: 3 hours
Depth of Discharge: 15%

Status: 10 cells cycling after 5603 cycling.

Notes

1. Cycles 4271, 4918: Capacity Check.

FIGURE 8(c) (Contd)



Cell Number	Cycle Failed

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

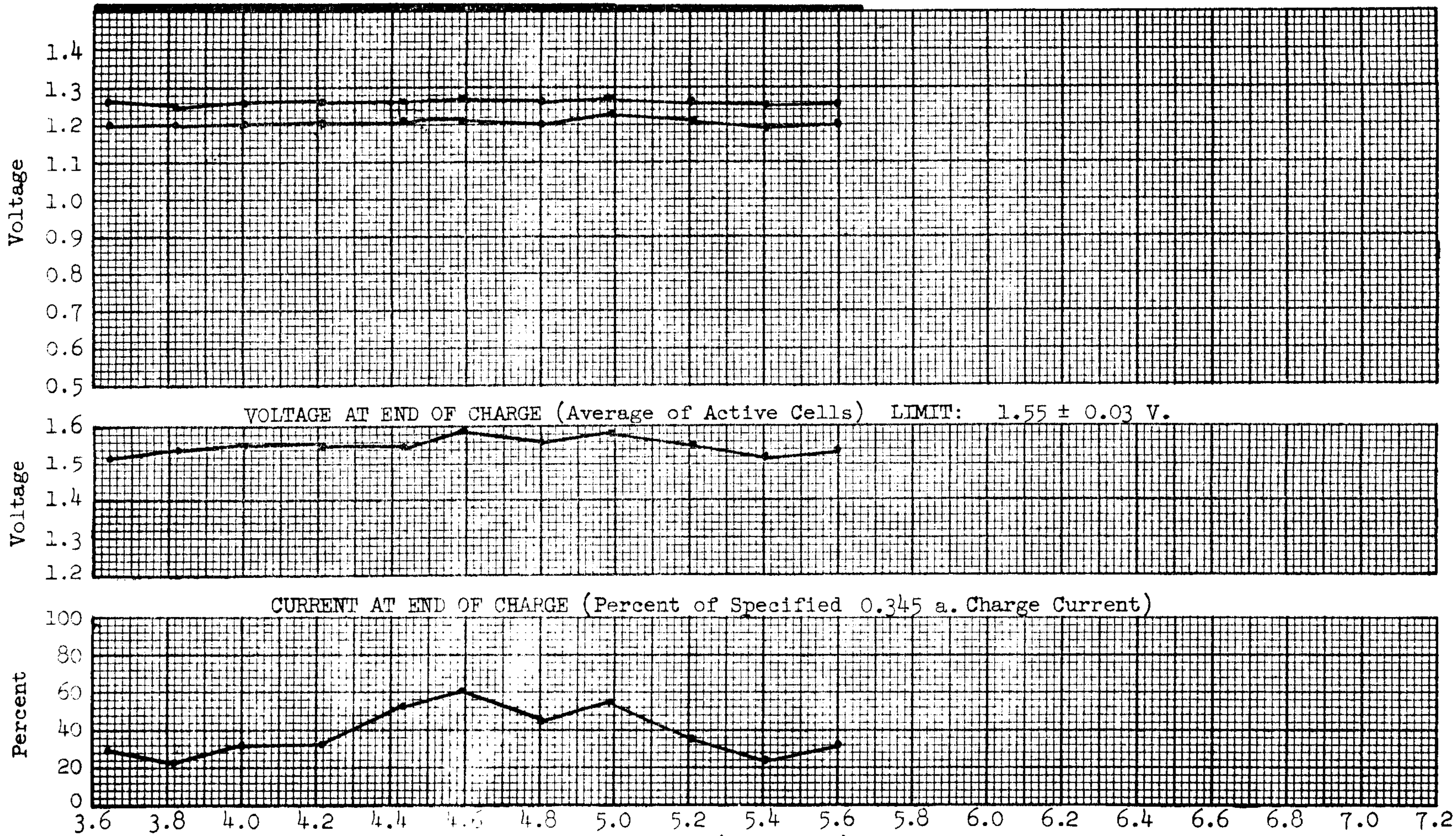
Status: Continued

Notes

1. Cycles 715, 1431, 2050, 2804, 3508: Capacity Check.

FIGURE 8(d)

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



Cell Number	Cycle Failed

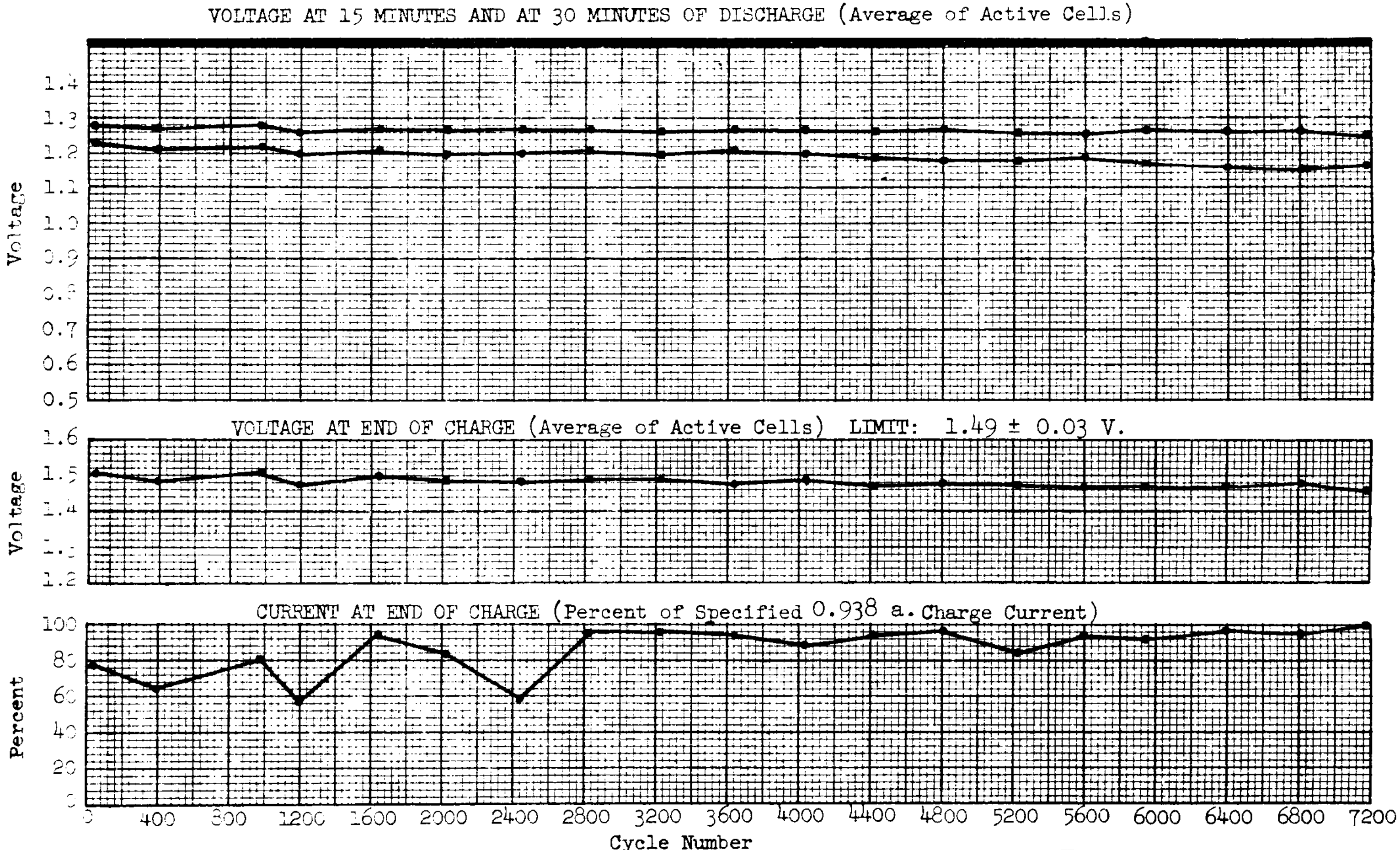
G.E. 3.0 a.h. (Pack 68)
Test Temperature: 0° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: 10 cells cycling after 5664 cycles.

Notes

1. Cycles 4364, 4956: Capacity check.

FIGURE 3(d) (Contd)



Cell Number	Cycle Failed

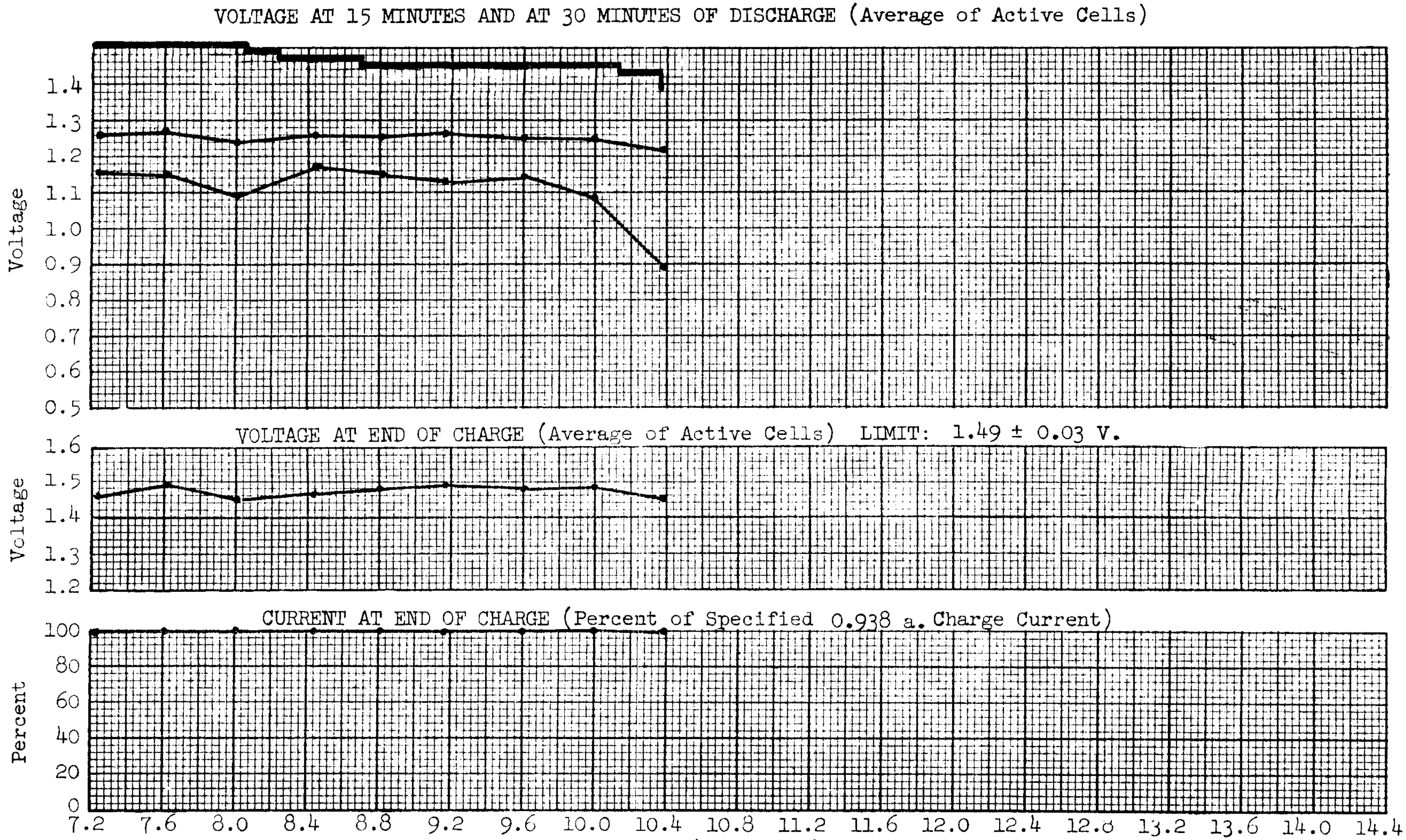
G.E. 3.0 a.h. (Pack 15)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: Continued

Notes

1. Cycles 1544, 2878, 4151, 5543, 7163: Capacity Check.

FIGURE 8(e)



Cell Number	Cycle Failed
432	8065
414	8254
479	8714
267	10123
447, 485	10382

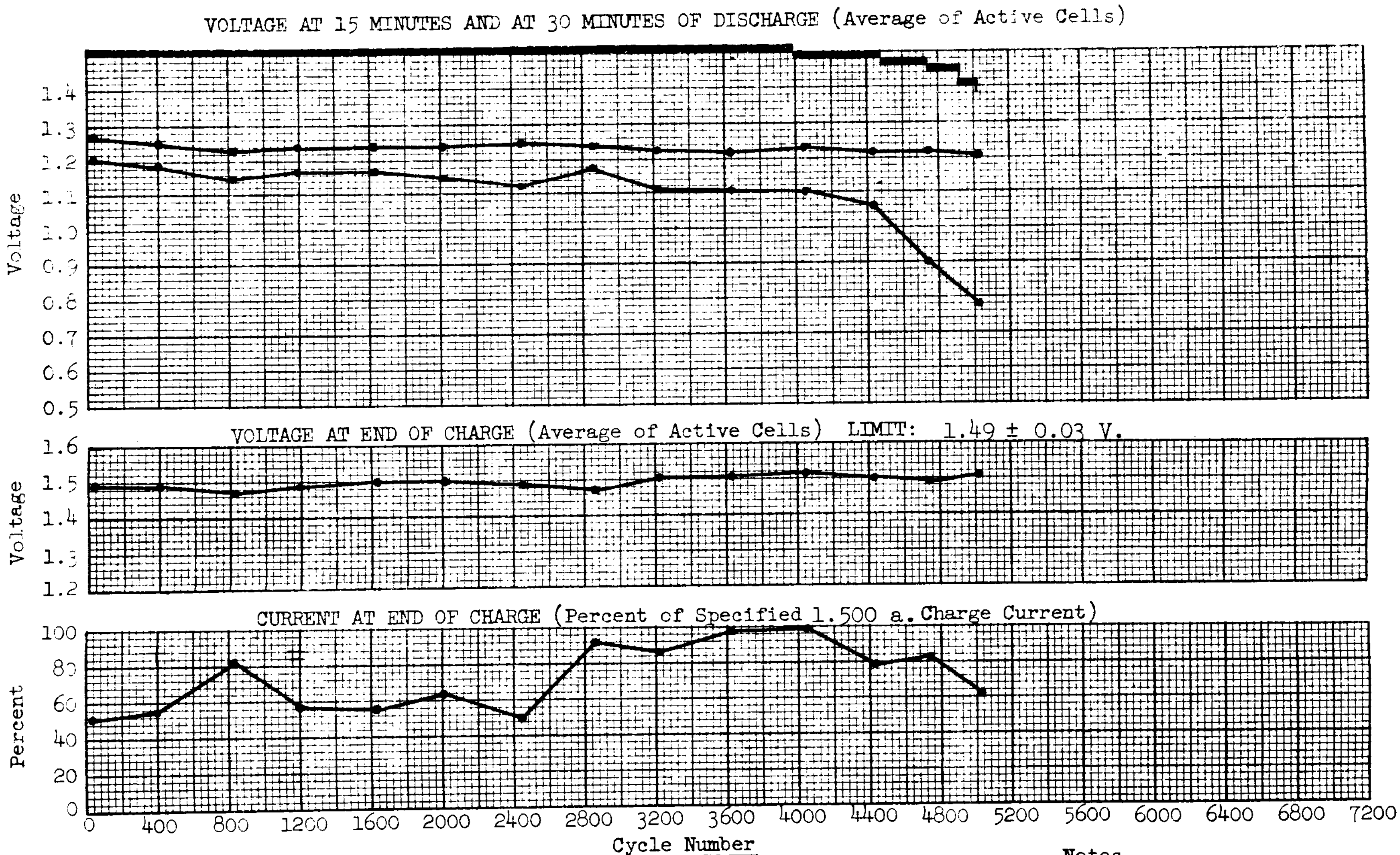
G.E. 3.0 a.h. (Pack 15)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: Pack Failed: Cycle 10382

Notes

1. Cycles 8673, 9726, 9750: Capacity Check

FIGURE 8(e) (Contd)



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

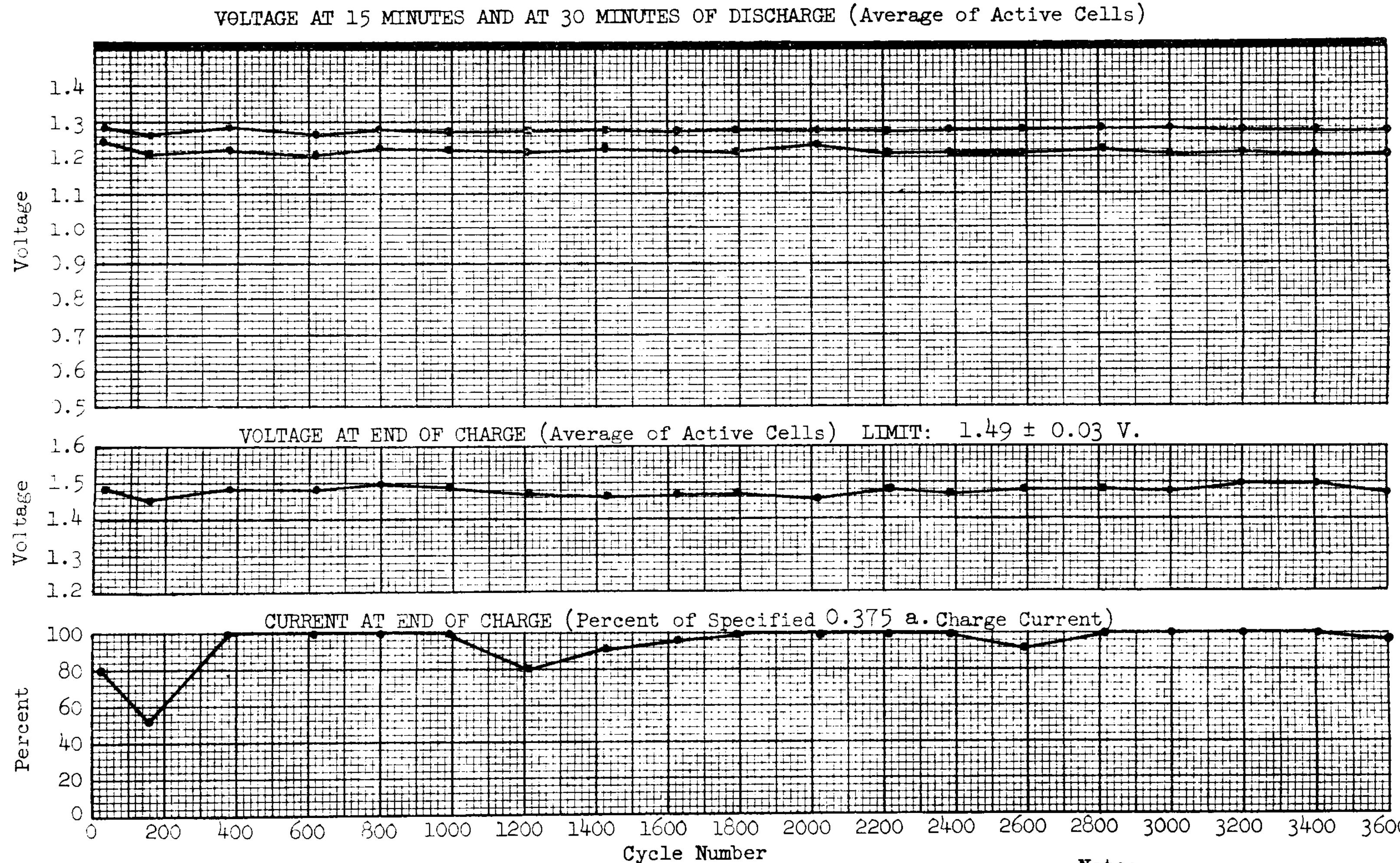
G.E. 3.0 a.h. (Pack 16)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 40%

Status: Pack Failed: Cycle 5013

Notes

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

FIGURE 8(f)



Cell Number	Cycle Failed

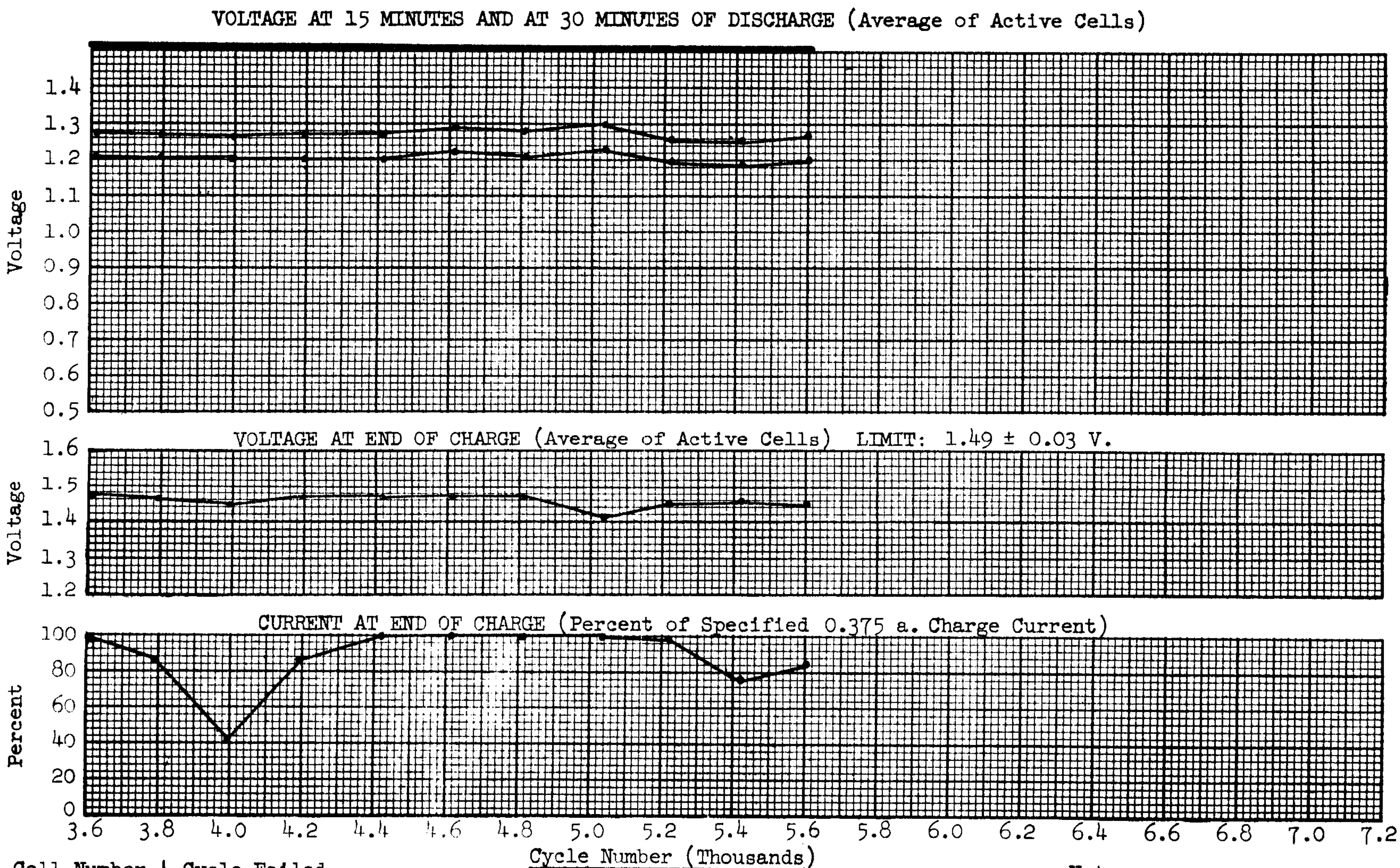
G.E. 3.0 a.h. (Pack 19)
Test Temperature: 25° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: Continued

Notes

1. Cycles 674, 1381, 2008, 2722, 3432: Capacity Check.

FIGURE 8(g)



Cell Number	Cycle Failed

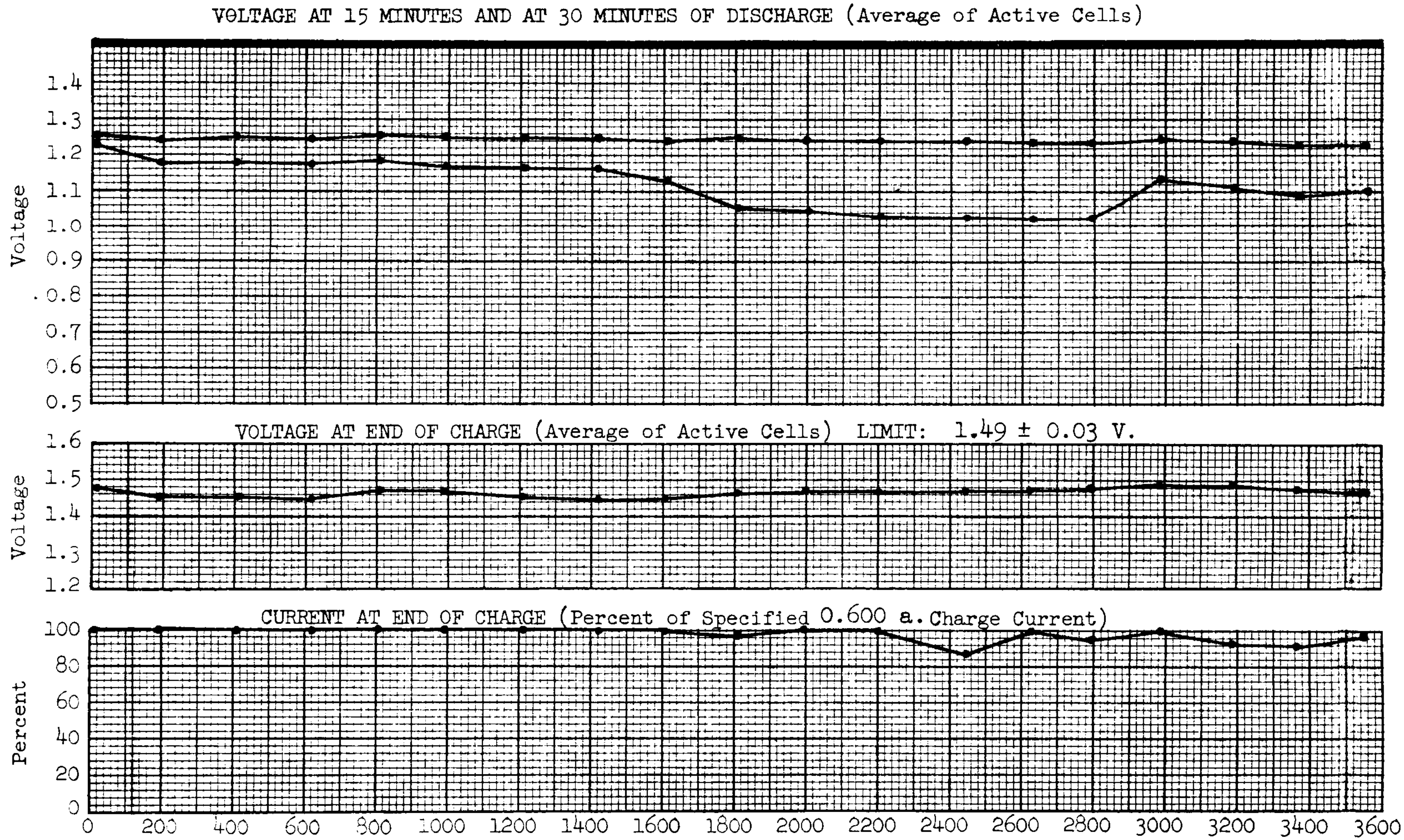
G.E. 3.0 a.h. (Pack 19)
Test Temperature: 25° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: 10 cells cycling after 5636 cycles.

Notes

1. Cycles 4241, 4822, 5607: Capacity Check.

FIGURE 8(g) (Contd)



Cell Number	Cycle Failed

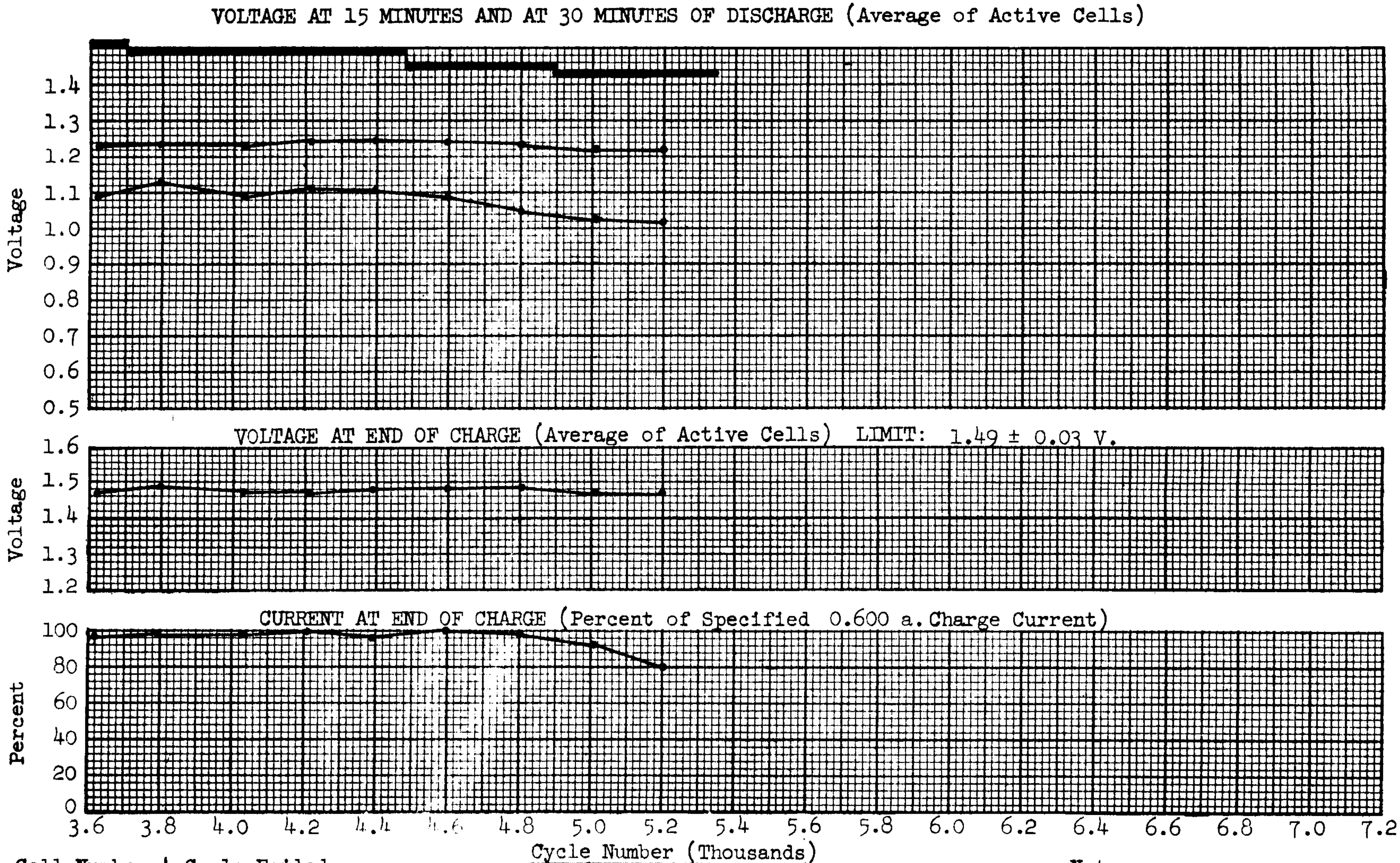
G.E. 3.0 a.h. (Pack 20)
Test Temperature: 25° C
Orbit Period: 3 hours
Depth of Discharge: 40%

Status: Continued

Notes

1. Cycles 676, 1373, 2071, 2601, 3219: Capacity Check.

FIGURE 8(h)



Cell Number	Cycle Failed
421	3704
433	4485
711	4485
710	4889

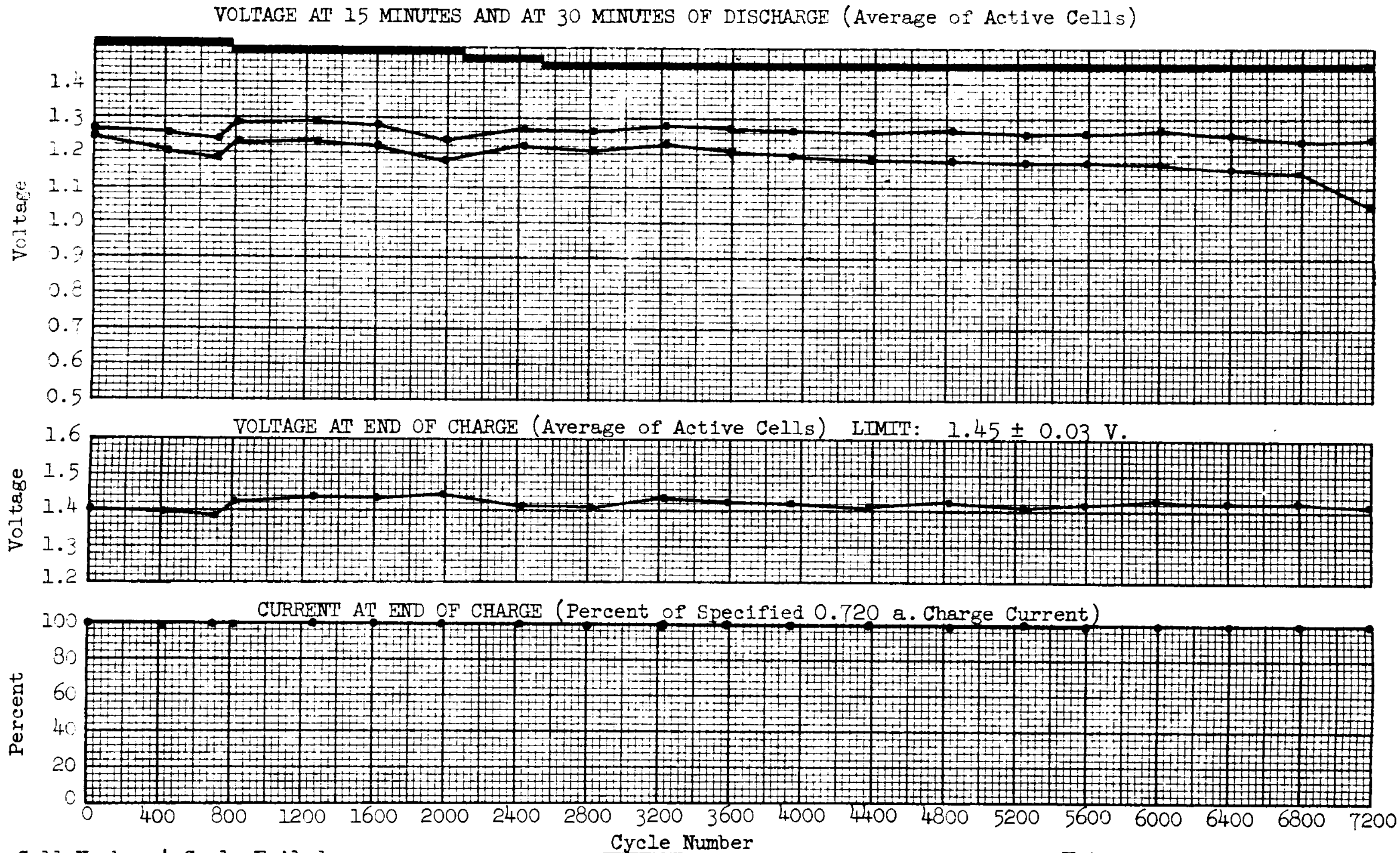
G.E. 3.0 a.h. (Pack 20)
Test Temperature: 25° C
Orbit Period: 3 hours
Depth of Discharge: 40%

Status: 6 cells cycling after 5349 cycles.

Notes

1. Cycles 3984, 4557, 5304: Capacity Check.

FIGURE 8(h) (Contd)



Cell Number	Cycle Failed
541	779
540	2083
549	2523

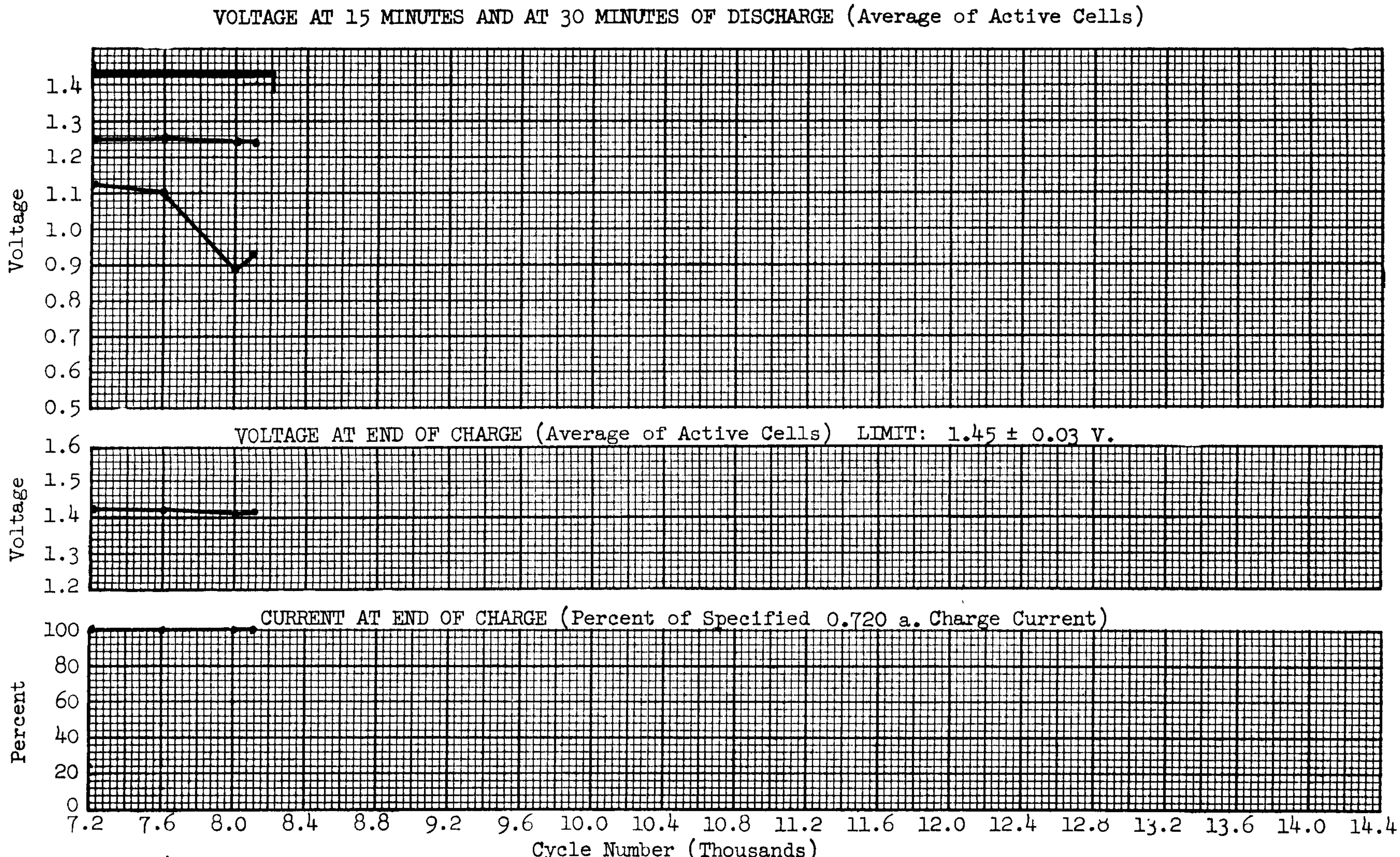
G.E. 3.0 a.h. (Pack 39)
Test Temperature: 50° - 40° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

Status: Continued

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, 6790: Capacity Check.

FIGURE 8(i)



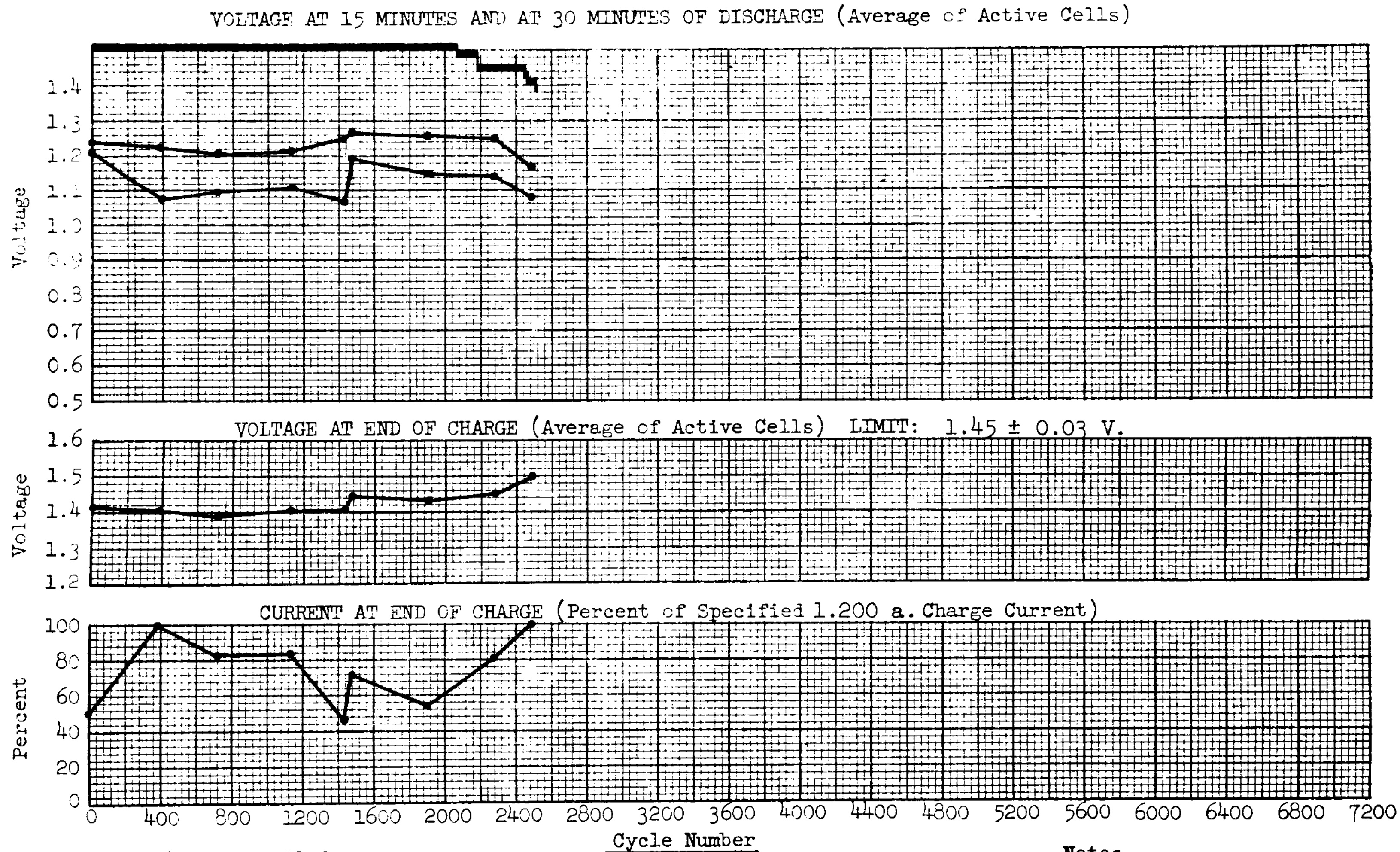
Cell Number	Cycle Failed
527	7213
534	8109
550	8109

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

Status: Pack Failed: Cycle 8109

Notes

FIGURE 8(i) (Contd)



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

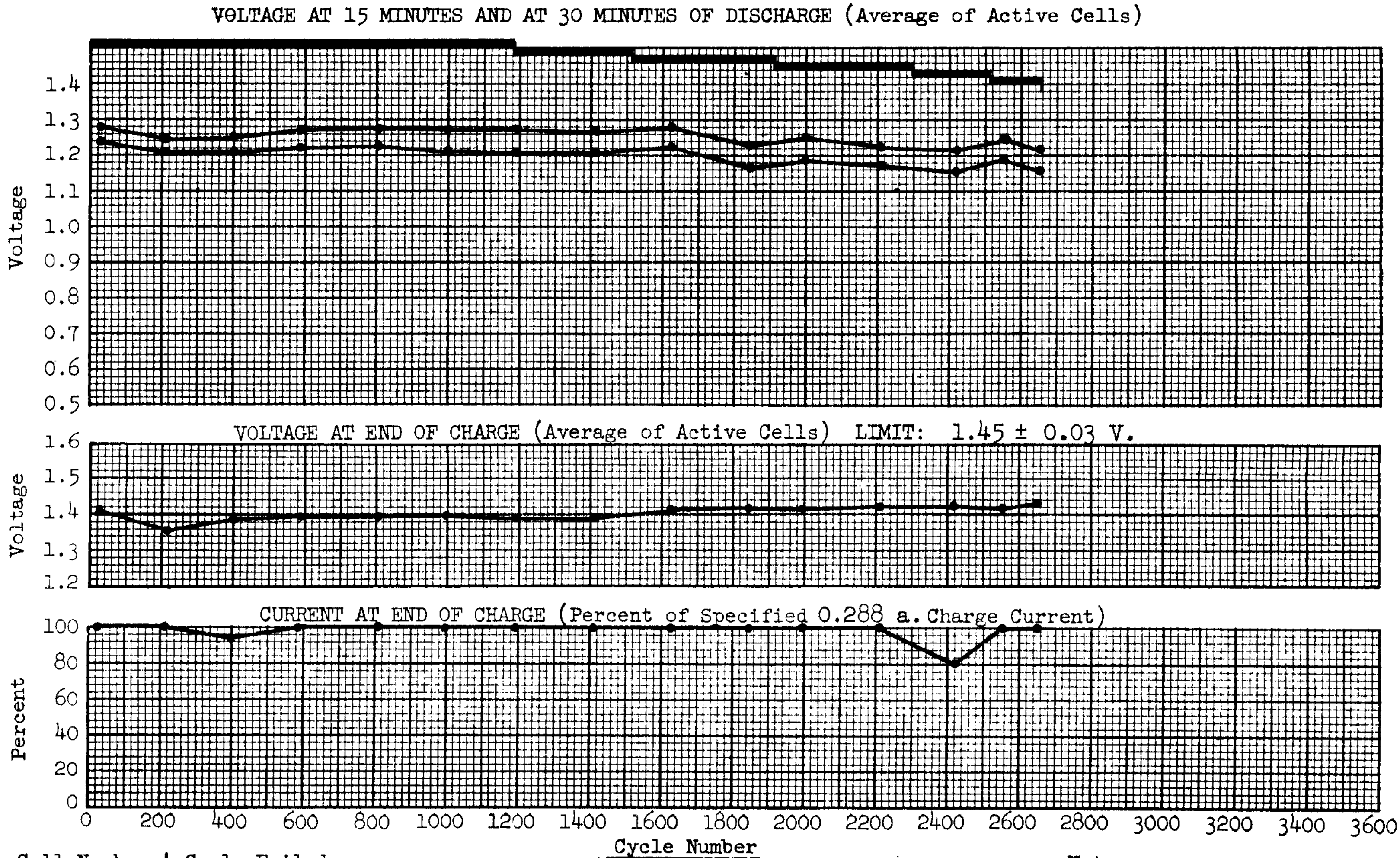
G.E. 3.0 a.h. (Pack 40)
Test Temperature: 50° - 40° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

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 8(j)



Cell Number	Cycle Failed
416	1182
499	1515
412	1911
426	22[illegible]8
436	2515
435	2656

G.E. 3.0 a.h. (Pack 43)

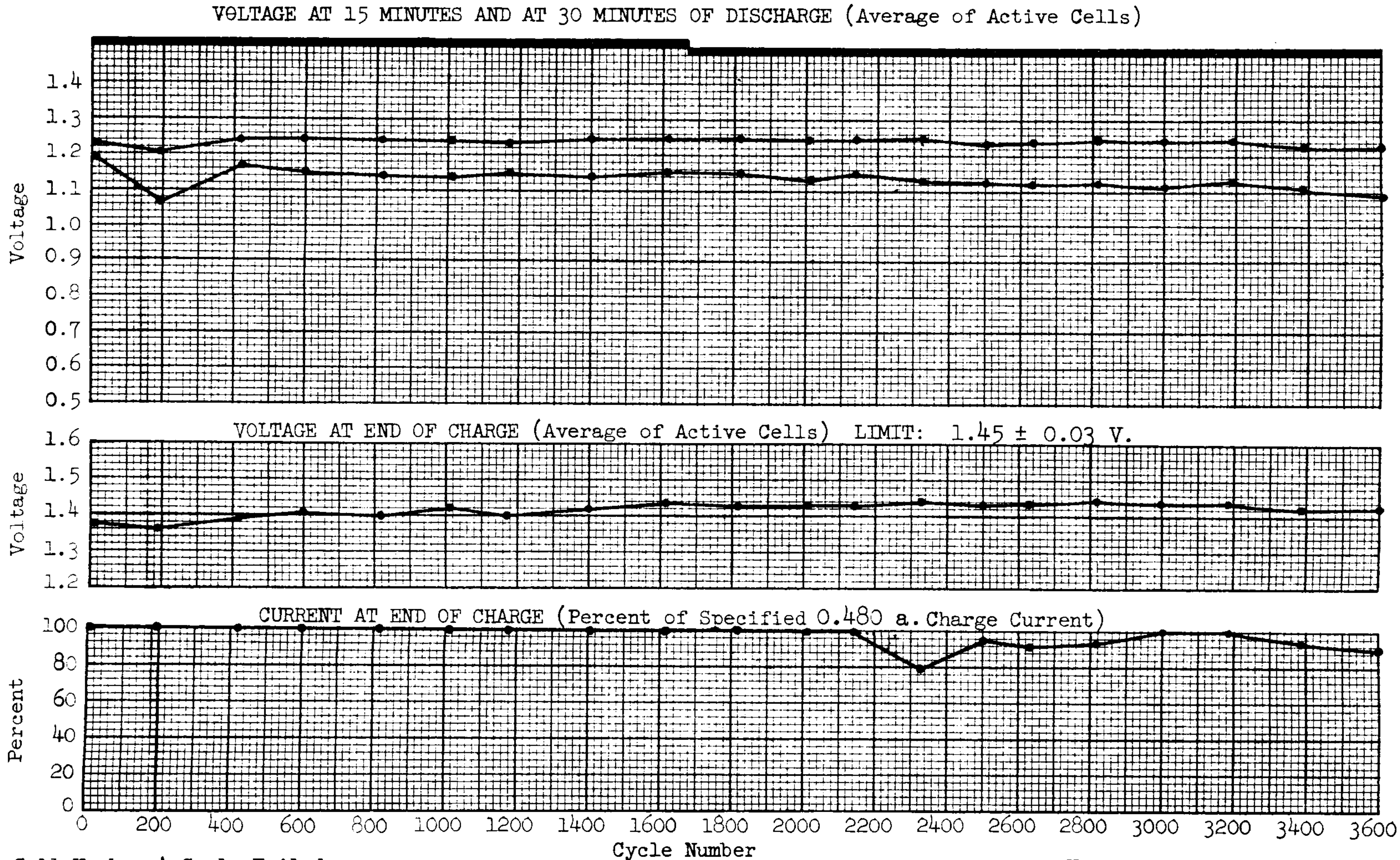
Test Temperature: 50° - 40° C
Orbit Period: 3 hours
Depth of Discharge: 15%

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 8(k)



Cell Number	Cycle Failed
222	1672

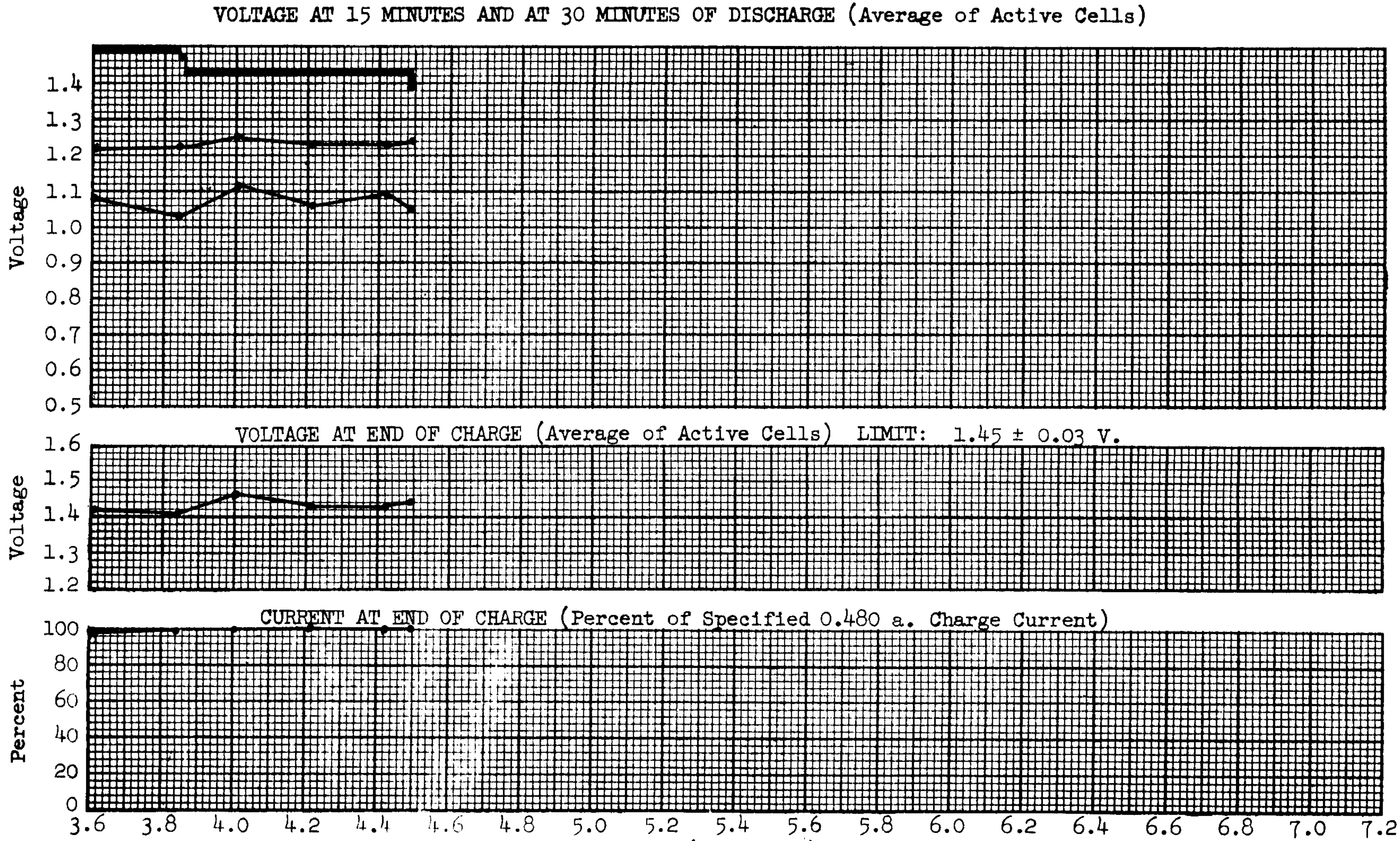
G.E. 3.0 a.h. (Pack 44)
Test Temperature: 50° - 40° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: Continued

Notes

1. Cycle 327: Changed to 40° C.
2. Cycle 487: Voltage limit raised to 1.45 V/cell.
3. Cycles 696, 1402, 2053, 2695, 3357: Capacity Check.

FIGURE 8(1)



Cell Number	Cycle Failed
366	3848
459	3854
77	3854
3120	4487
296	4487

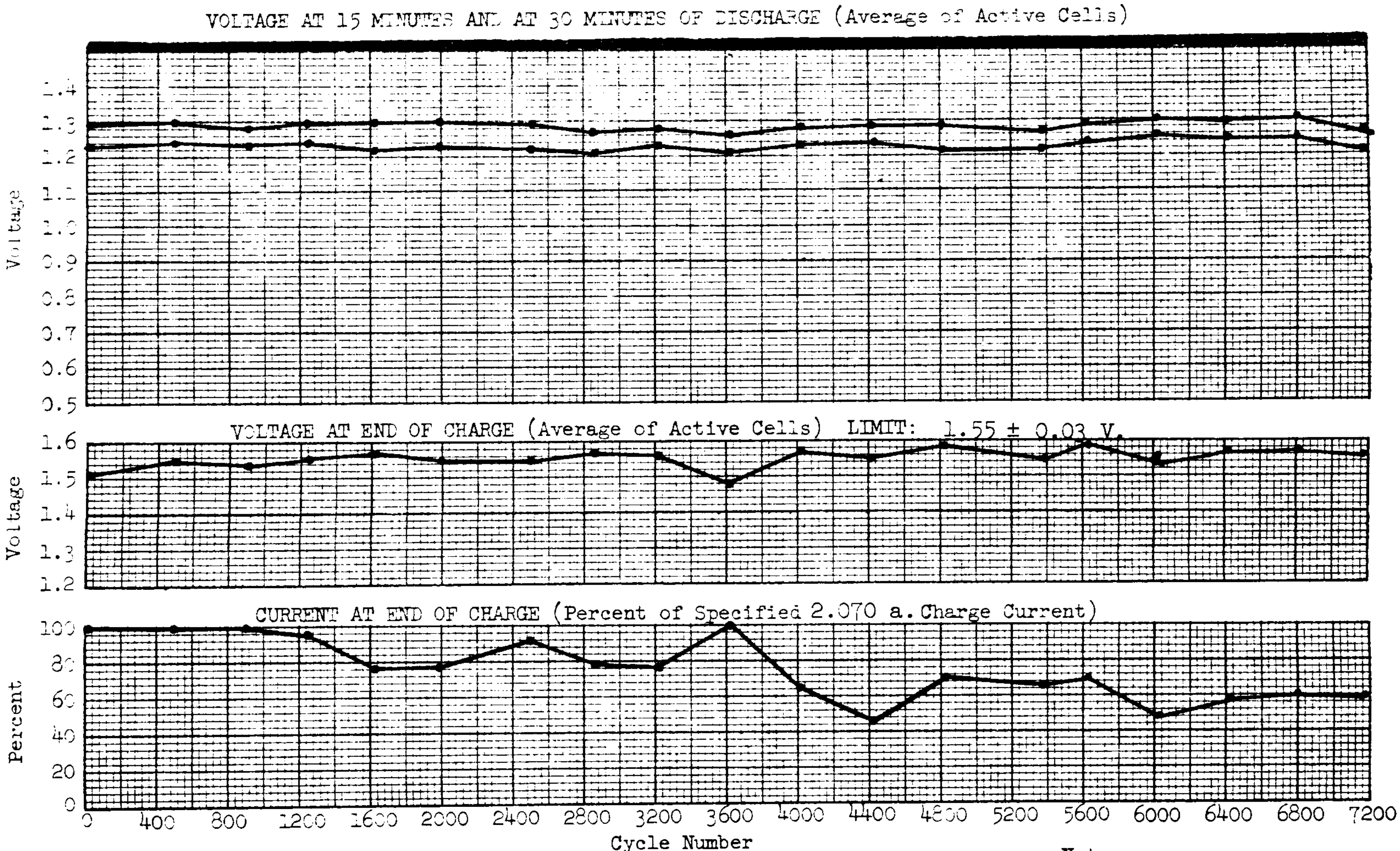
G.E. 3.0 a.h. (Pack 44)
Test Temperature: 50°-40° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: Pack Failed: Cycle 4487

Notes

1. Cycles 4127: Capacity Check.

FIGURE 8(1) (Contd)



Cell Number	Cycle Failed

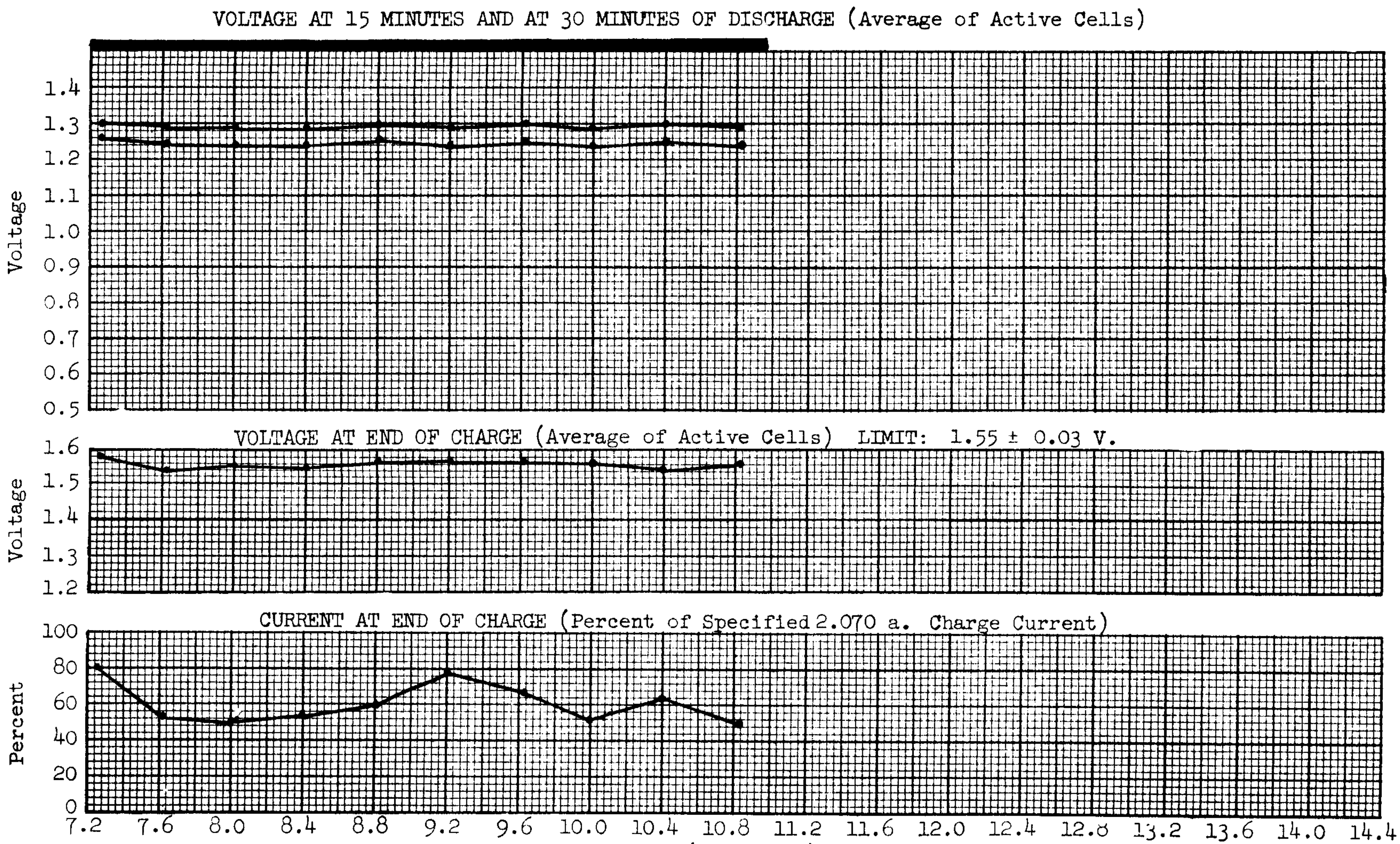
G.E. 12 a.h. (Pack 110)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

Status: Continued

Notes

1. Cycles 1440, 2898, 4410, 5805, 7189: Capacity Check.

FIGURE 9(a)



Cell Number	Cycle Failed

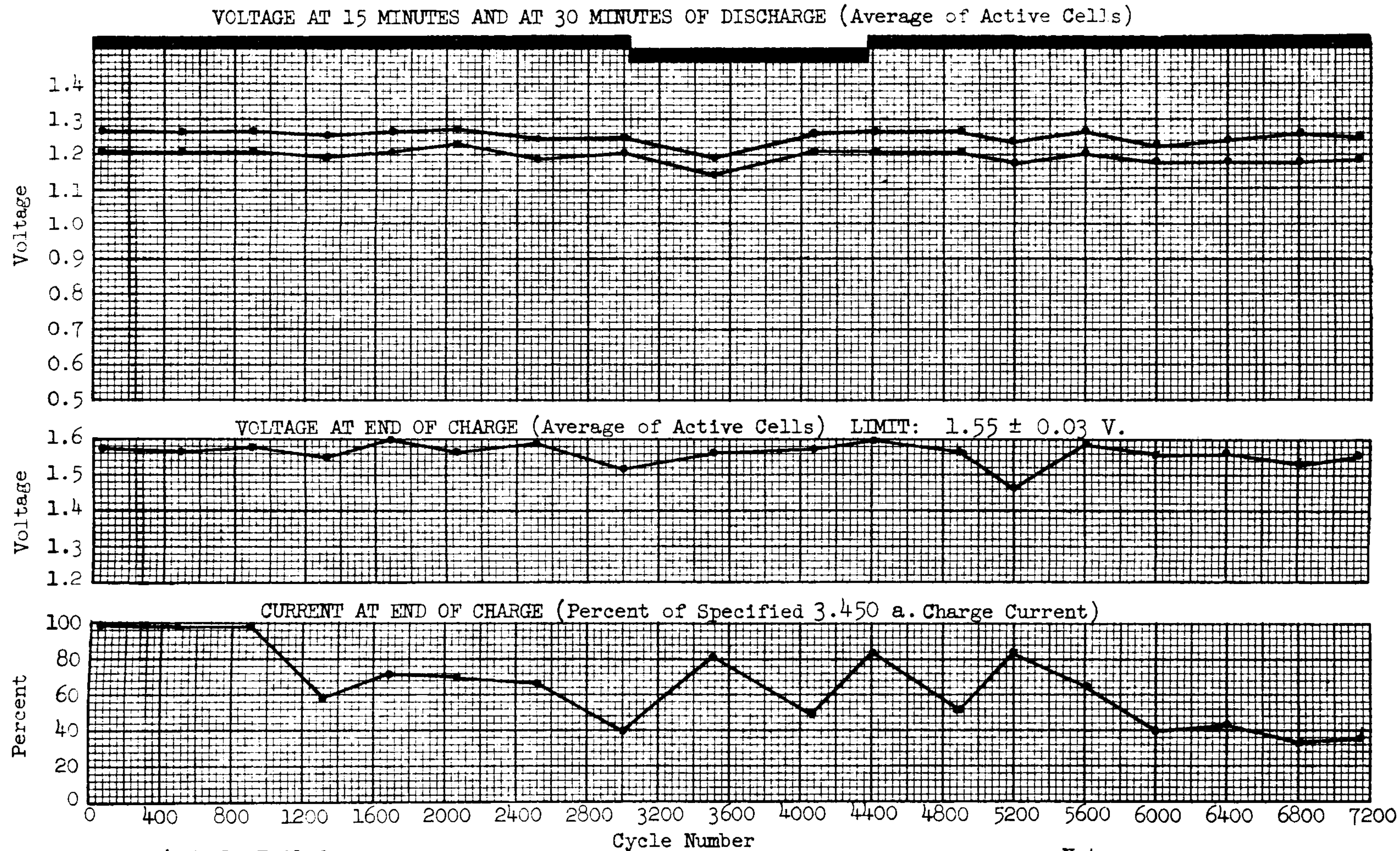
G.E. 12 a.h. (Pack 110)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

Status: 5 cells cycling after 10963 cycles.

Notes

1. Cycles 8619, 9777: Capacity Check.

FIGURE 9(a) (Contd)



Cell Number	Cycle Failed

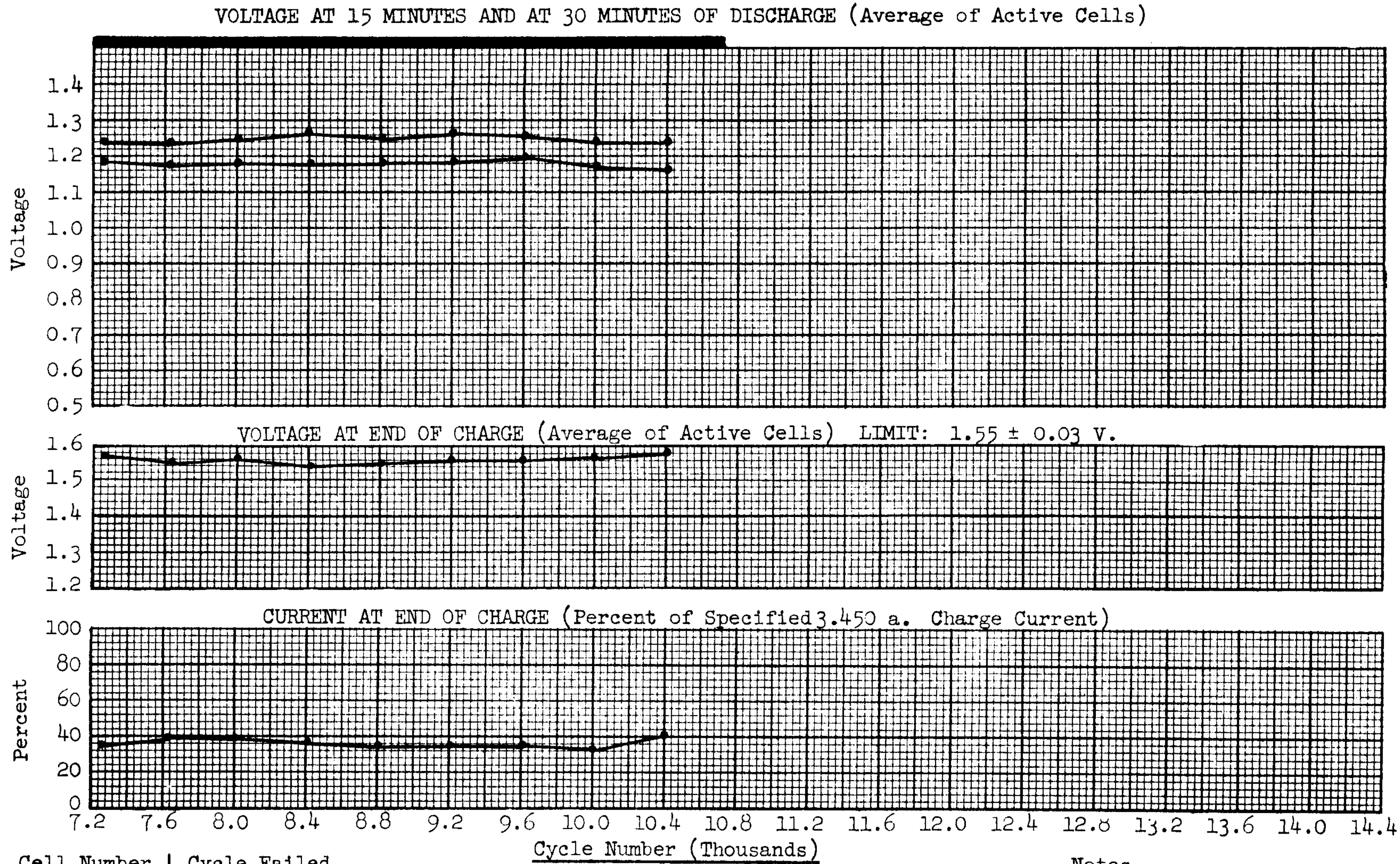
G.E. 12 a.h. (Pack 124)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: Continued

Notes

1. Cycles 1481, 2976, 4301, 5620, 6956: Capacity Check.
2. Cycles 3037-4375: Cell 410 failed; returned to pack after it regained normal capacity during failure tests.

FIGURE 9(b)



Cell Number	Cycle Failed

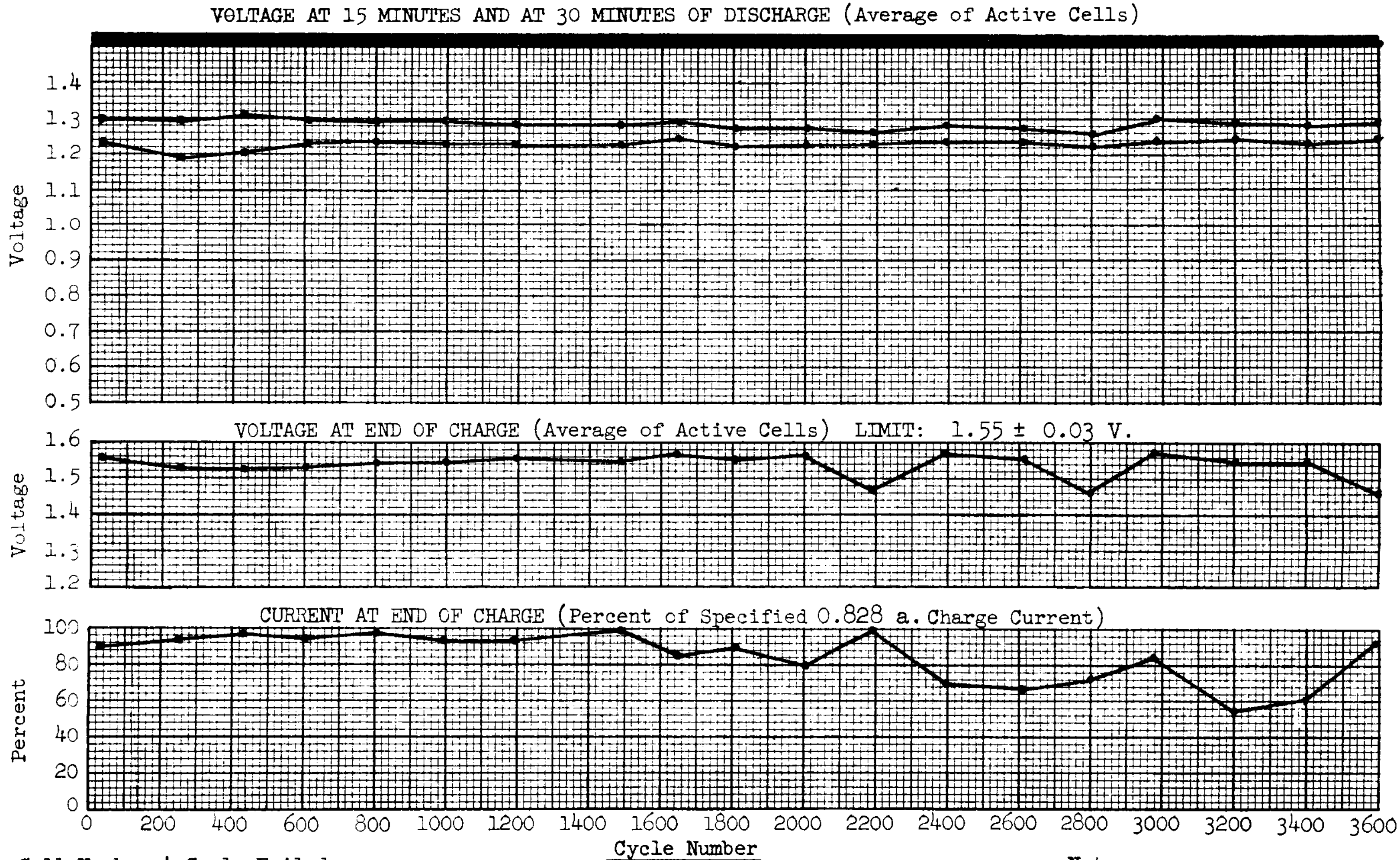
G.E. 12.0 a.h. (Pack 124)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: 5 cells cycling after 10730 cycles.

Notes

1. Cycles 8468, 9544: Capacity Check.

FIGURE 9(b) (Contd)



Cell Number	Cycle Failed

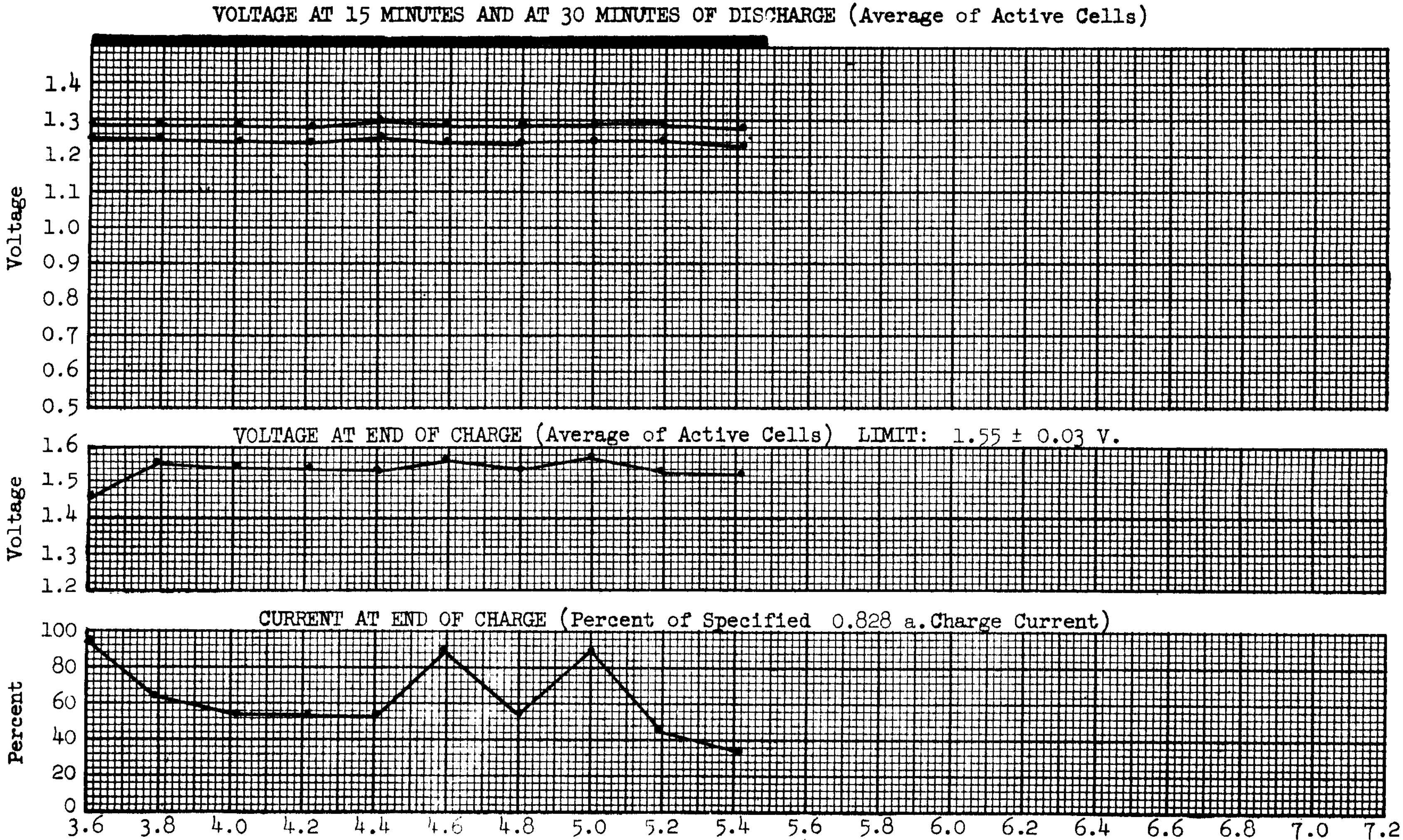
G.E. 12 a.h. (Pack 111)
Test Temperature: 0° C
Orbit Period: 3 hours
Depth of Discharge: 15%

Status: Continued

Notes

1. Cycles 696, 1533, 2179, 2871, 3558: Capacity Check.

FIGURE 9(c)



Cell Number	Cycle Failed

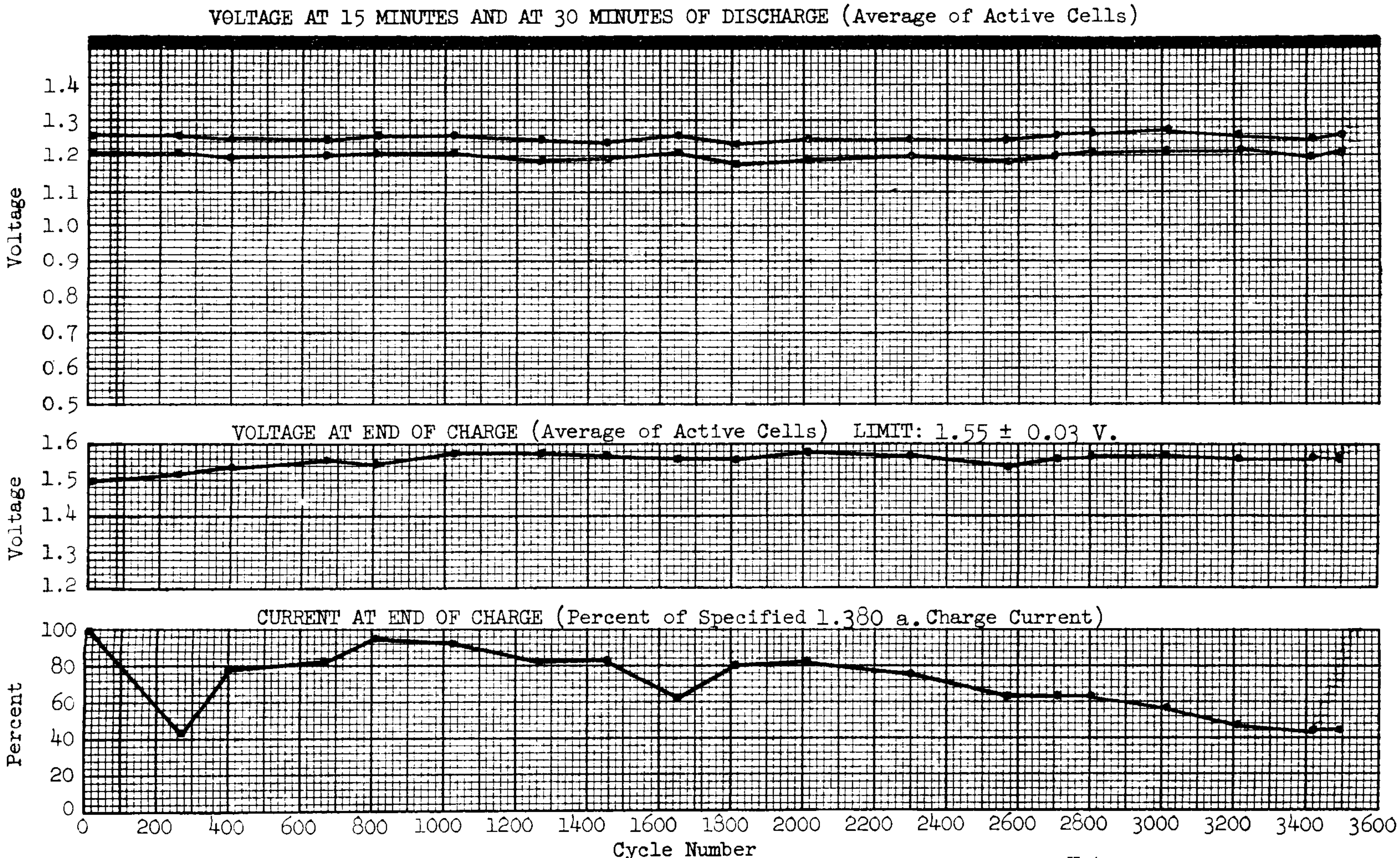
G.E. ls a.h. (Pack 111)
Test Temperature: 0° C
Orbit Period: 3 hours
Depth of Discharge: 15%

Status: 5 cells cycling after 5479 cycles.

Notes

1. Cycles 4320, 4884: Capacity Check.

FIGURE 9(c) (Contd)



Cell Number	Cycle Failed

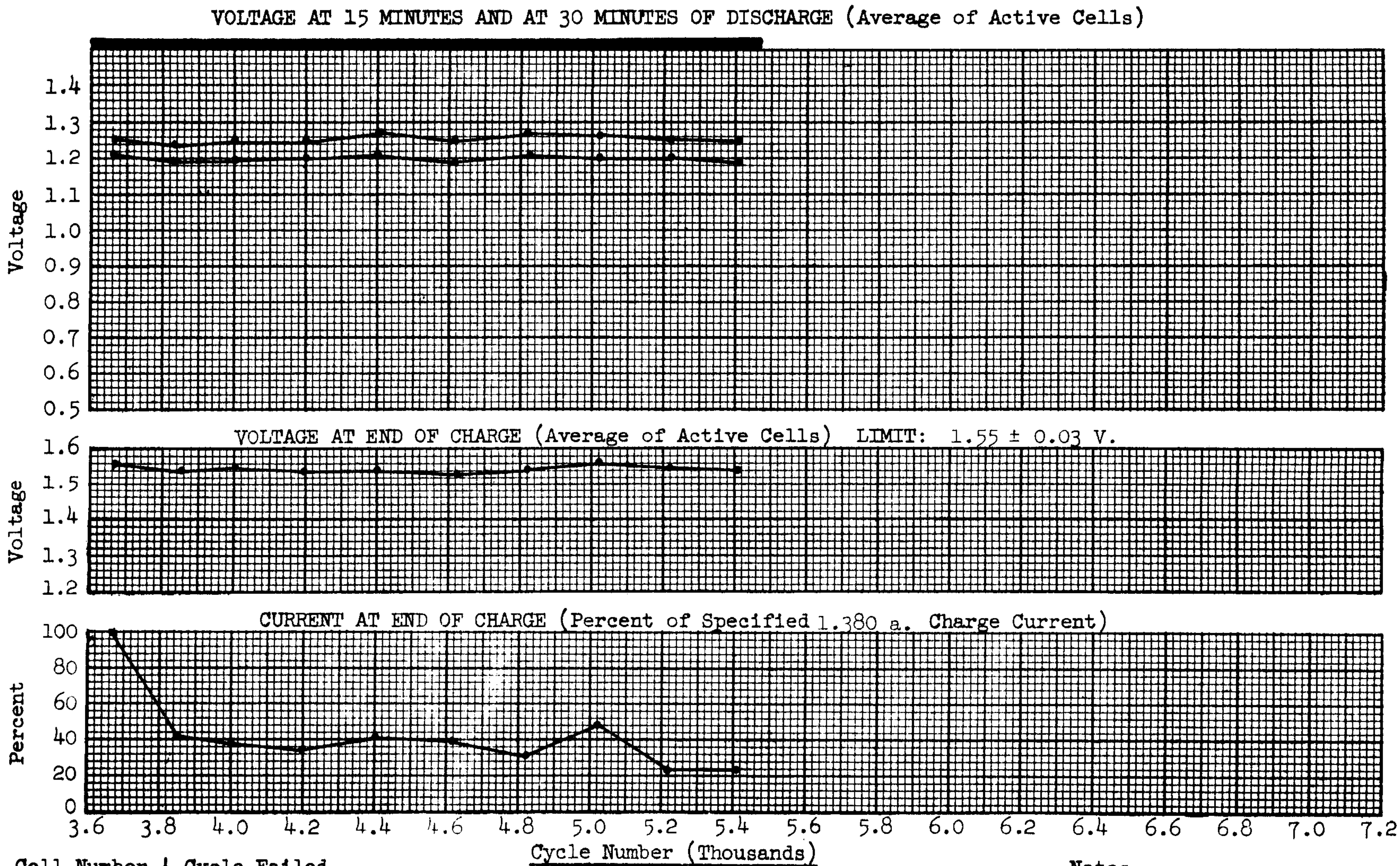
G.E. 12 a.h. (Pack 125)
Test Temperature: 0° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: Continued

Notes

1. Cycles 695, 1533, 2178, 2870, 3532: Capacity Check.

FIGURE 9(d)



Cell Number	Cycle Failed

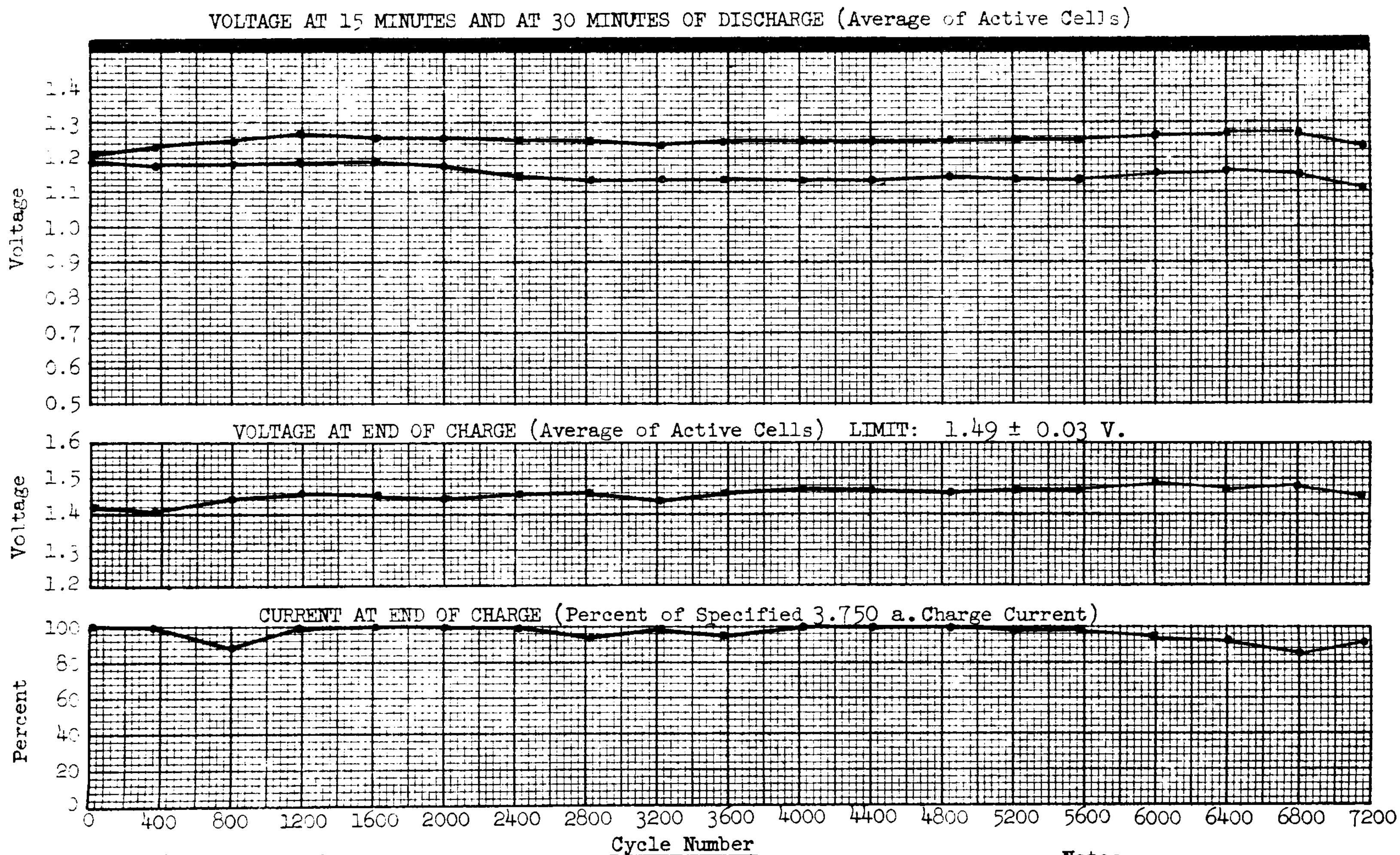
G.E. 12 a.h. (Pack 125)
Test Temperature: 0° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: 5 cells cycling after 5472 cycles.

Notes

1. Cycles 4343, 4877: Capacity Check.

FIGURE 9(d) (Contd)



Cell Number	Cycle Failed

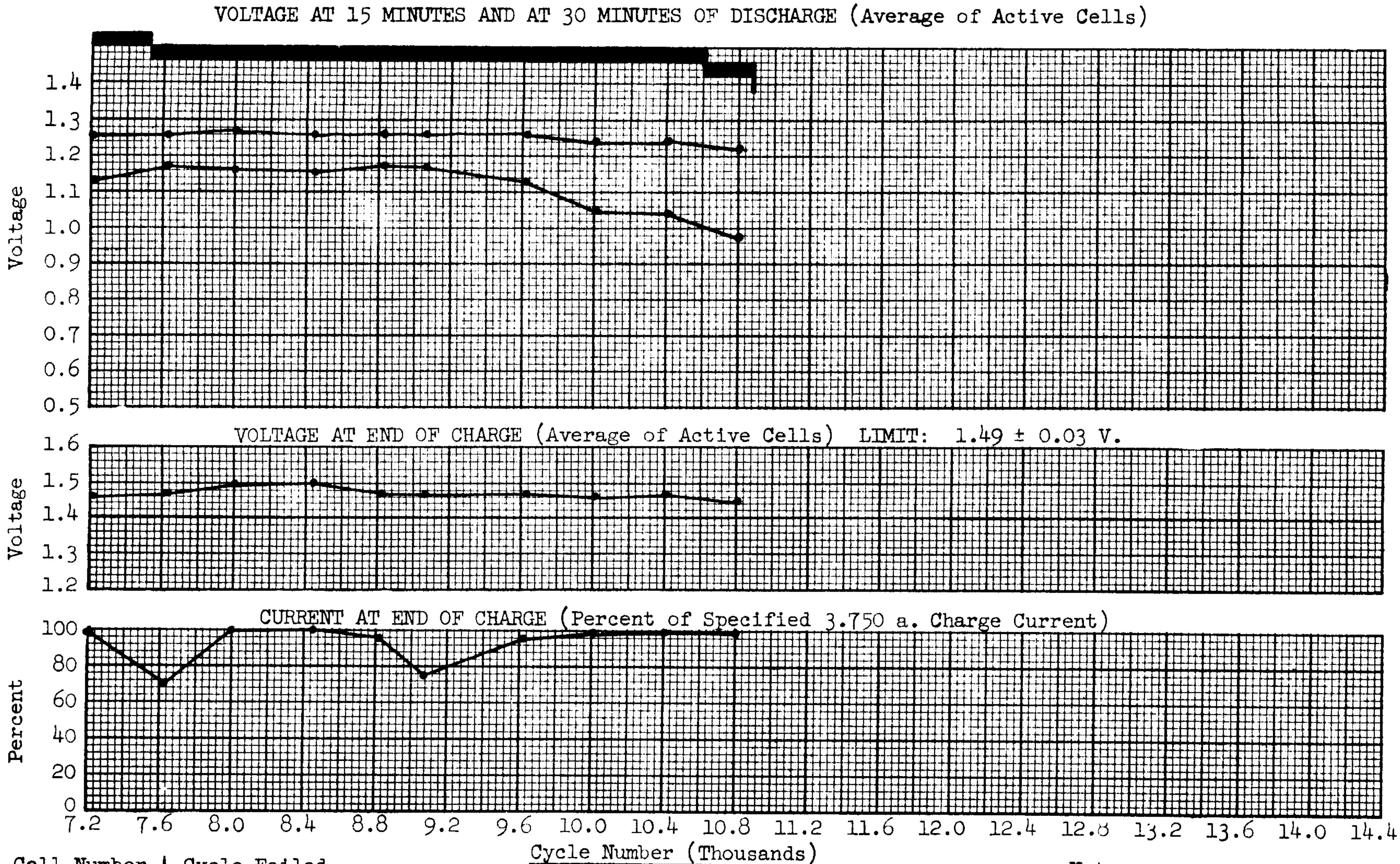
G.E. 12 a.h. (Pack 82)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: Continued

Notes

1. Cycles 1479, 2948, 4604, 6033, 7149: Capacity Check.

FIGURE 9(e)



Cell Number	Cycle Failed
430	7527
397	10624
437	10878

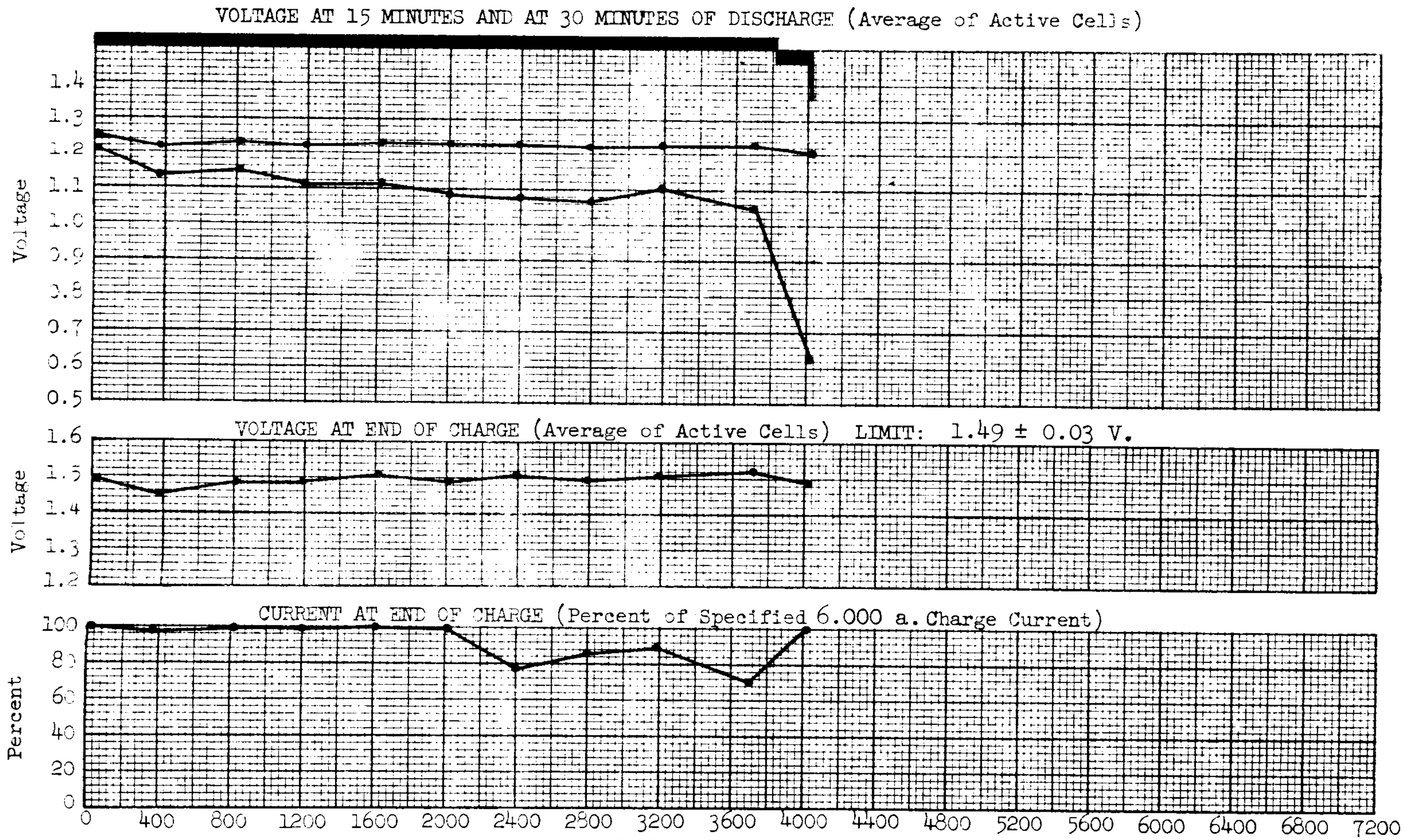
G.E. 12 a.h. (Pack 82)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: Pack Failed: Cycle 10878

Notes

1. Cycles 8595, 9734: Capacity Check.

FIGURE 9(e) (Contd)



Cell Number	Cycle Failed
445	3822
446, 442	4020

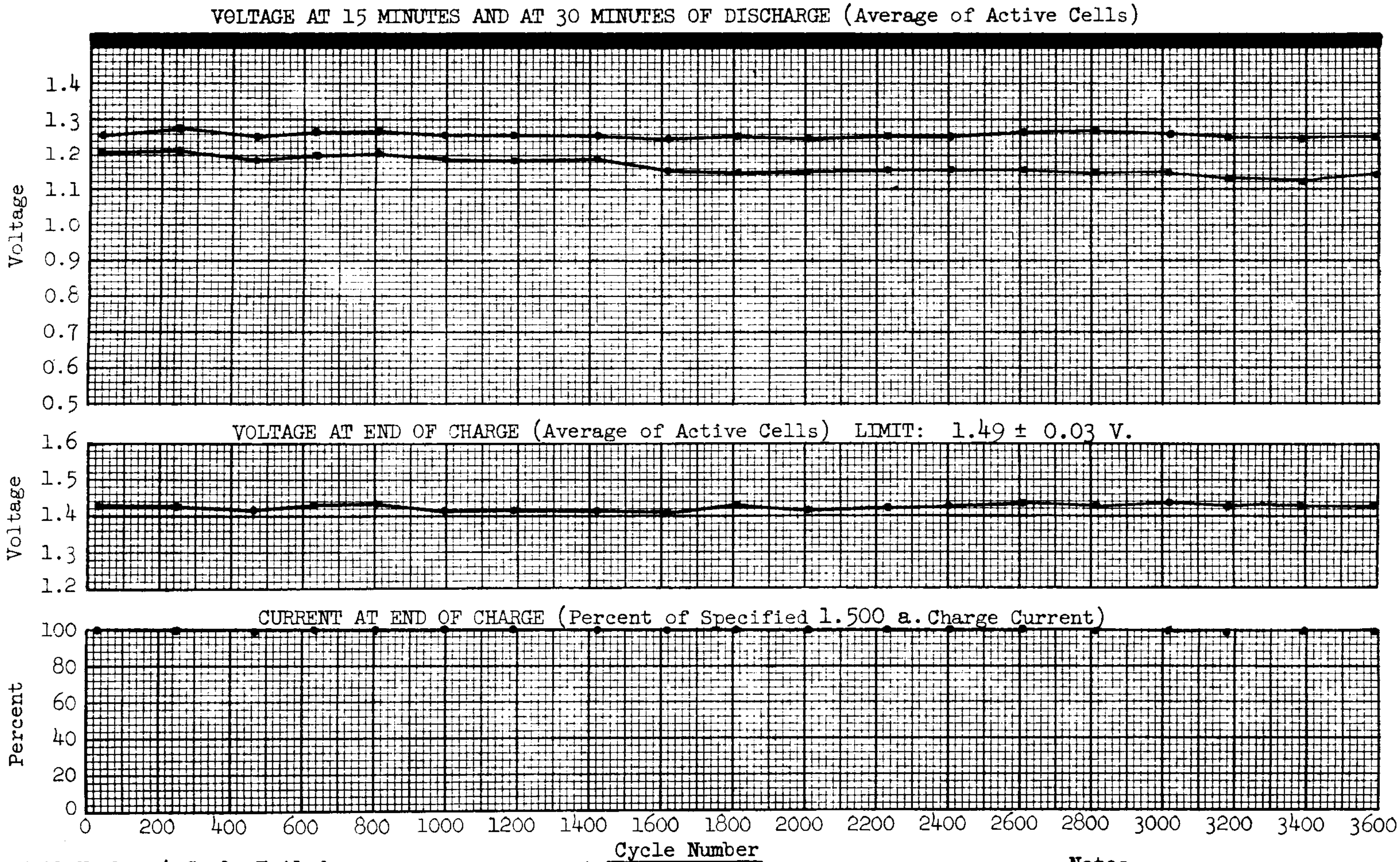
G.E. 12 a.h. (Pack 96)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 40%

Status: Pack Failed: Cycle 4020

Notes

1. Cycles 1478, 2946: Capacity Check.

FIGURE 9(f)



Cell Number	Cycle Failed

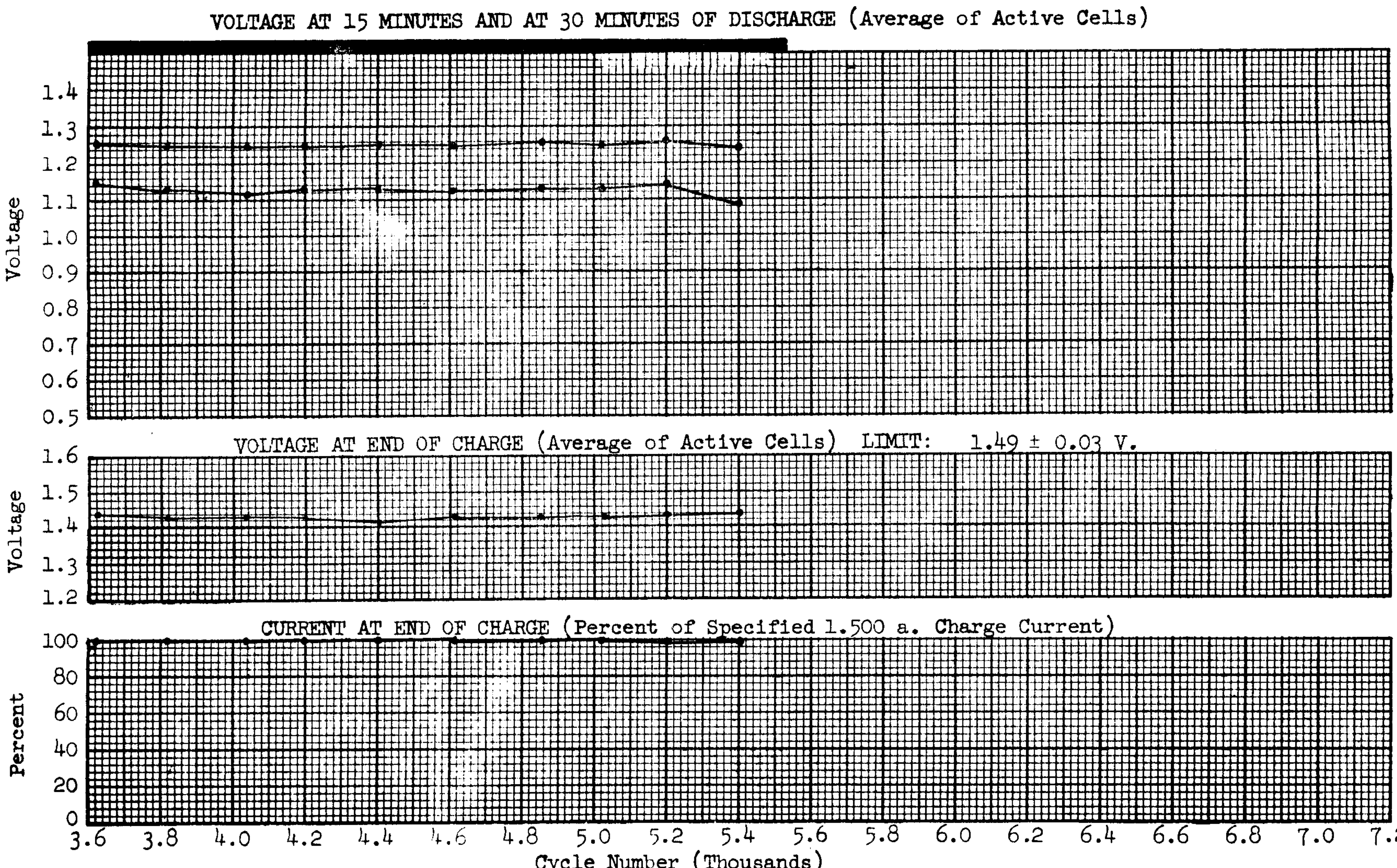
G.E. 12 a.h. (Pack 83)
Test Temperature: 25° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: Continued

Notes

1. Cycles 693, 1362, 2155, 2816, 3496: Capacity Check.

FIGURE 9(g)



Cell Number	Cycle Failed

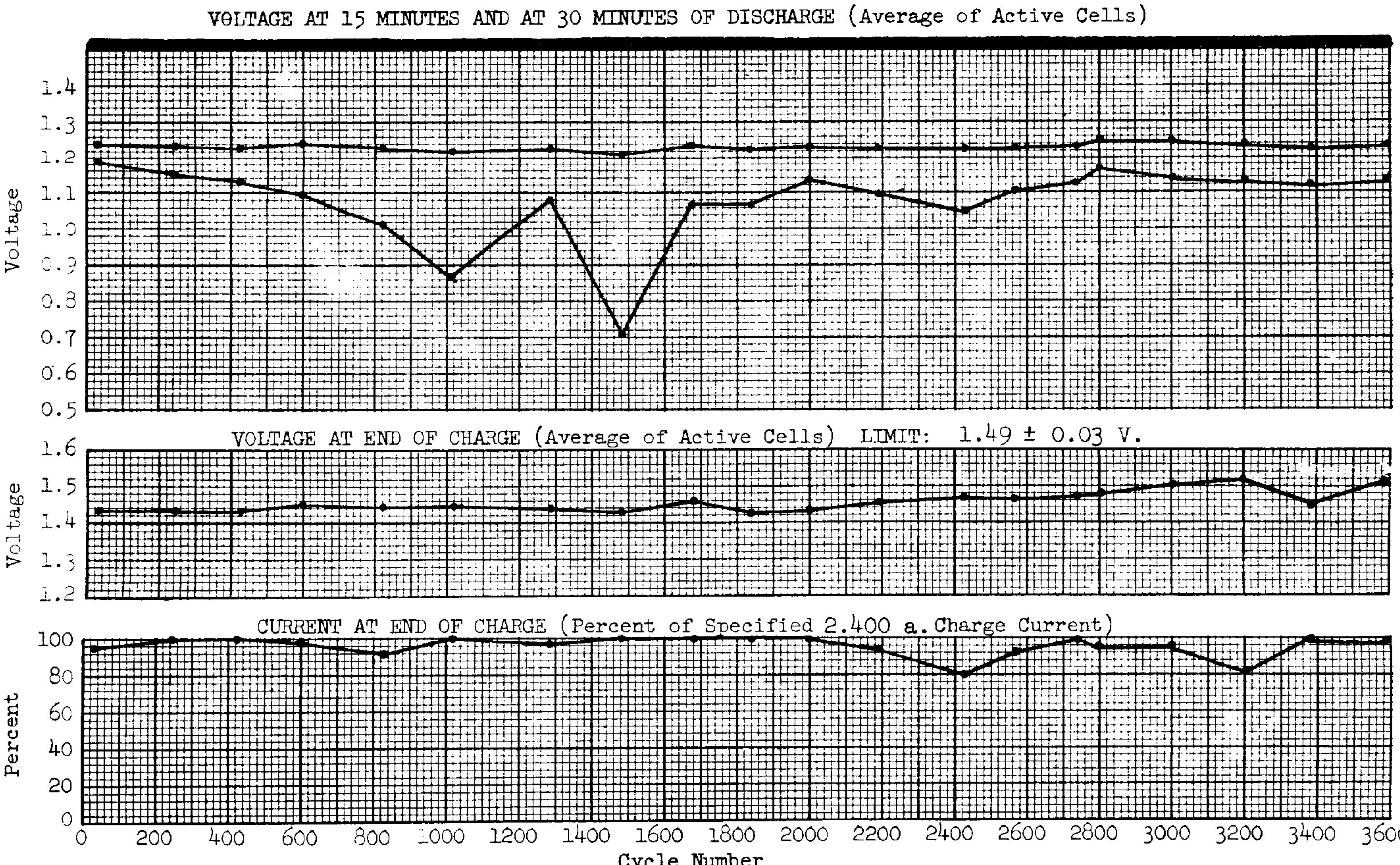
G.E. 12 a.h. (Pack 83)
Test Temperature: 25° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: 5 cells cycling after 5528 cycles.

Notes

1. Cycles 4362, 4923: Capacity Check.

FIGURE 9(g) (Contd)



Cell Number	Cycle Failed

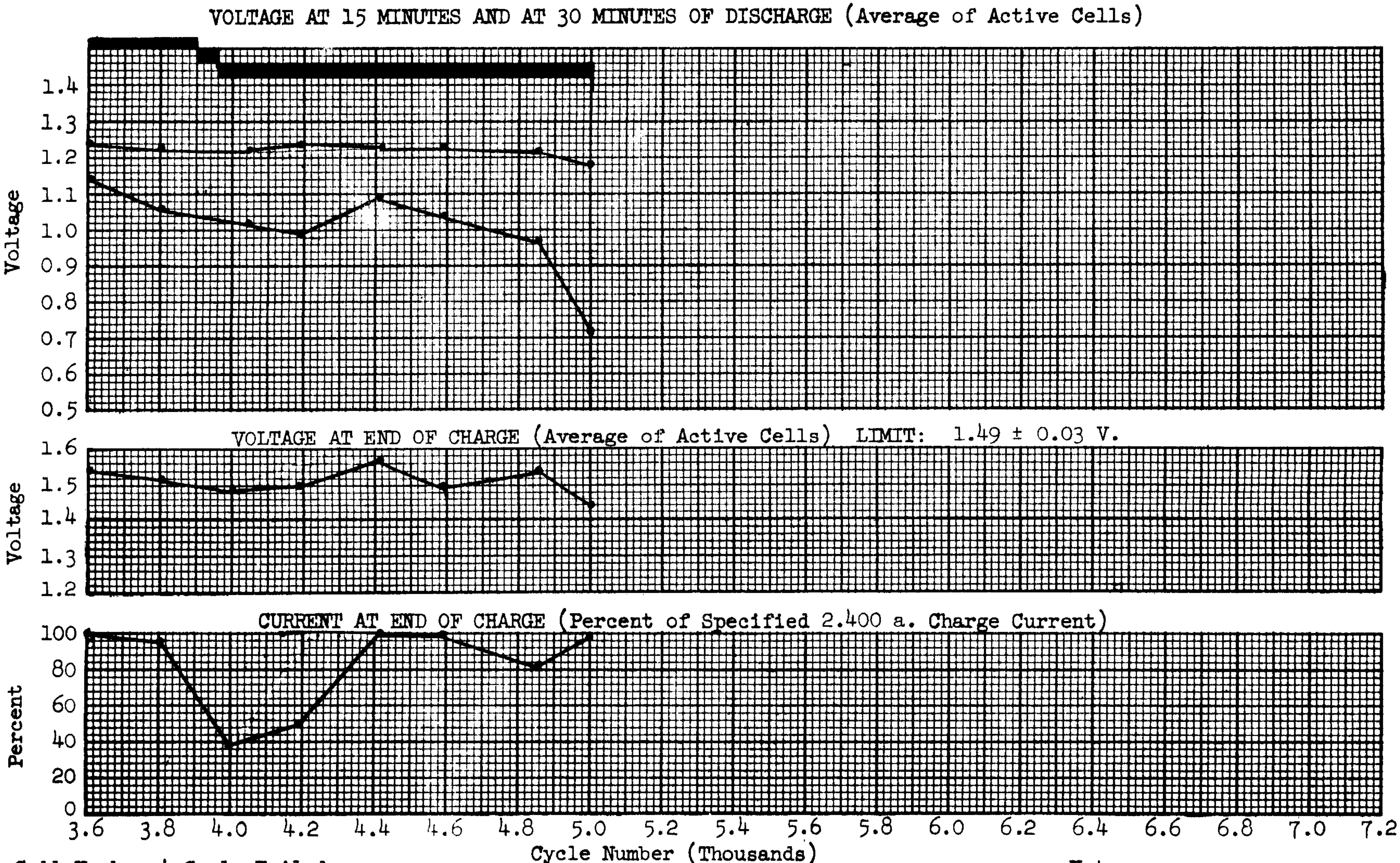
G.E. 12 a.h. (Pack 97)
Test Temperature: 25° C
Orbit Period: 3 hours
Depth of Discharge: 40%

Status: Continued

Notes

1. Cycles 749, 1447, 2209, 2806, 3486: Capacity Check.

FIGURE 9(h)



Cell Number	Cycle Failed
438	3894
435	3946
434	5002

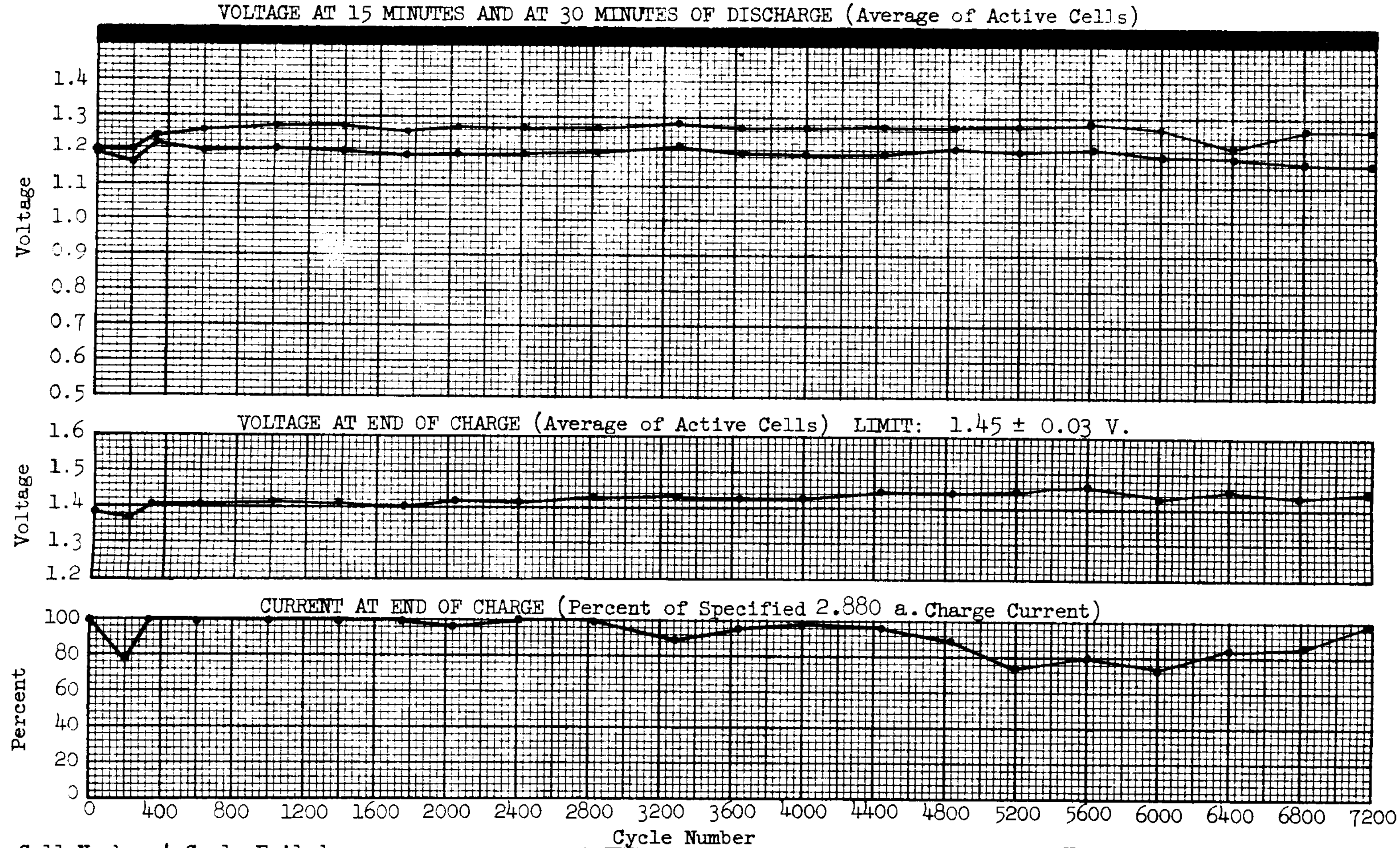
G.E. 12 a.h. (Pack 97)
Test Temperature: 25° C
Orbit Period: 3 hours
Depth of Discharge: 40%

Status: Pack Failed: Cycle 5002

Notes

1. Cycles 4176, 4725: Capacity Check.

FIGURE 9(h) (Contd)



Cell Number	Cycle Failed

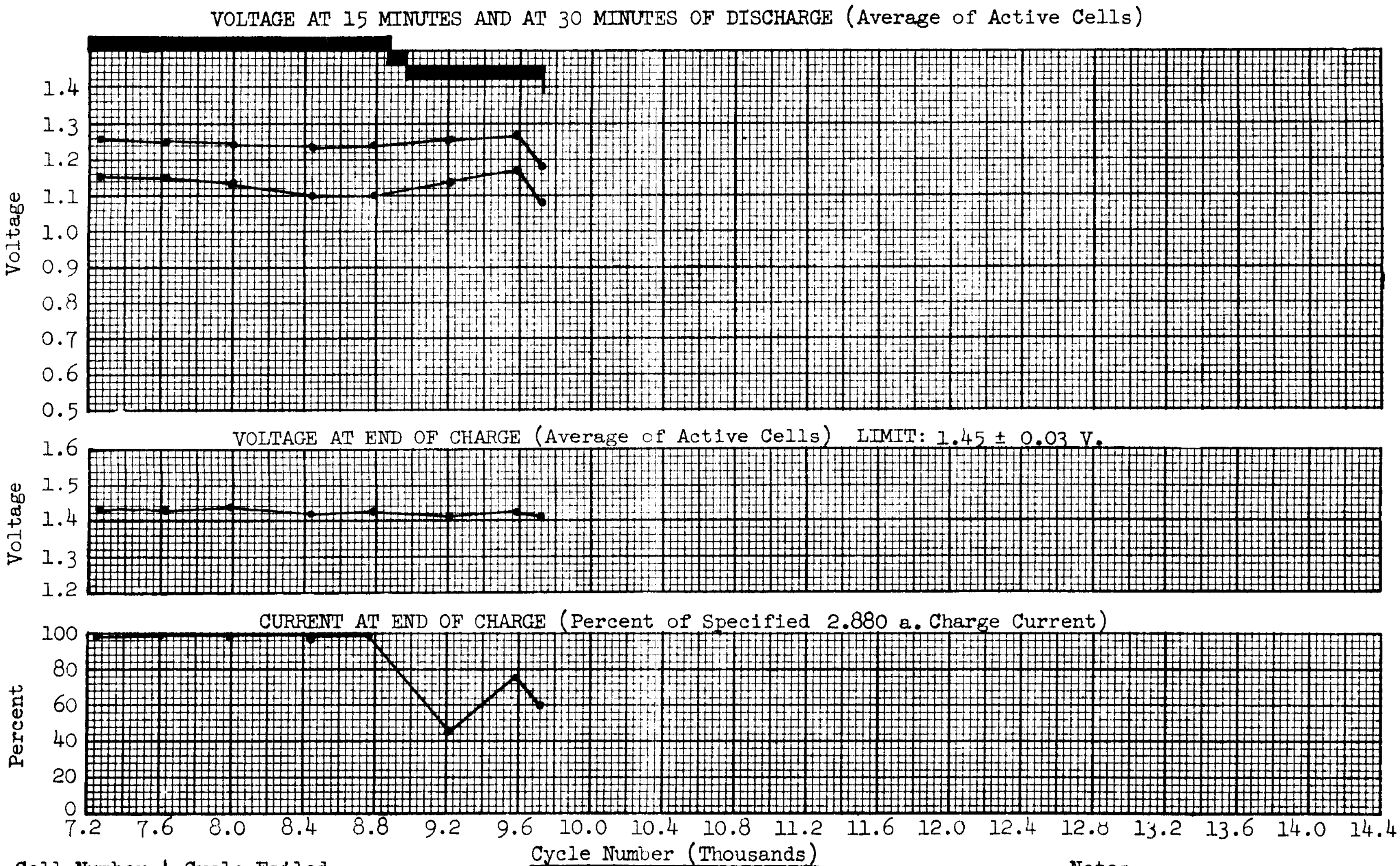
G.E. 12 a.h. (Pack 85)
Test Temperature: 50° - 40° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

Status: Continued

Notes

1. Cycle 334: Changed to 40° C.
2. Cycle 434: Voltage limit raised to 1.45 V/cell.
3. Cycles 1494, 3037, 4483, 5897, 7294: Capacity Check.

FIGURE 9(i)



Cell Number	Cycle Failed
428	8888
448	8947
455	9710

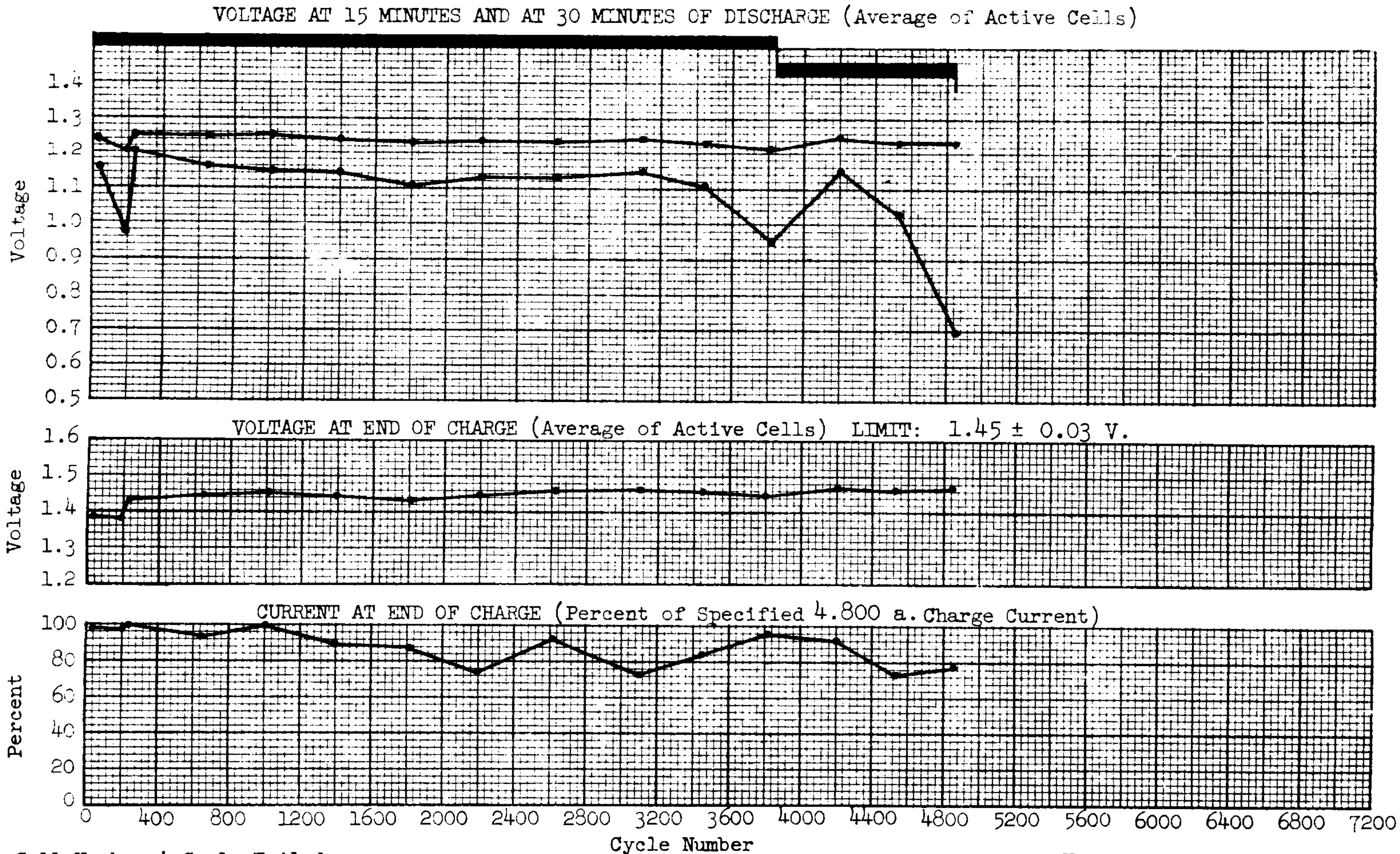
G.E. 12 a.h. (Pack 85)
Test Temperature: 50°-40° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

Status: Pack Failed: Cycle 9710

Notes

1. Cycles 8695, 9628: Capacity Check.

FIGURE 9(i) (Contd)



Cell Number	Cycle Failed
429, 432	3841
440	4853

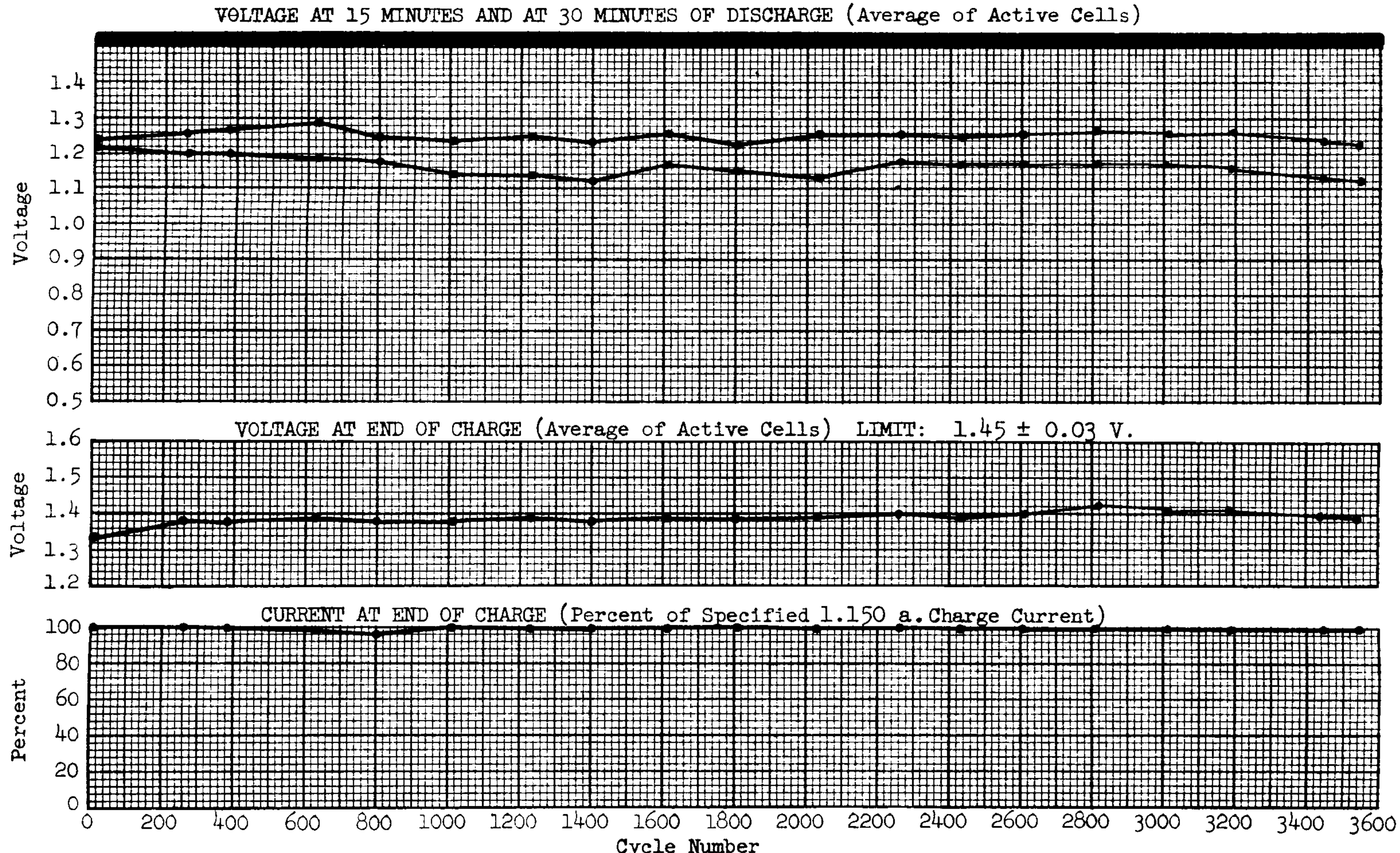
G.E. 12 a.h. (Pack 99)
Test Temperature: 50° - 40° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

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 9(j)



Cell Number	Cycle Failed

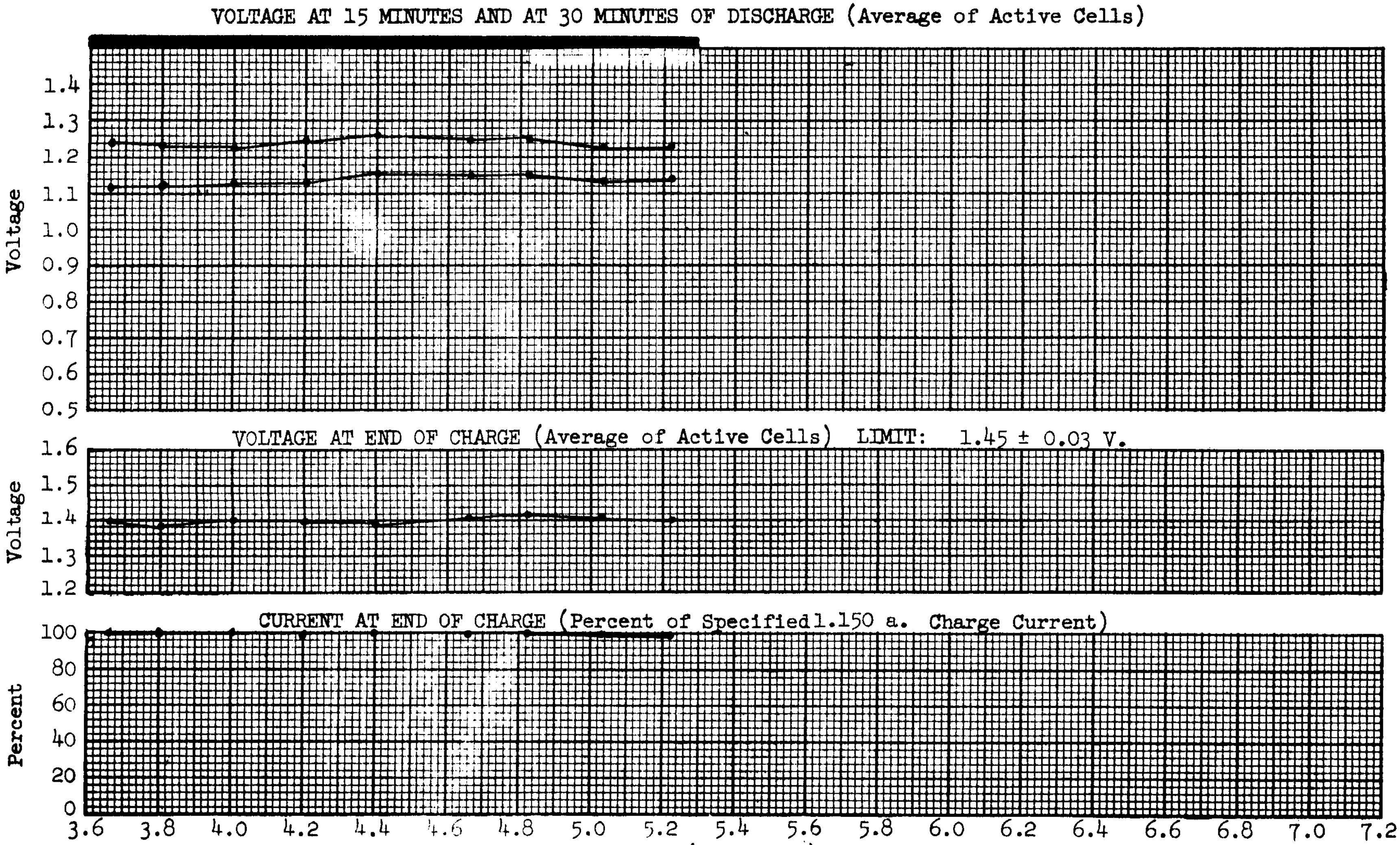
G.E. 12 a.h. (Pack 86)
Test Temperature: 50° - 40° C
Orbit Period: 3 hours
Depth of Discharge: 15%

Status: Continued

Notes

1. Cycle 205: Changed to 40° C.
2. Cycle 365: Voltage limit raised to 1.45 V/cell.
3. Cycles 682, 1519, 2213, 2971: Capacity Check.

FIGURE 9(k)



Cell Number	Cycle Failed

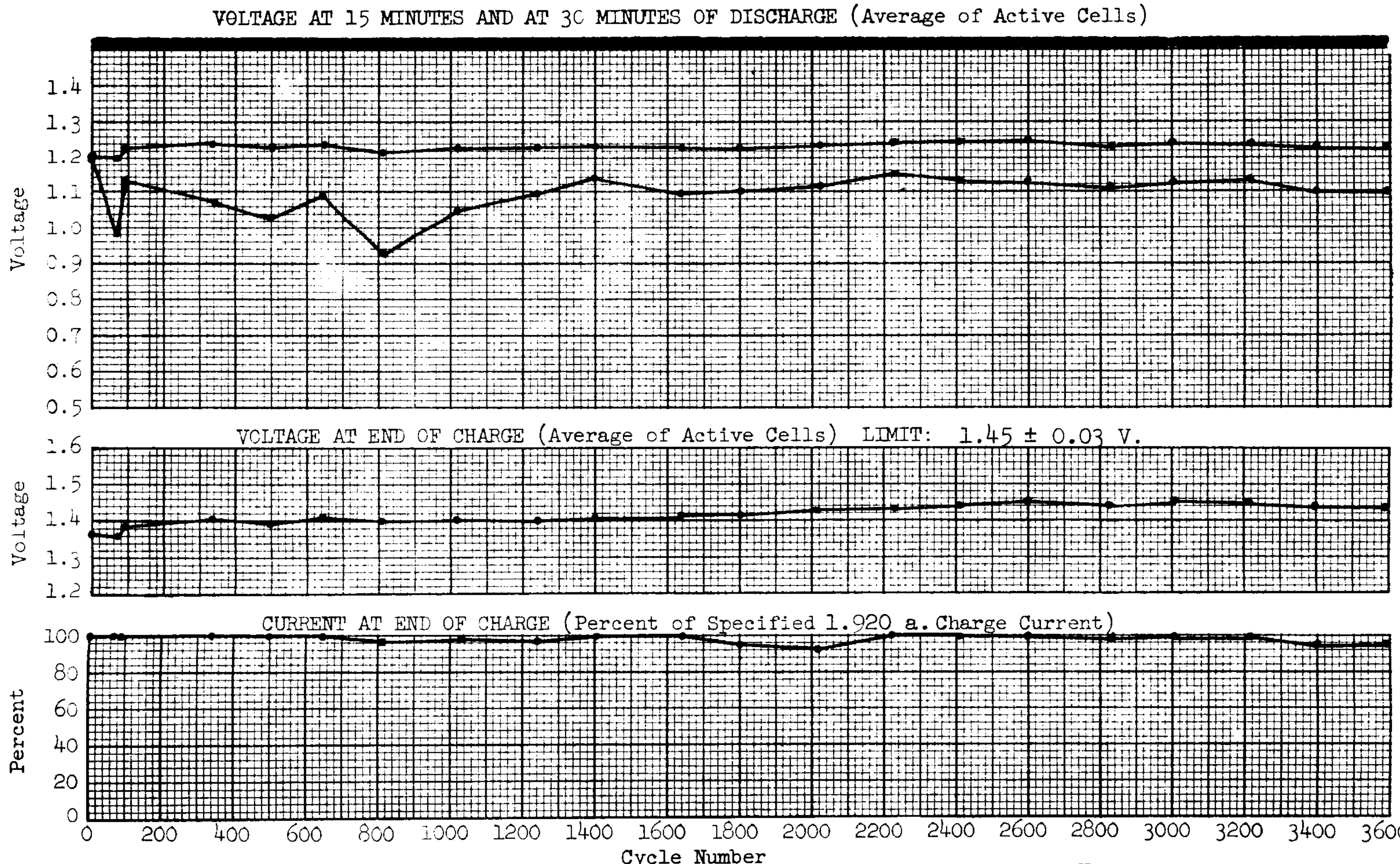
G.E. 12 a.h. (Pack 86)
Test Temperature: 50°-40° C
Orbit Period: 3 hours
Depth of Discharge: 15%

Status: 5 cells cycling after 5289 cycles.

Notes

1. Cycles 3670, 4372, 4823: Capacity Check.

FIGURE 9(k) (Contd)



Cell Number	Cycle Failed

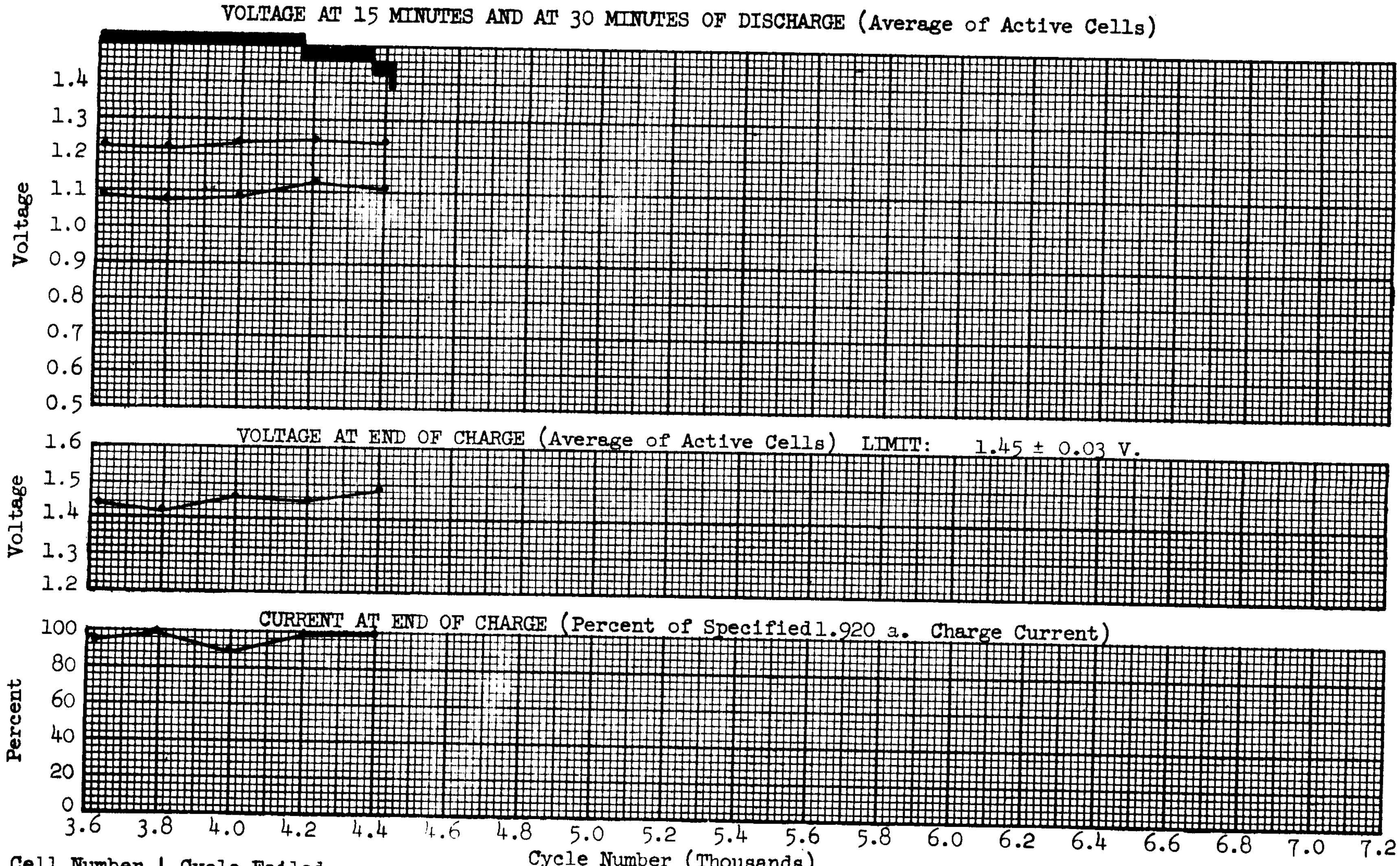
G.E. 12 a.h. (Pack 100)
Test Temperature: 50° - 40° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: Continued

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, 2996: Capacity Check.

FIGURE 9(1)



Cell Number	Cycle Failed
427	4170
431	4358
436	4424

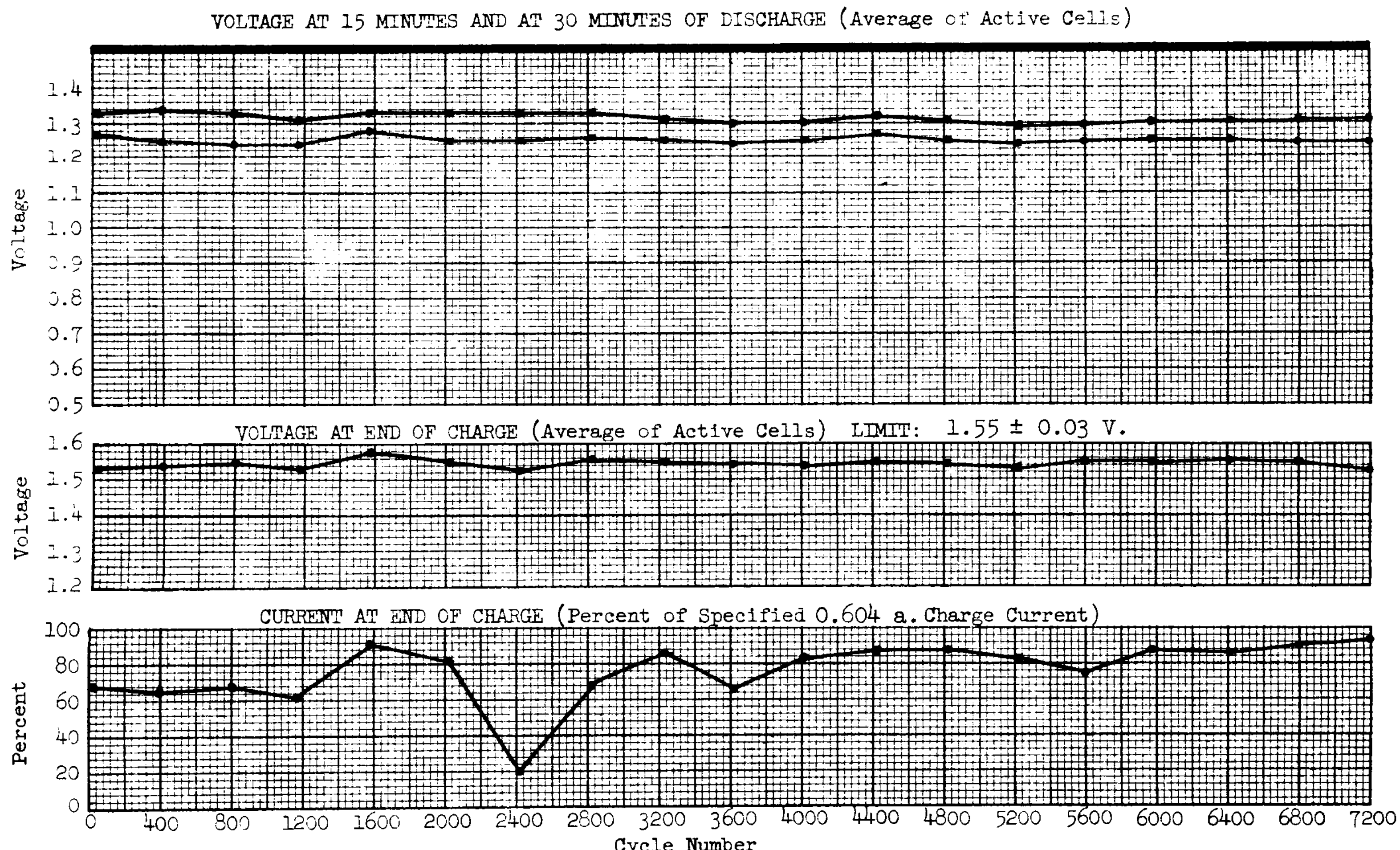
G.E. 12 a.h. (Pack 100)
Test Temperature: 50°-40° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: Pack Failed: Cycle 4424

Notes

1. Cycles 3696, 4308: Capacity Check.

FIGURE 9(1) (Contd)



Cell Number	Cycle Failed

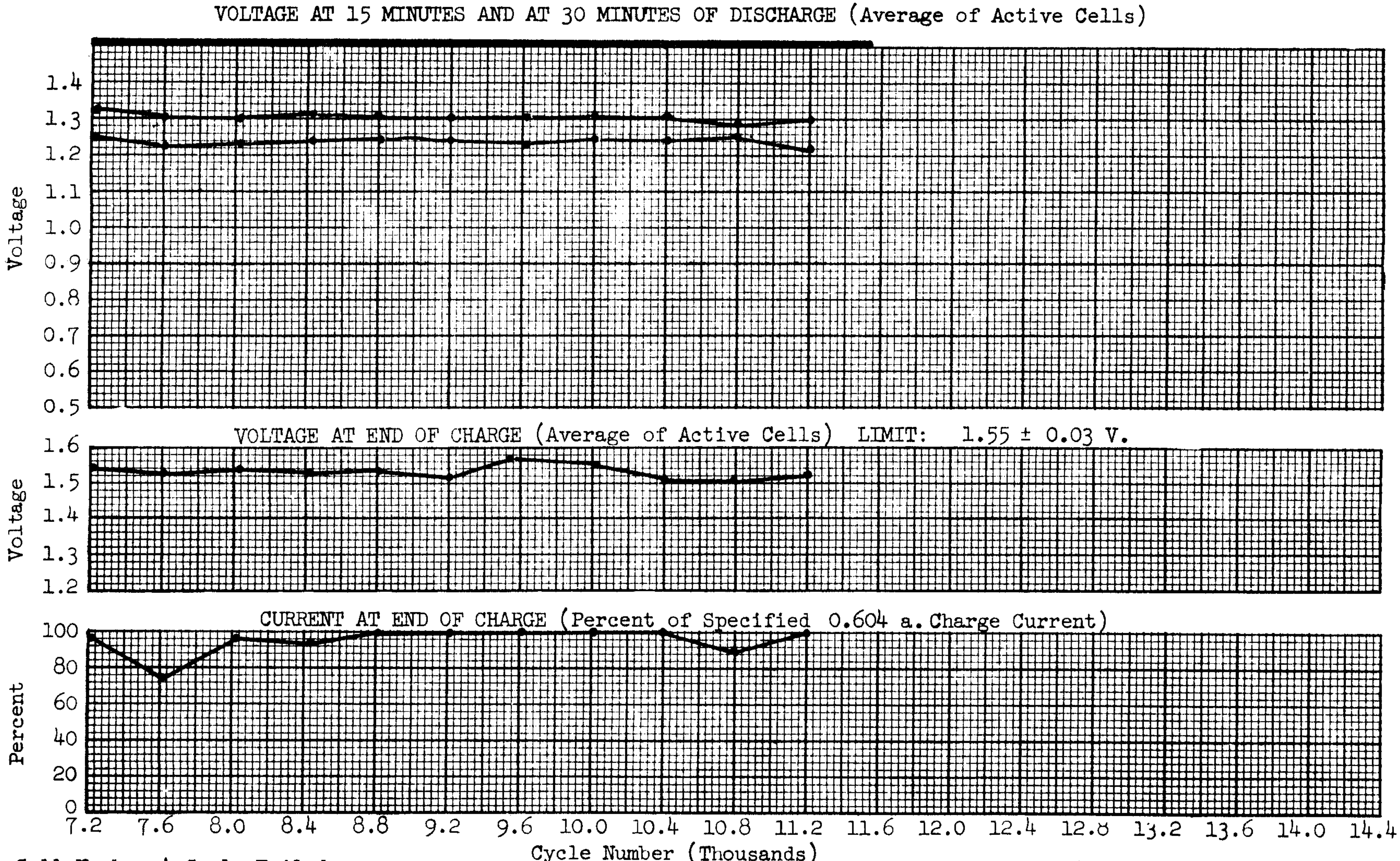
GOULD 3.5 a.h. (Pack 51)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

Status: Continued

Notes

1. Cycles 1546, 2944, 4165, 5565, 7074: Capacity Check.

FIGURE 10(a)



Cell Number	Cycle Failed

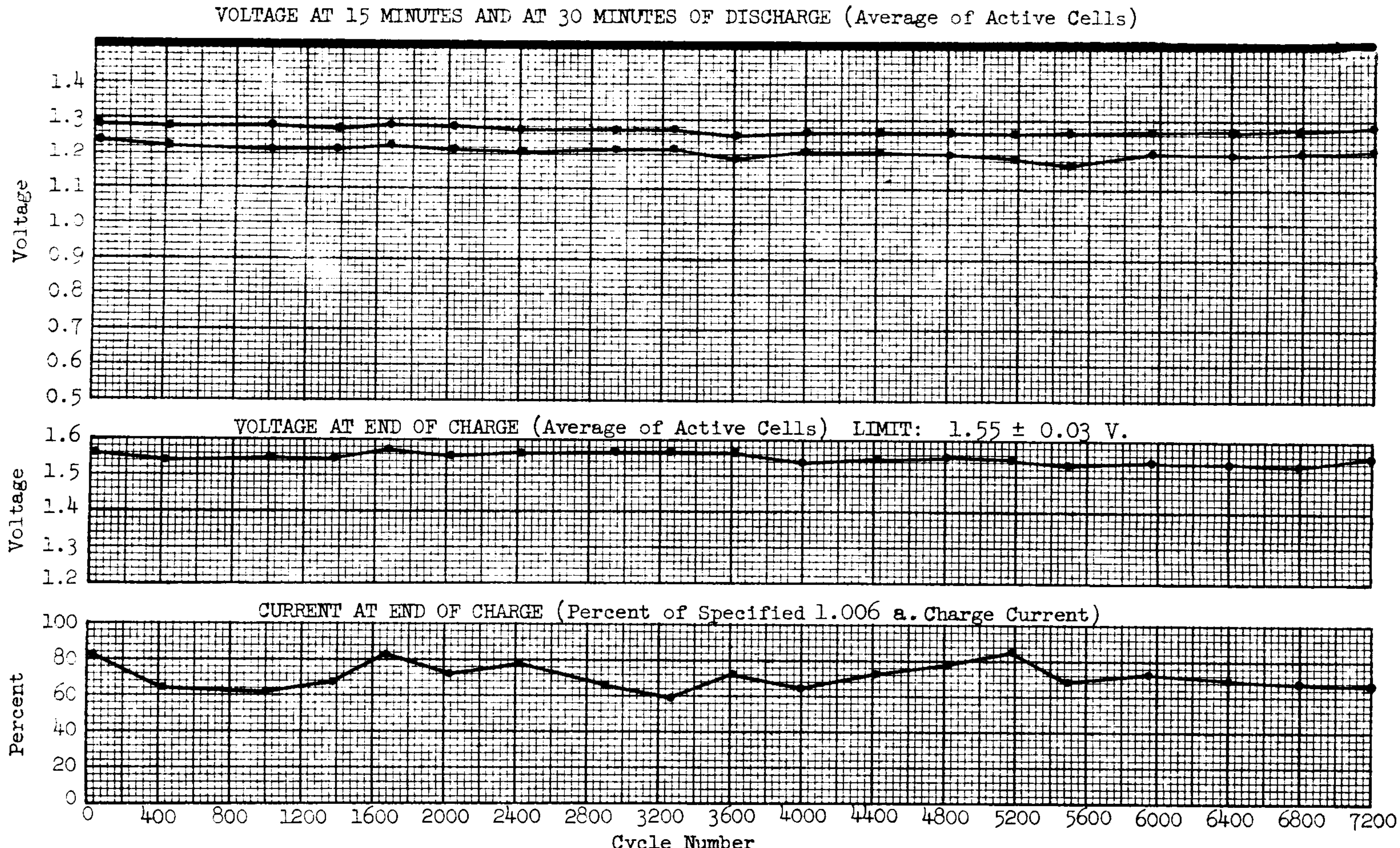
GOULD 3.5 a.h. (Pack 51)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

Status: 10 cells cycling after 11533 cycles.

Notes

1. Cycles 8724, 8898, 9852, 11299: Capacity Check.

FIGURE 10(a) (Contd)



Cell Number	Cycle Failed

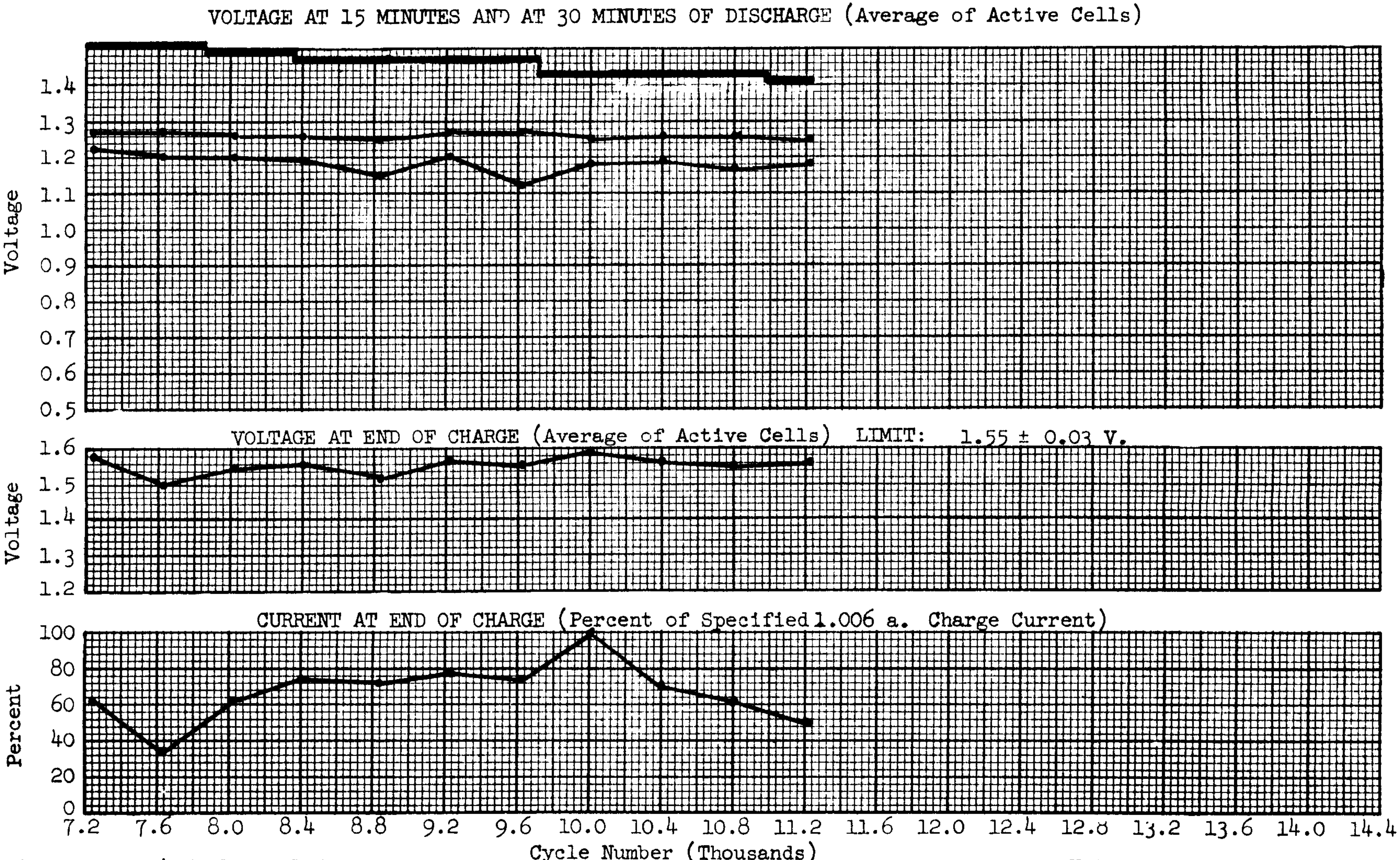
GOULD 3.5 a.h. (Pack 52)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: Continued

Notes

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

FIGURE 10(b)



Cell Number	Cycle Failed
116	7858
194	8367
108	9724
118	9724
55	10,994

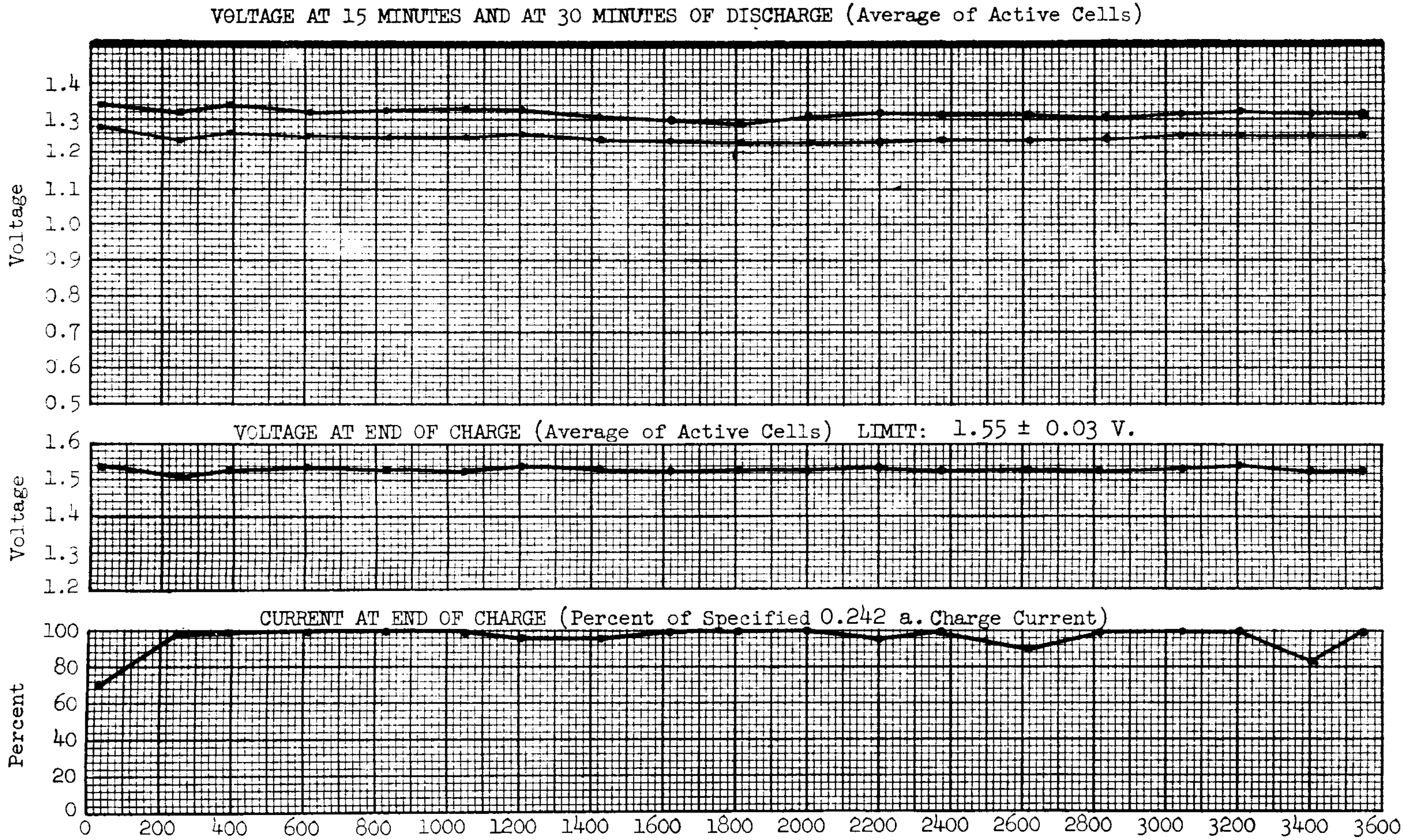
GOULD 3.5 a.h. (Pack 52)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: 5 cells cycling after 11246 cycles.

Notes

1. Cycles 7212, 8525, 9805: Capacity Check.

FIGURE 10(b) (Contd)



Cell Number	Cycle Failed

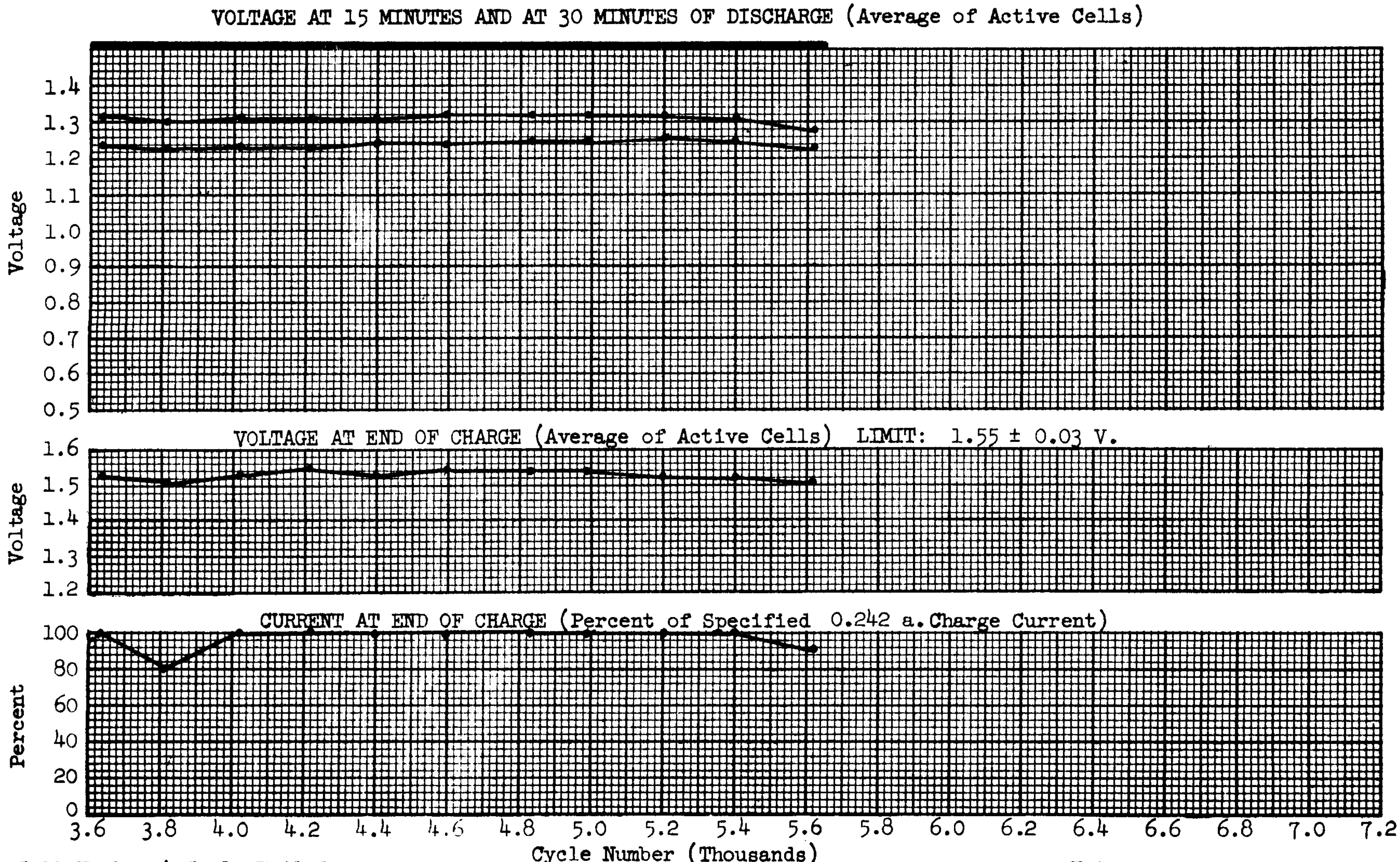
GOULD 3.5 a.h. (Pack 55)
Test Temperature: 0° C
Orbit Period: 3 hours
Depth of Discharge: 15%

Status: Continued

Notes

1. Cycles 719, 1374, 2015, 2762, 3504: Capacity Check.

FIGURE 10(c)



Cell Number	Cycle Failed

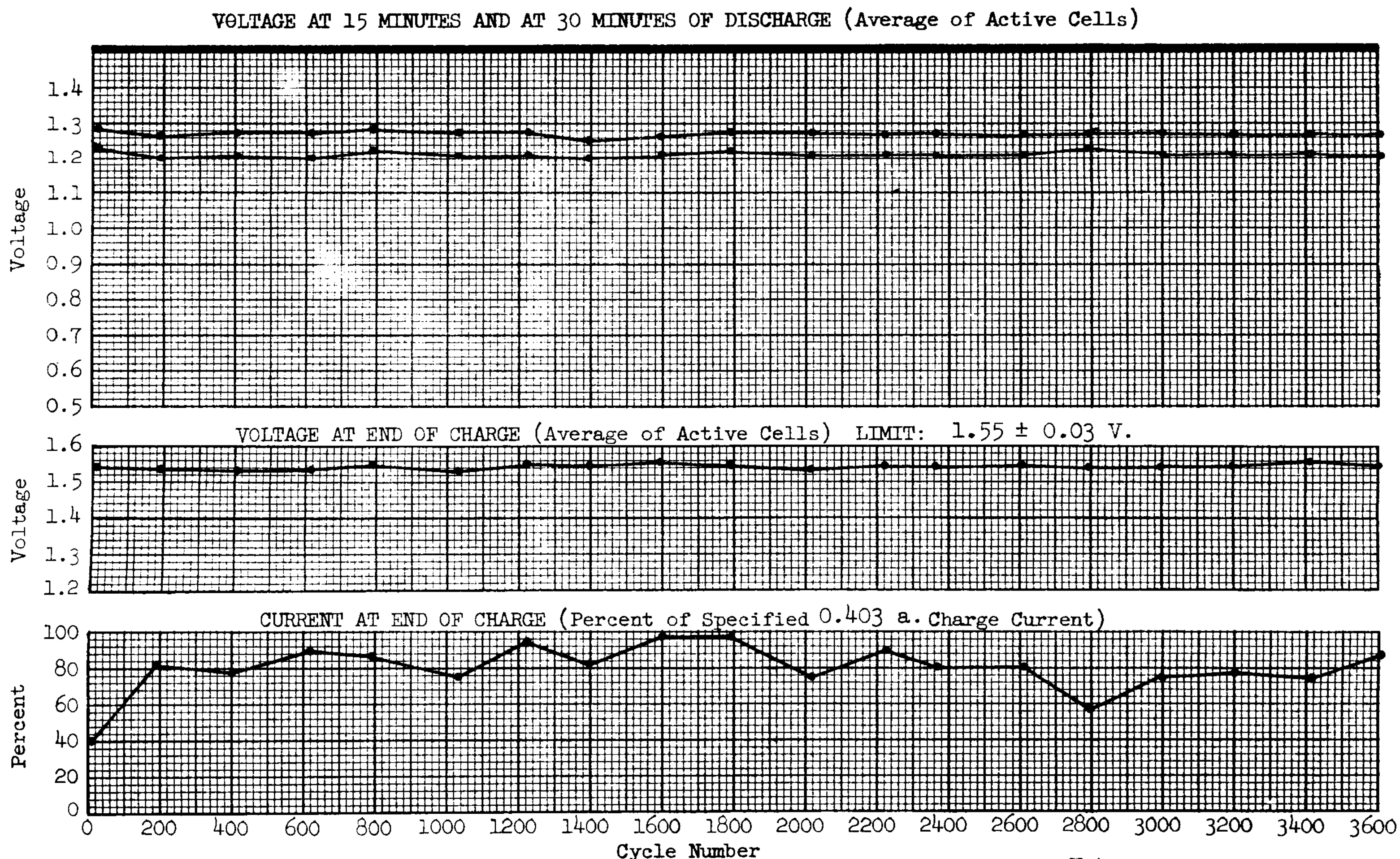
GOULD 3.5 a.h. (Pack 55)
Test Temperature: 0° C
Orbit Period: 3 hours
Depth of Discharge: 15%

Status: 10 cells cycling after 5655 cycles.

Notes

1. Cycles 4301, 4949: Capacity Check.

FIGURE 10(c) (Contd)



Cell Number	Cycle Failed

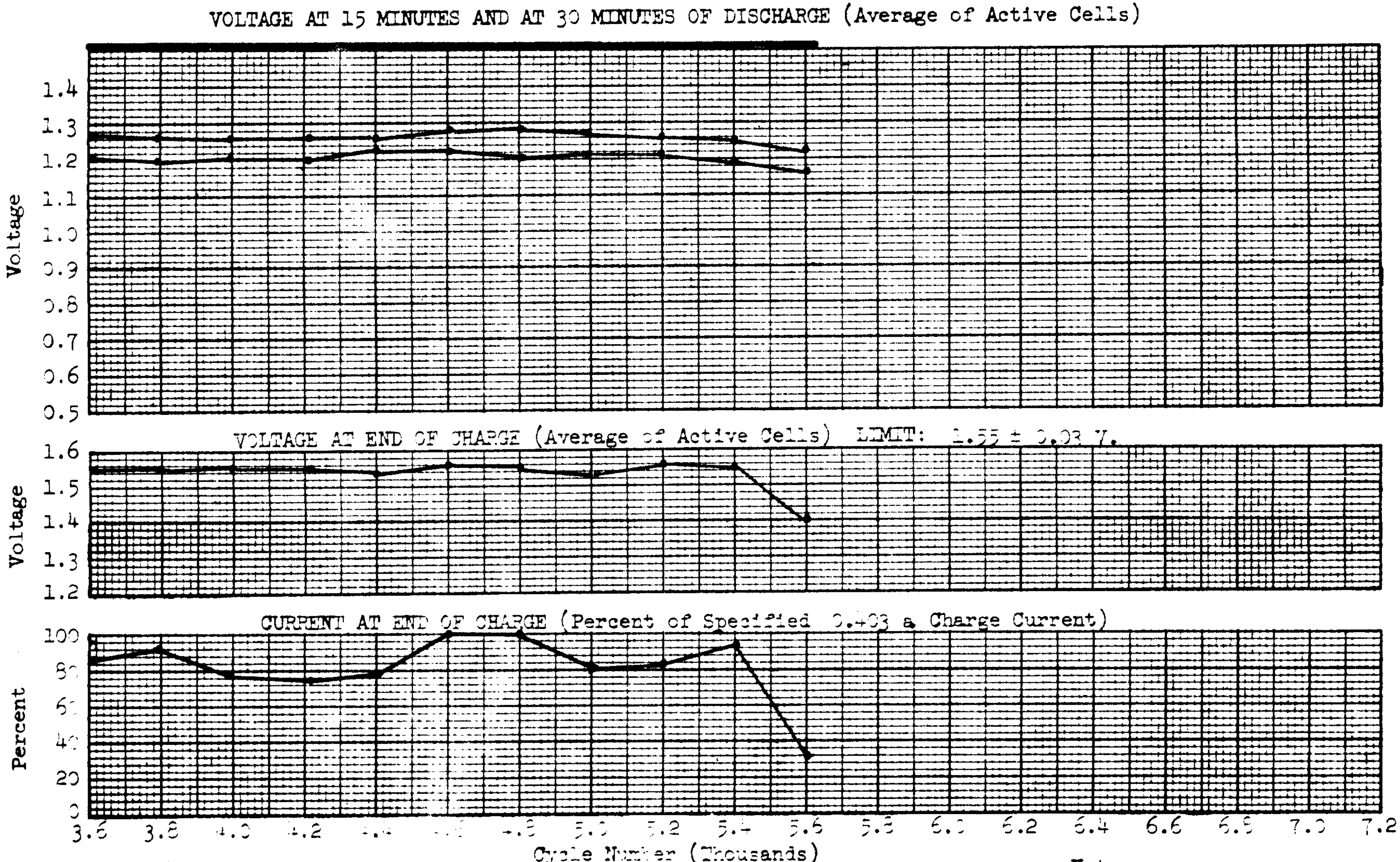
GOULD 3.5 a.h. (Pack 56)
Test Temperature: 0° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: Continued

Notes

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

FIGURE 10(d)



Cell Number	Cycle Failed

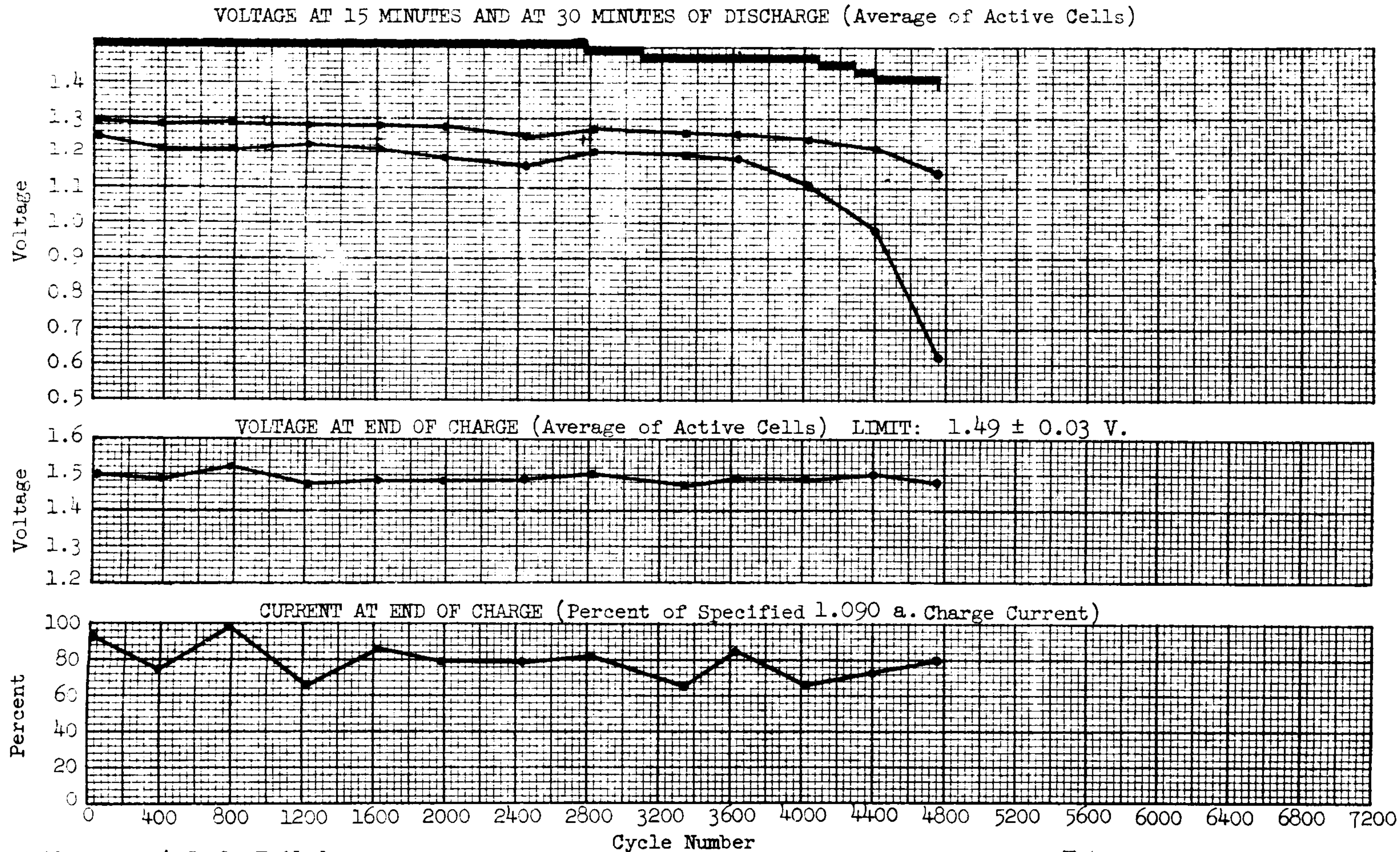
GOULD 3.5 a.h. (Pack 56)
Test Temperature: 0° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: 10 cells cycling after 5634 cycles.

Notes

1. Cycles 4335, 4927: Capacity Check.

FIGURE 10(d) (Contd)



Cell Number	Cycle Failed
73	2785
54	3090
165	4081
93	4289
97	4401
77, 188	4751

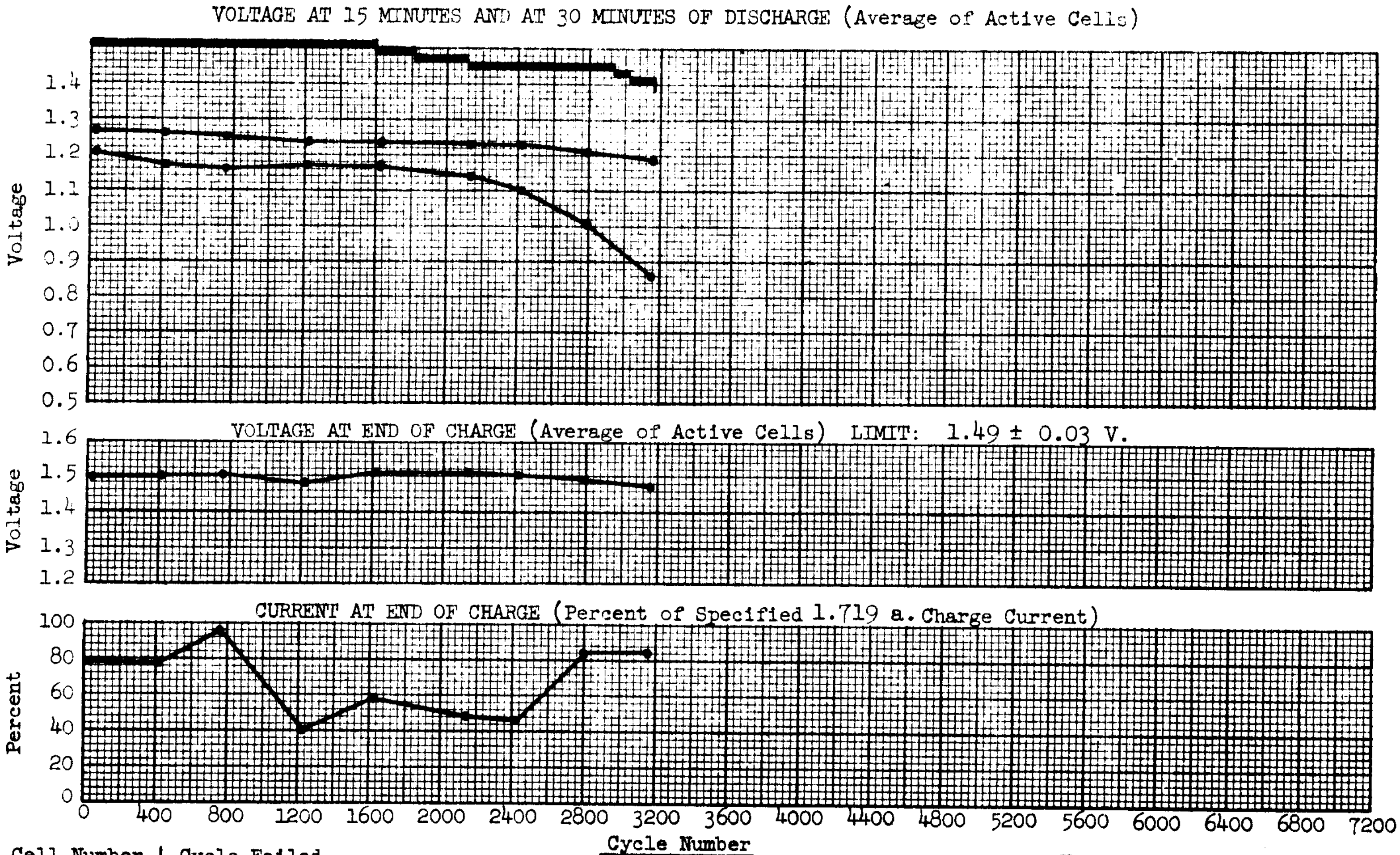
GOULD 3.5 a.h. (Pack 3)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: Pack Failed: Cycle 4751

Notes

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

FIGURE 10(e)



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

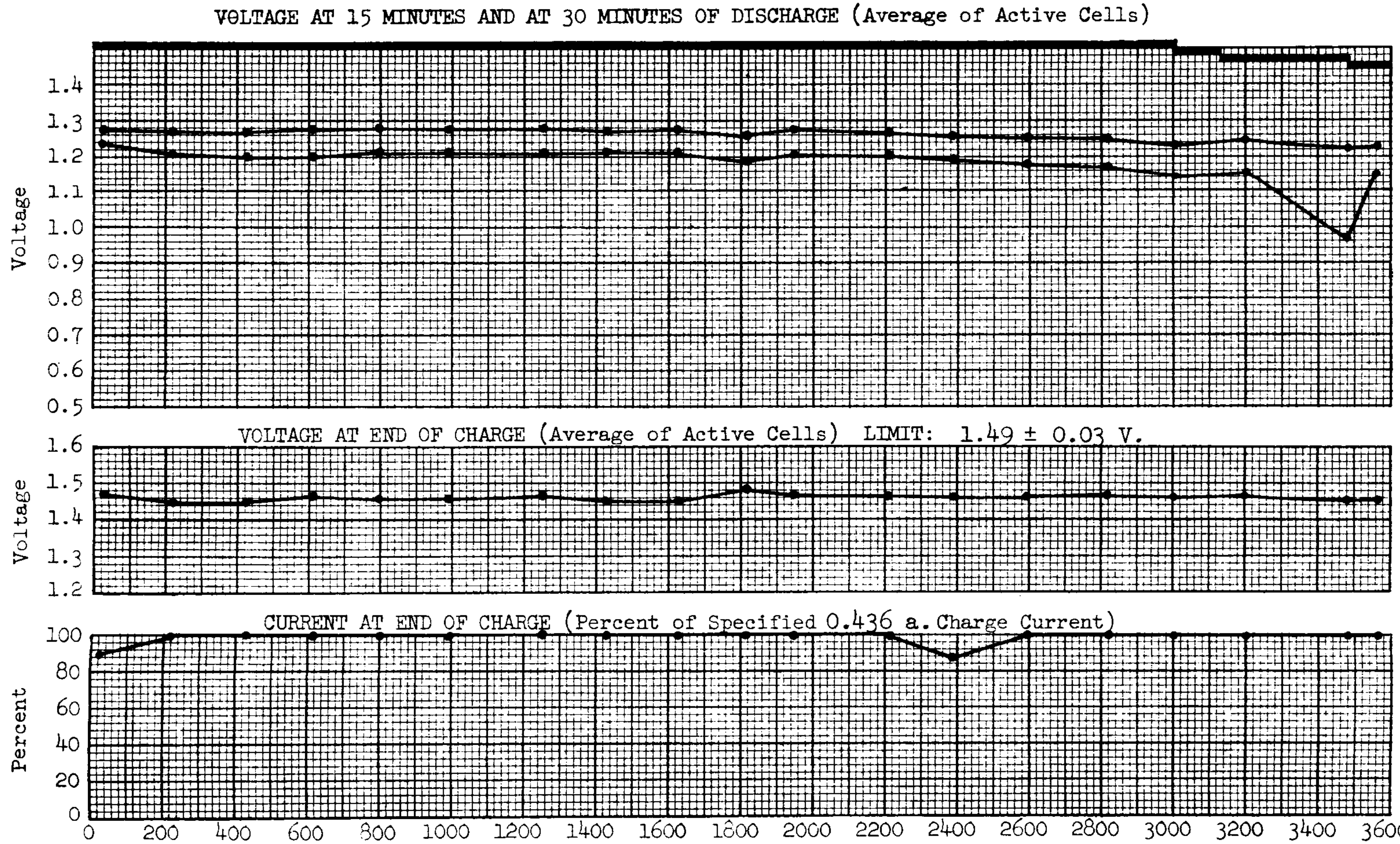
GOULD 3.5 a.h. (Pack 4)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 40%

Status: Pack Failed: Cycle 3164

Notes

1. Cycles 1404, 2803: Capacity Check.

FIGURE 10(f)



Cell Number	Cycle Failed
49	3007
37	3130
109	3483

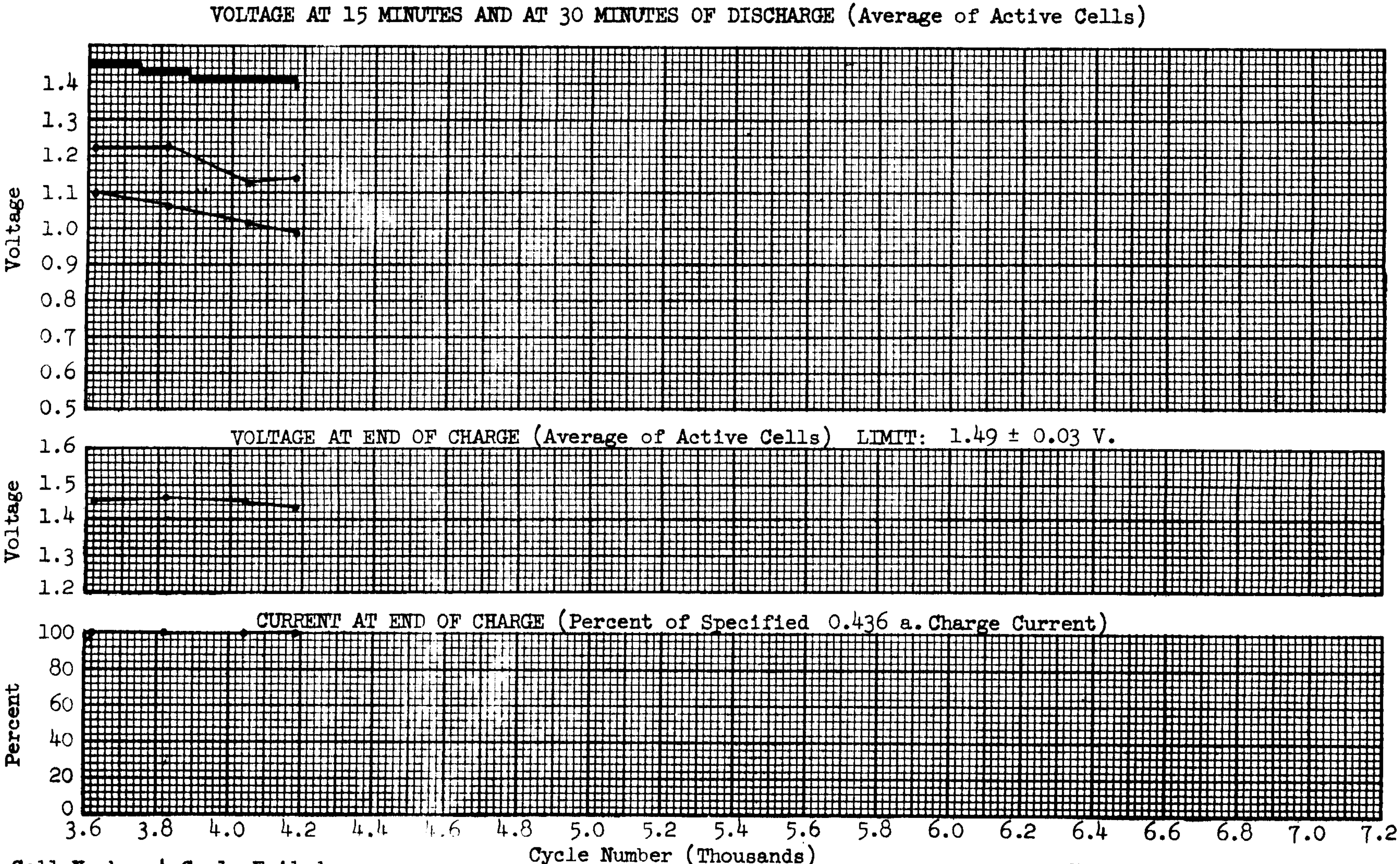
GOULD 3.5 a.h. (Pack 7)
Test Temperature: 25° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: Continued

Notes

1. Cycles 674, 1381, 2006, 2758, 3293: Capacity Checks.

FIGURE 10(g)



Cell Number	Cycle Failed
104	3736
131	3884
62	4173

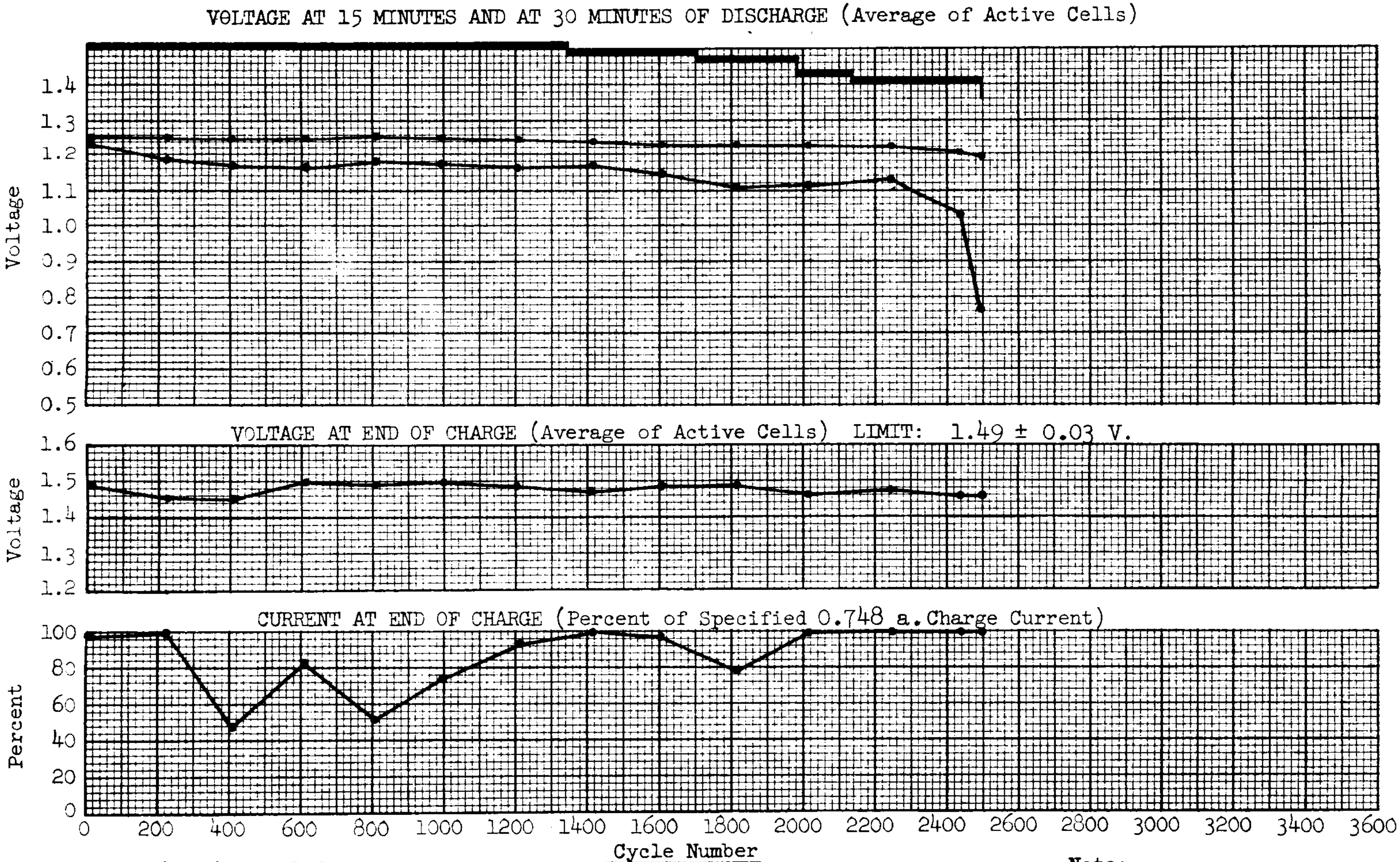
GOULD 3.5 a.h. (Pack 7)
Test Temperature: 25° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: Pack Failed: Cycle 4173

Notes

1. Cycles 3996: Capacity Checks.

FIGURE 10(g) (Contd)



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

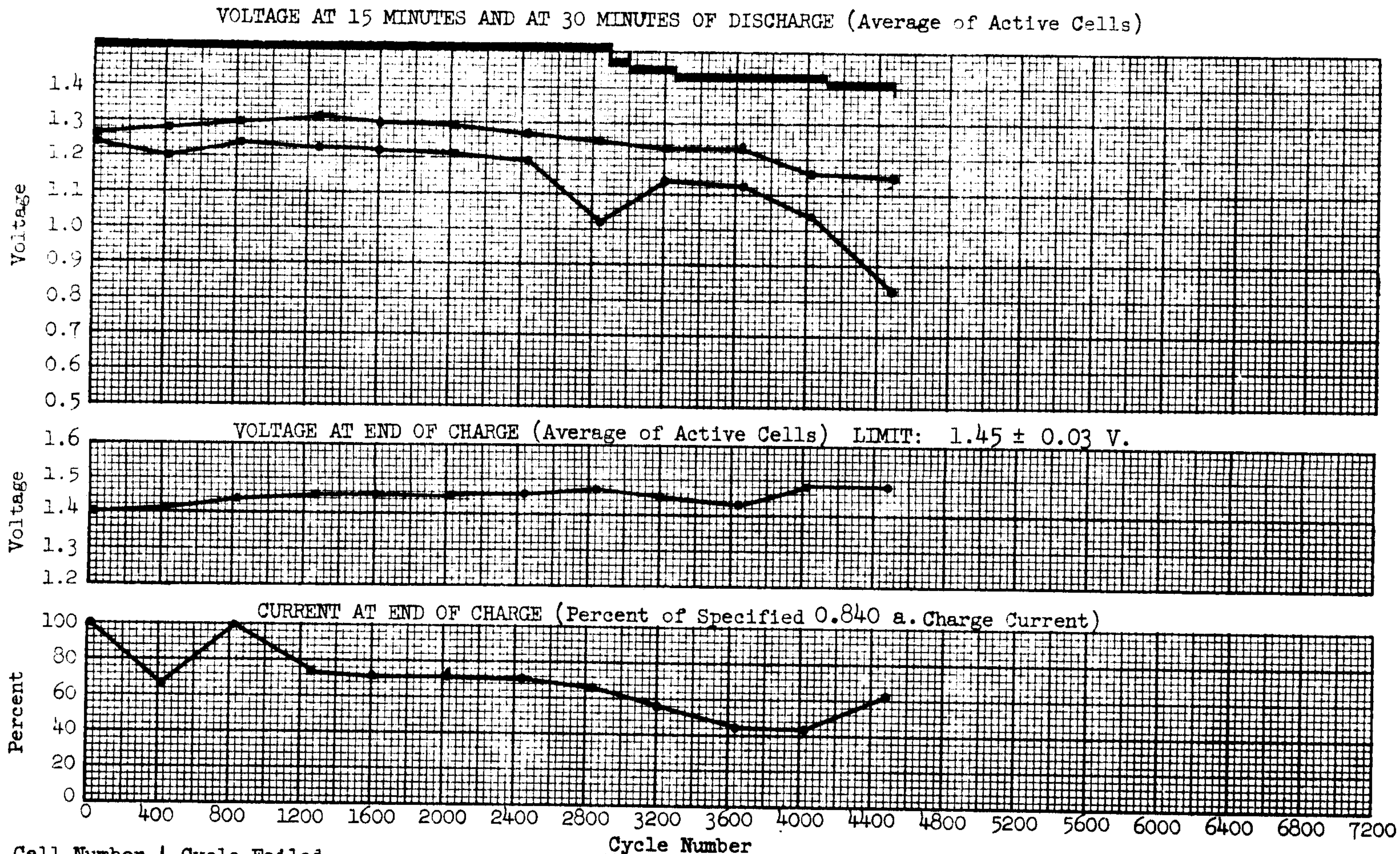
GOULD 3.5 a.h. (Pack 8)
Test Temperature: 25° C
Orbit Period: 3 hours
Depth of Discharge: 40%

Status: Pack Failed: Cycle 2494

Notes

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

FIGURE 10(h)



Cell Number	Cycle Failed
13, 195	2901
103	2998
200	3270
197	4102
11	4485

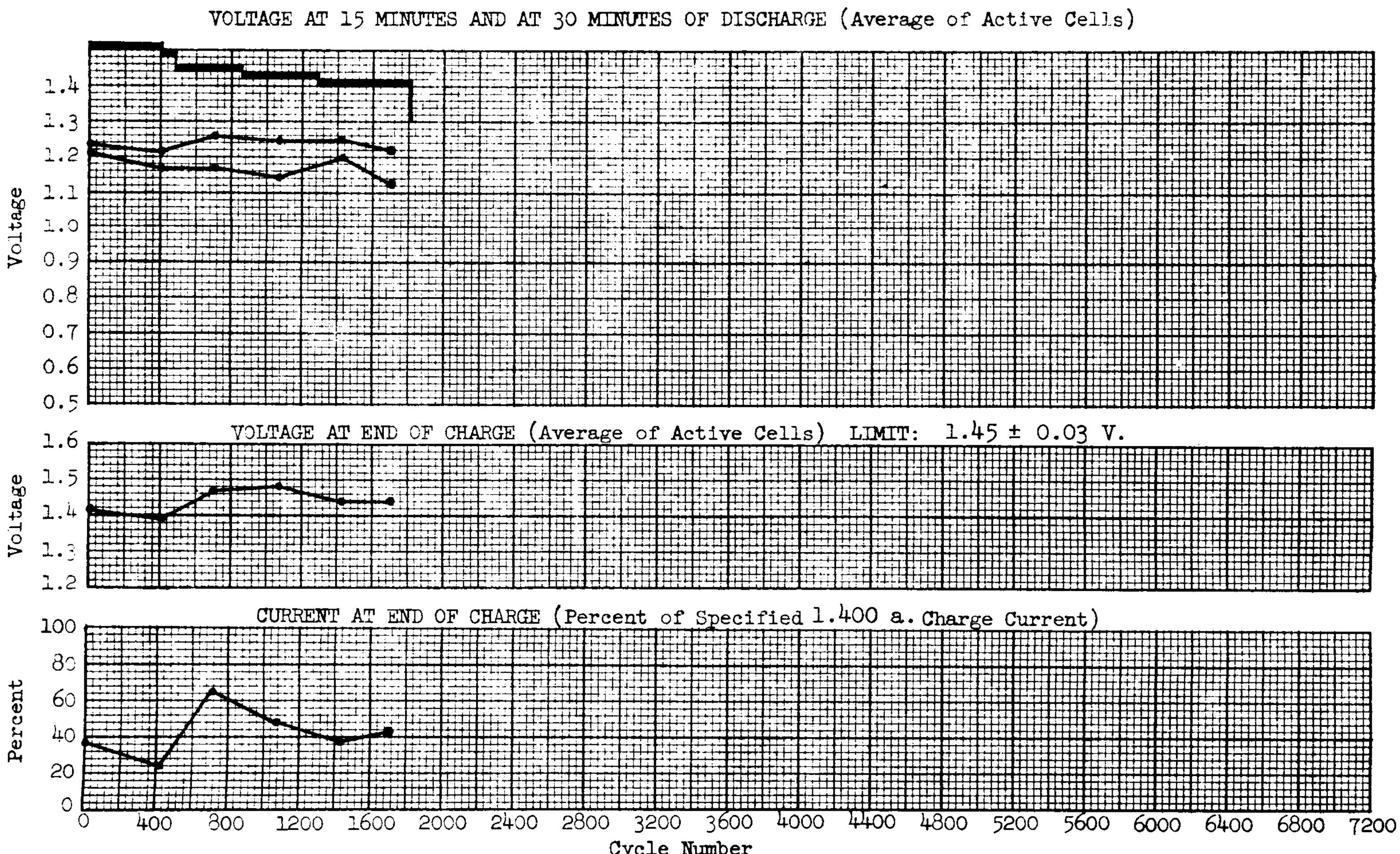
GOULD 3.5 a.h. (Pack 27)
Test Temperature: 50° - 40° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

Status: Pack Failed: Cycle 4485

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 10(i)



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

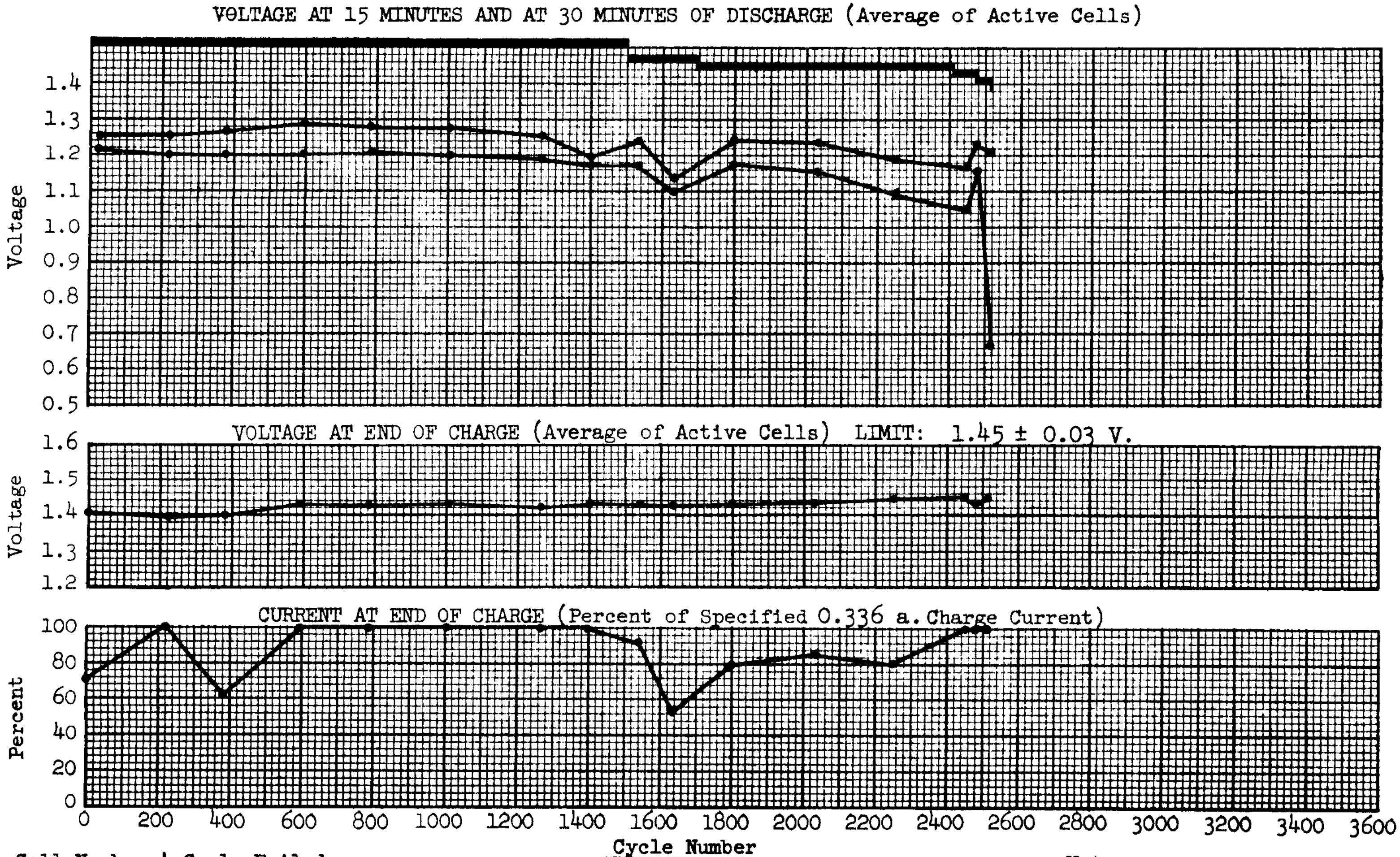
GOULD 3.5 a.h. (Pack 28)
Test Temperature: 50° - 40° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

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 10(j)



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

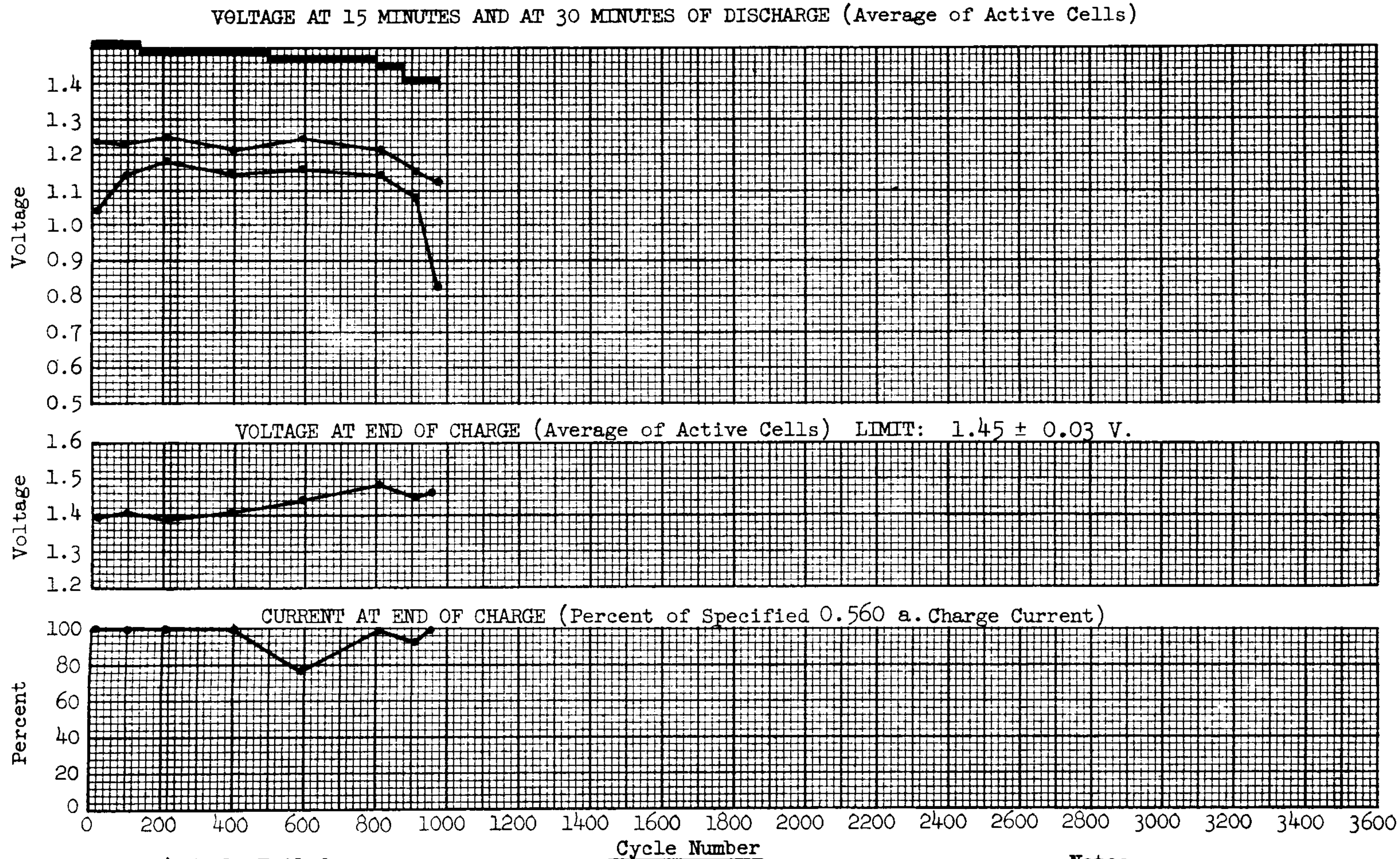
GOULD 3.5 a.h. (Pack 31)
Test Temperature: 50° - 40° C
Orbit Period: 3 hours
Depth of Discharge: 15%

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 10(k)



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

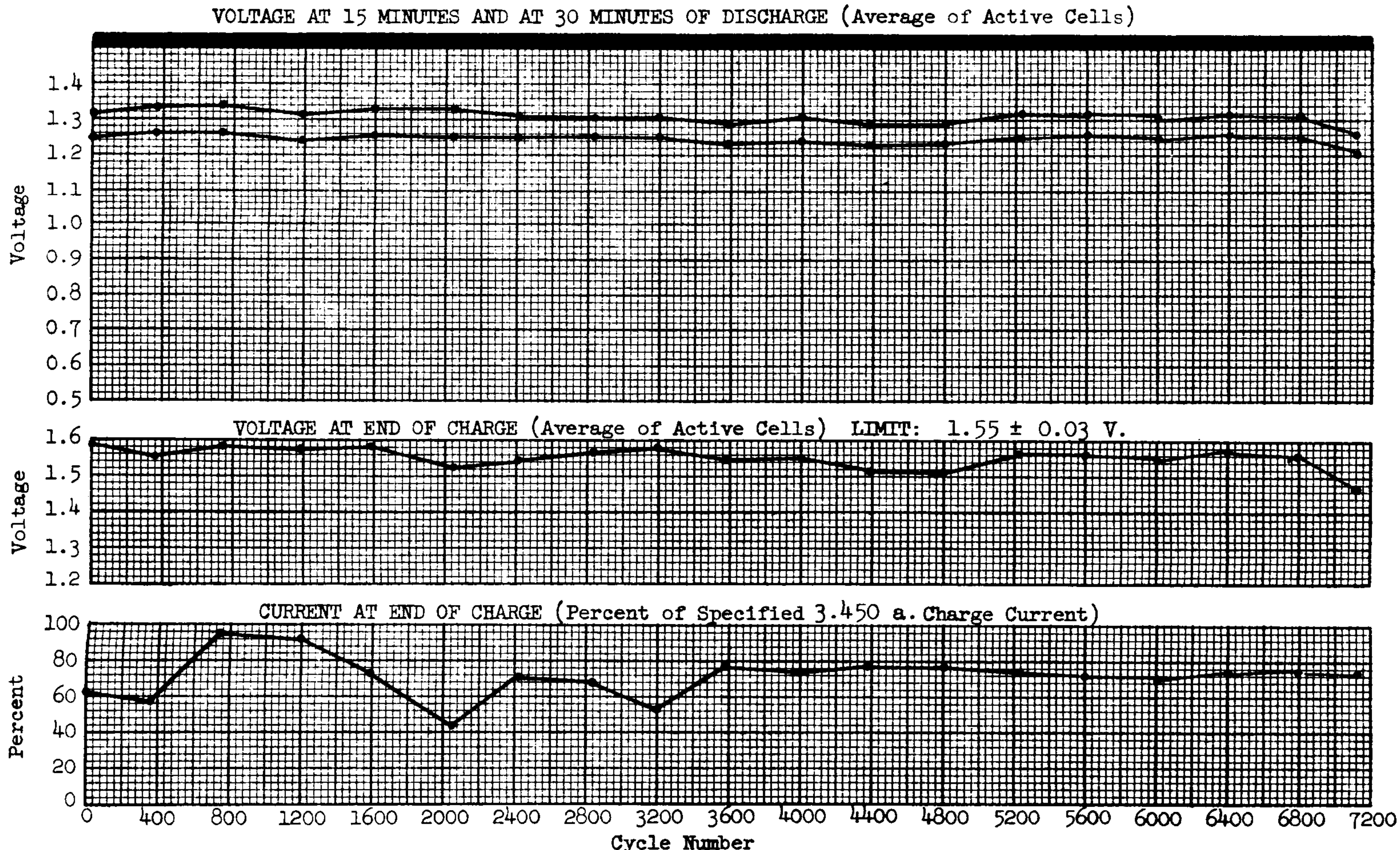
GOULD 3.5 a.h. (Pack 32)
Test Temperature: 50° - 40° C
Orbit Period: 3 hours
Depth of Discharge: 25%

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 10(1)



Cell Number	Cycle Failed

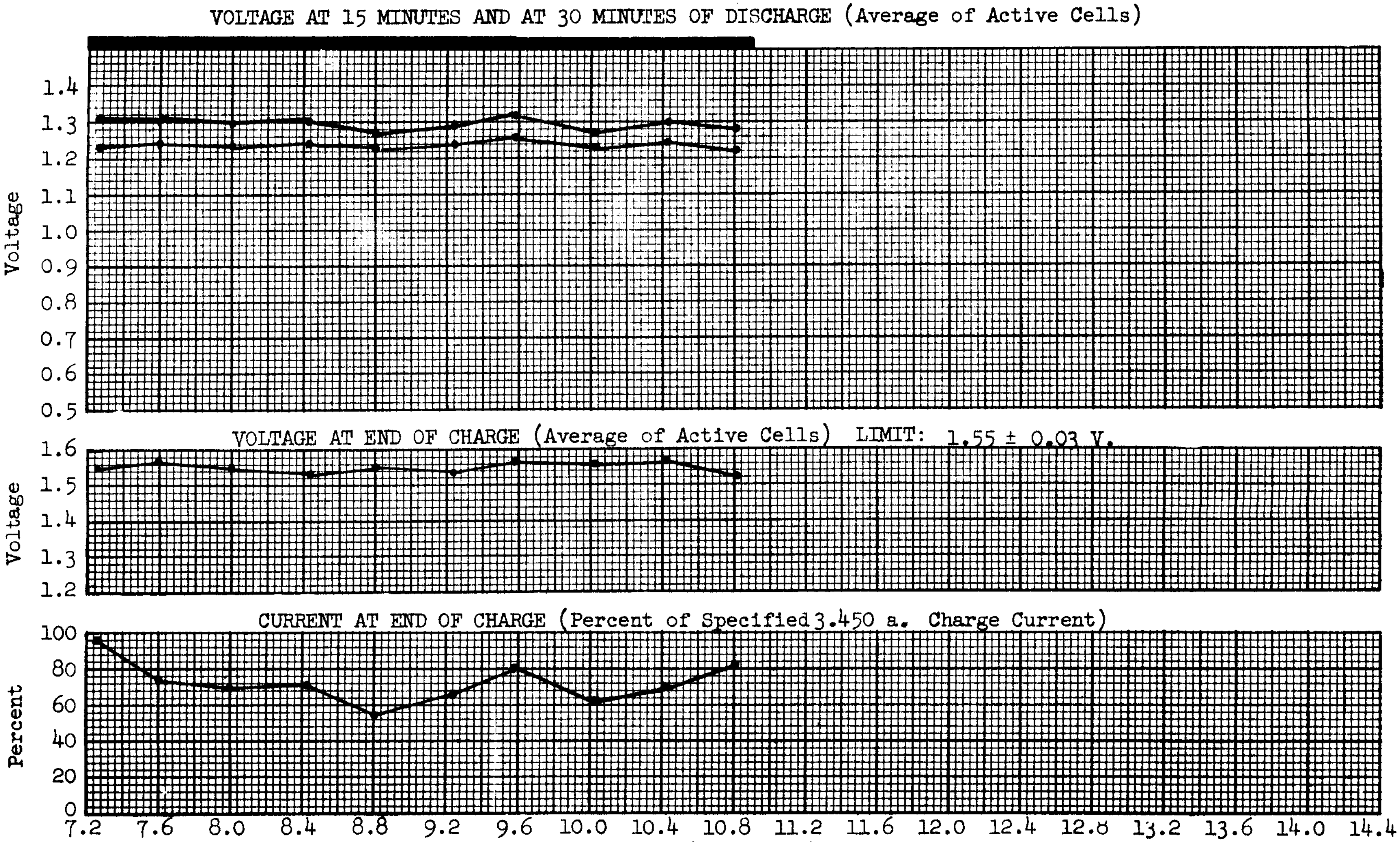
GOULD 20 a.h. (Pack 84)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

Status: Continued

Notes

1. Cycles 1471, 3133 4378, 5848, 7163: Capacity Check.

FIGURE 11(a)



Cell Number	Cycle Failed

GOULD 20 a.h. (Pack 84)

Test Temperature: 0° C

Orbit Period: 1.5 hours

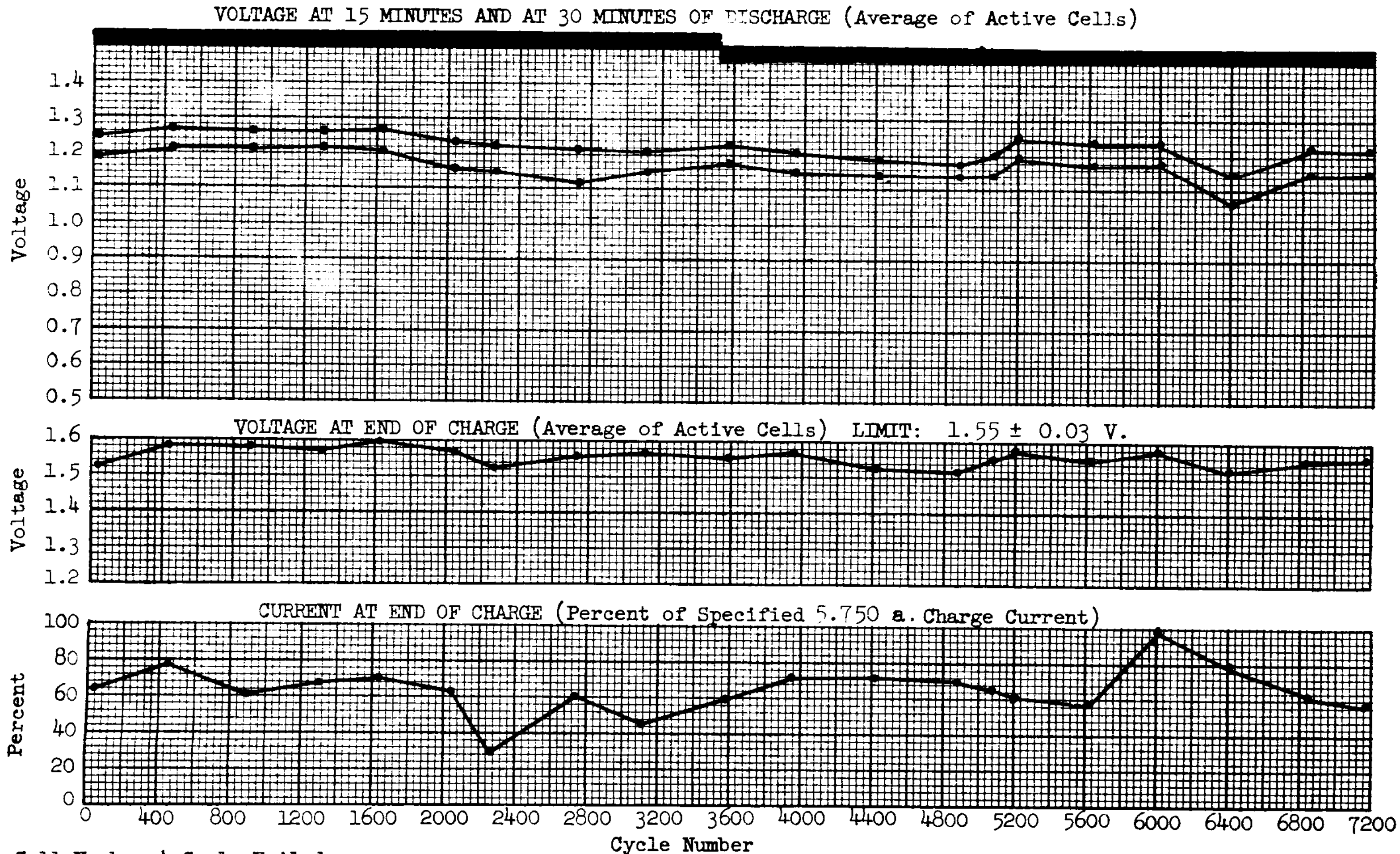
Depth of Discharge: 15%

Status: 5 cells cycling after 10909 cycles.

Notes

1. Cycles 8453, 9612; Capacity Check.

FIGURE 11(a) (Contd)



Cell Number	Cycle Failed
77	3556

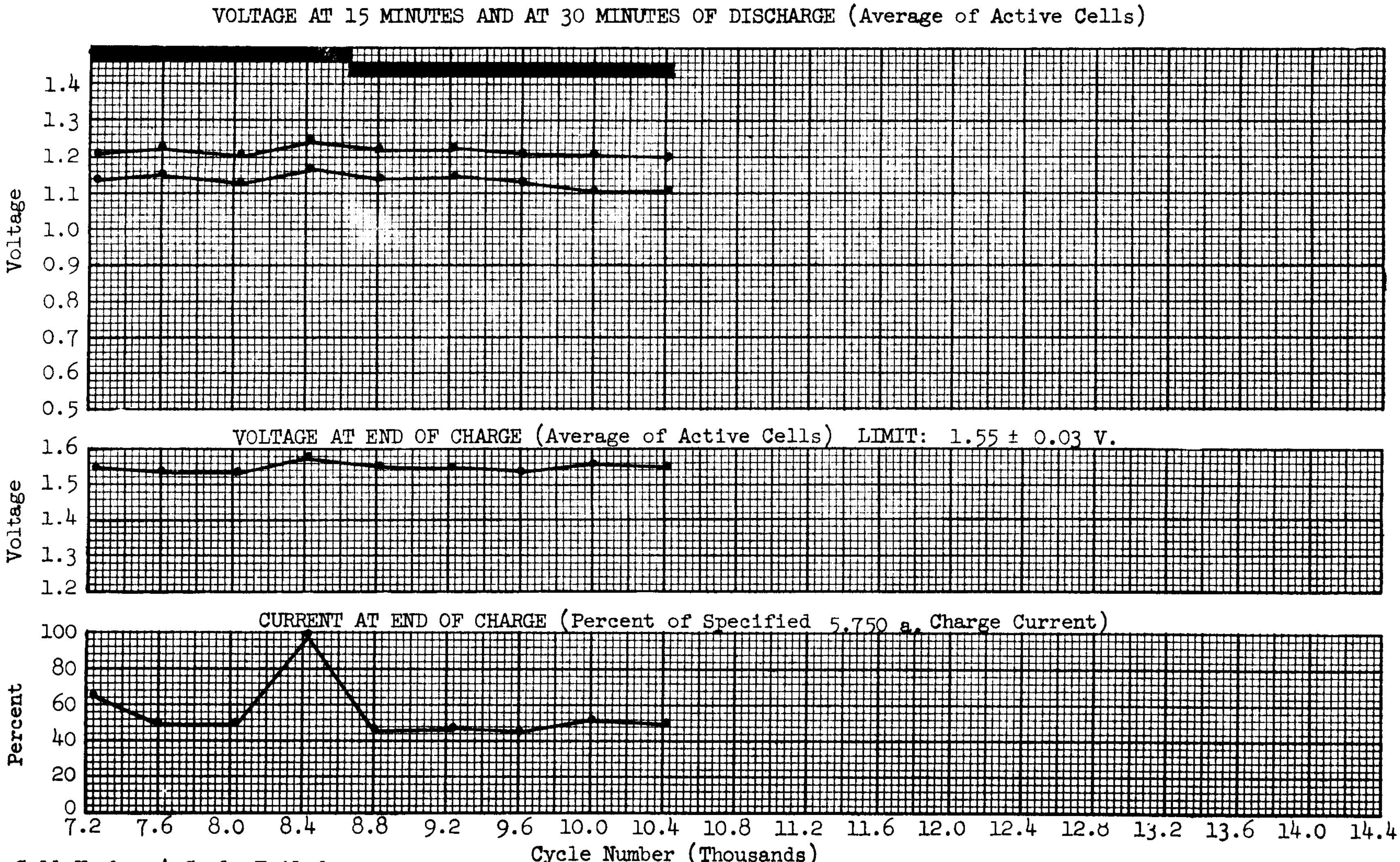
GOULD 20 a.h. (Pack 98)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: Continued

Notes

1. Cycles 1430, 3028, 4185, 5655, 6936: Capacity Check.

FIGURE 11(b)



Cell Number	Cycle Failed
47	8619

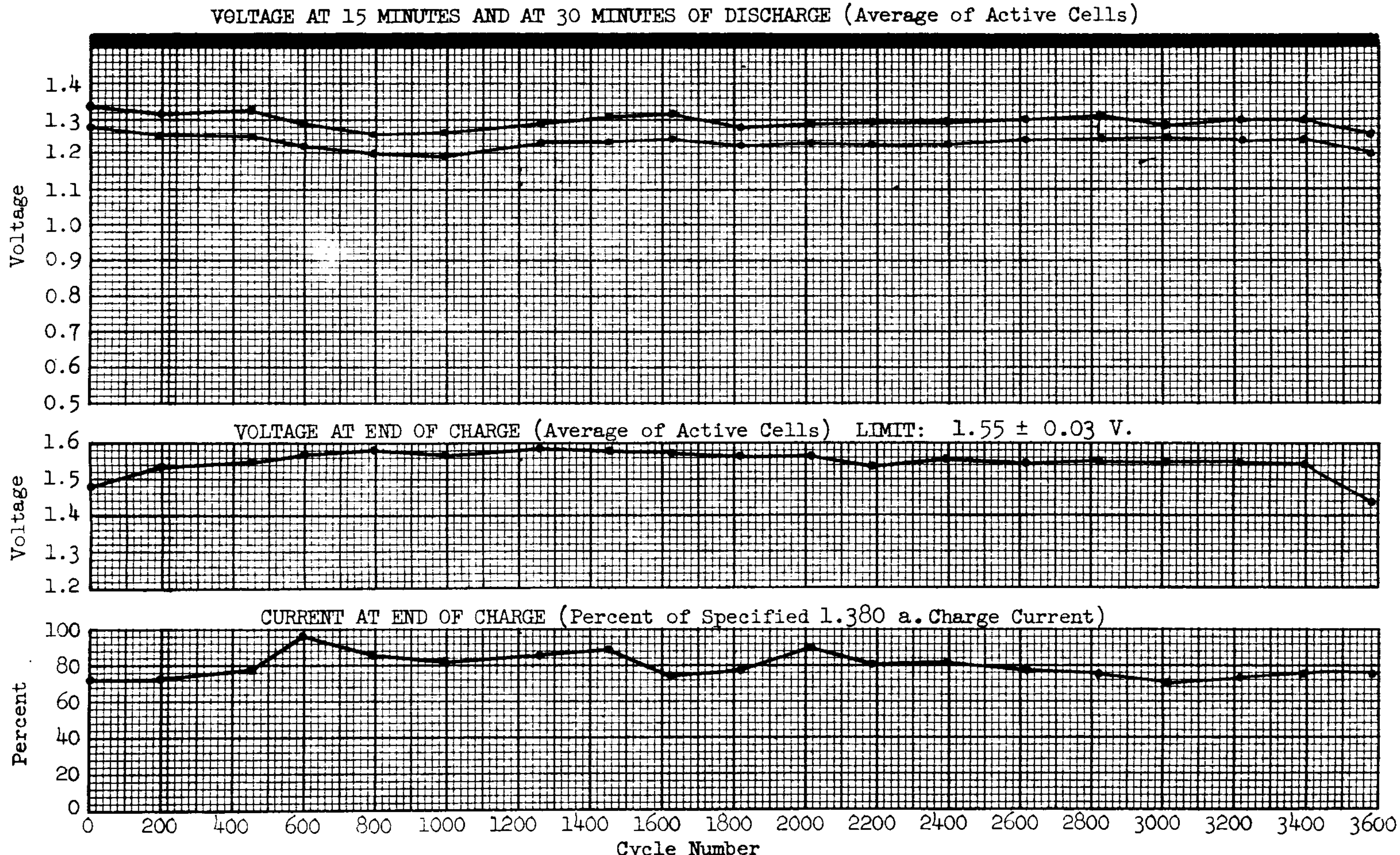
GOULD 20 a.h. (Pack 98)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: 3 cells cycling after 10422 cycles.

Notes

1. Cycles 8370, 9424: Capacity Check.

FIGURE 11(b) (Contd)



Cell Number	Cycle Failed

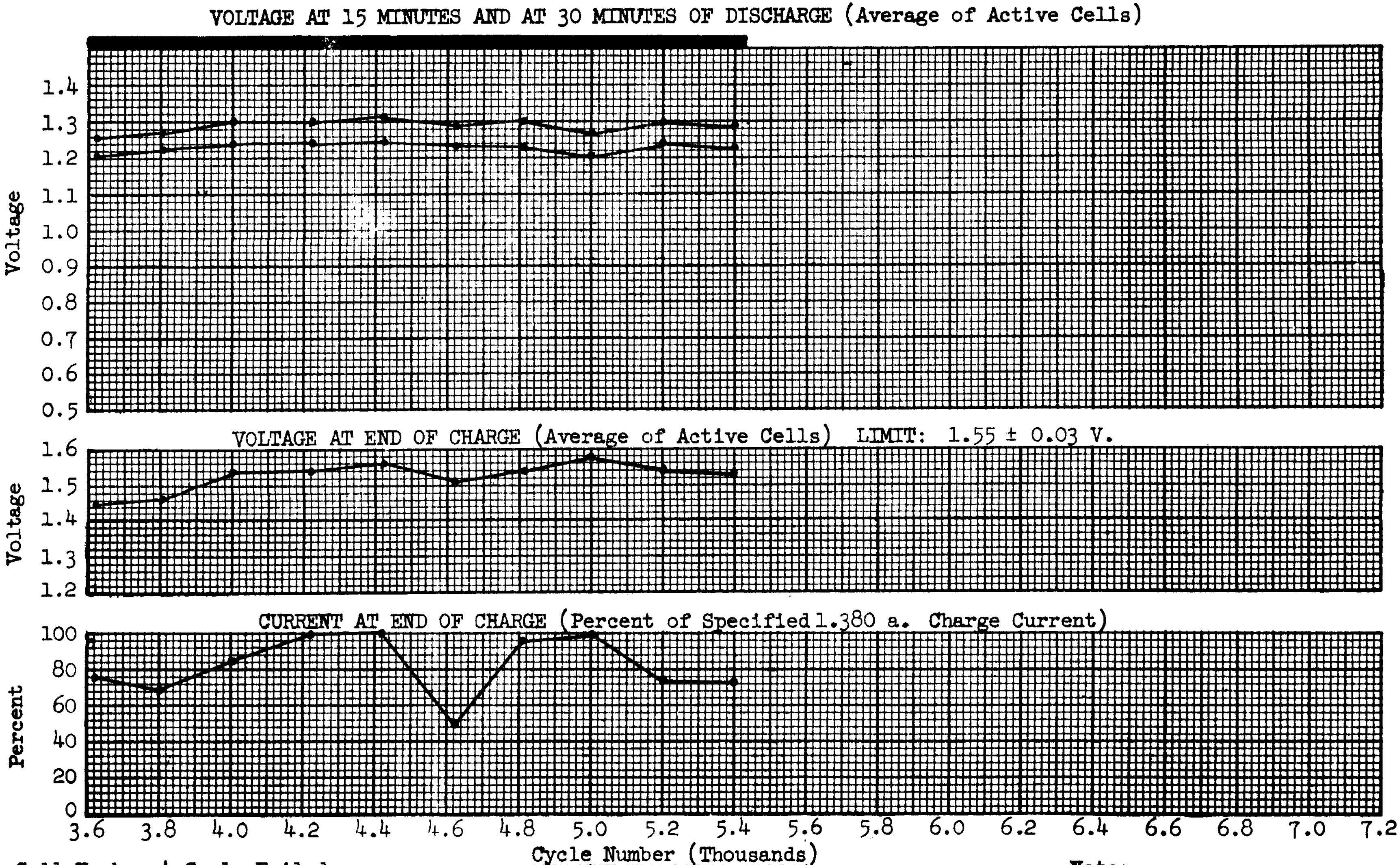
GOULD 20 a.h. (Pack 80)
Test Temperature: 0° C
Orbit Period: 3 hours
Depth of Discharge: 15%

Status: Continued

Notes

1. Cycles 740, 1611, 2468, 3220: Capacity Check.

FIGURE 11(c)



Cell Number	Cycle Failed

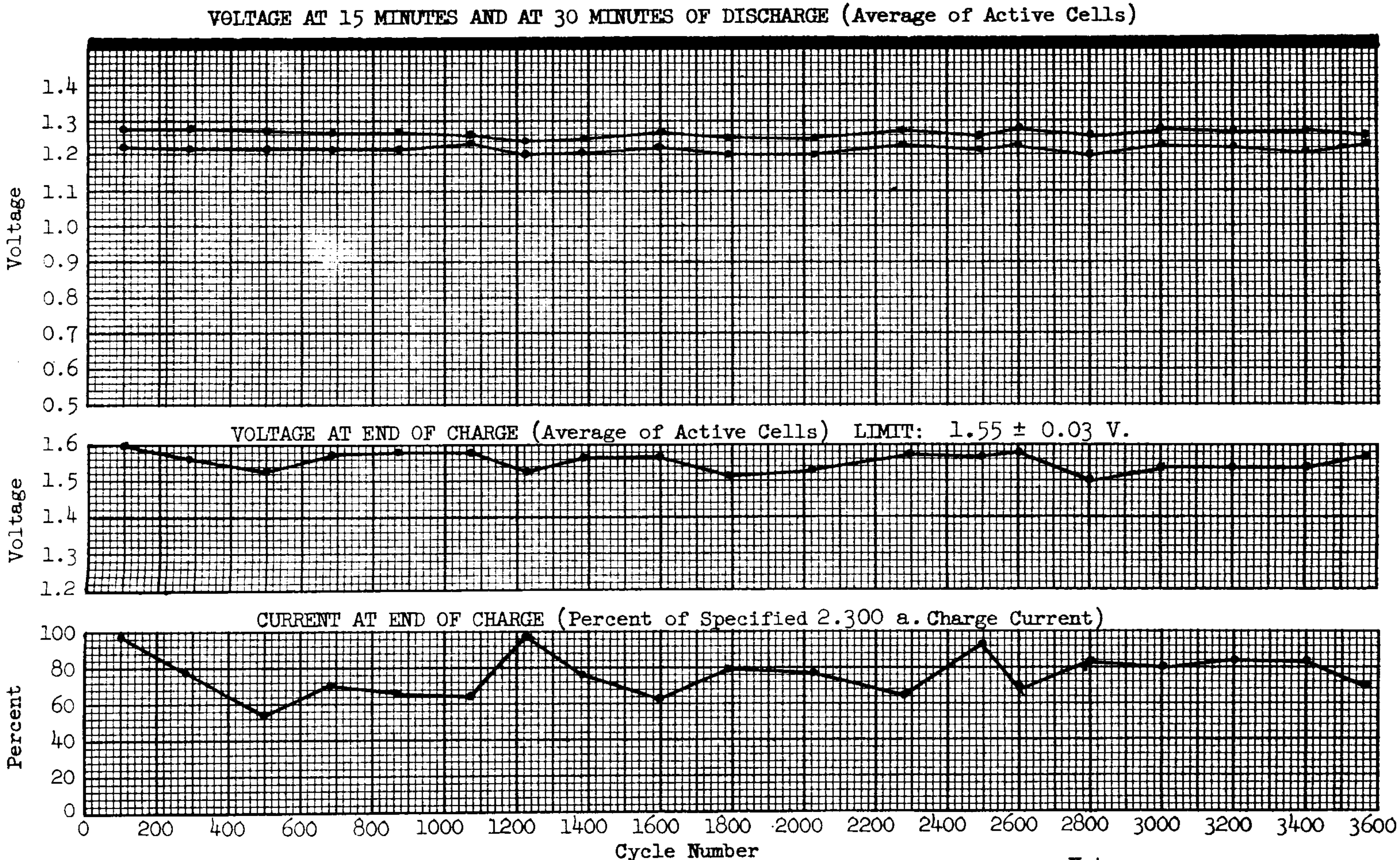
GOULD 20 a.h. (Pack 80)
Test Temperature: 0° C
Orbit Period: 3 hours
Depth of Discharge: 15%

Status: 5 cells cycling after 5427 cycles.

FIGURE 11(c) (Contd)

Notes

1. Cycles 4031, 4536, 5143: Capacity Check.



Cell Number	Cycle Failed

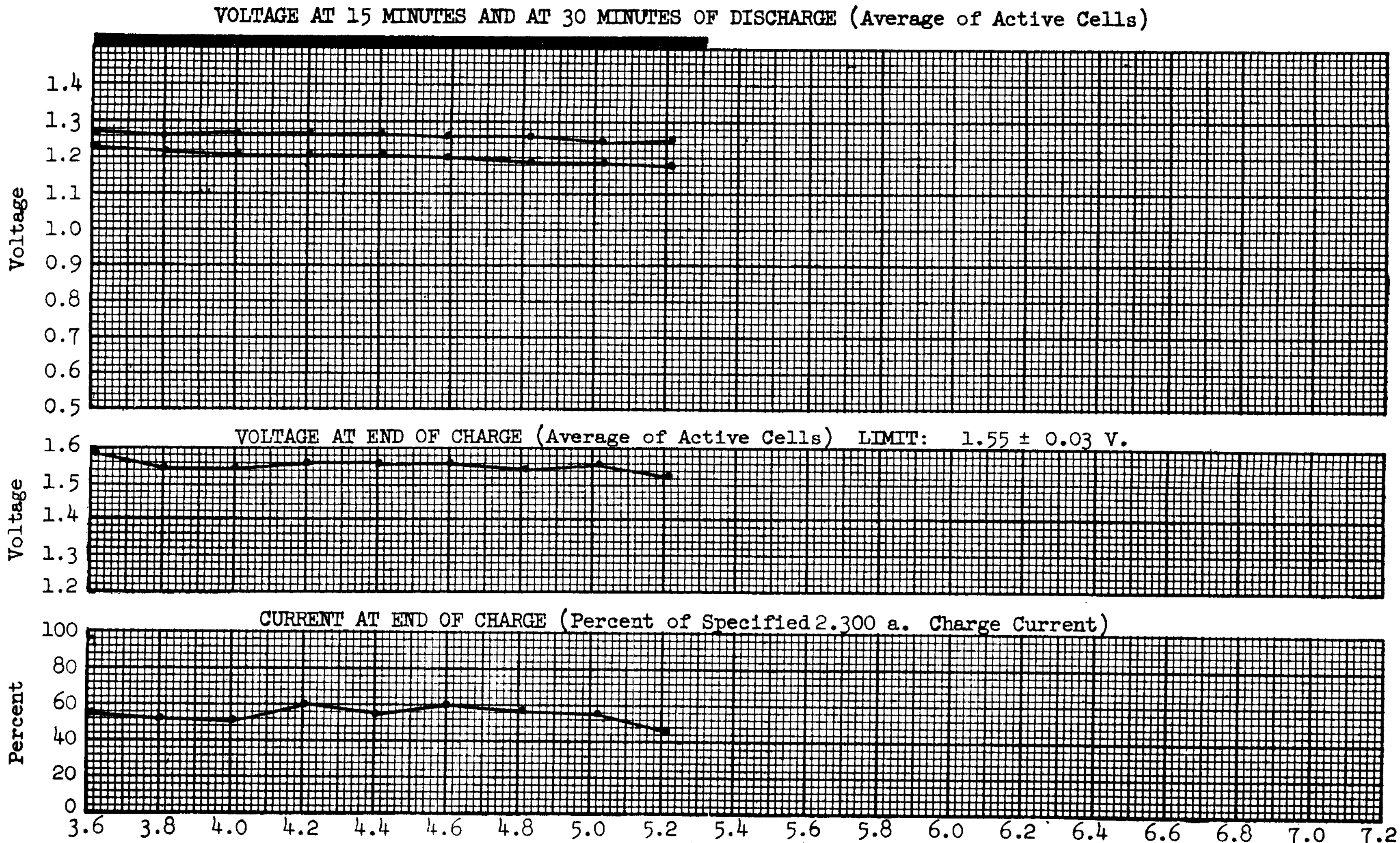
GOULD 20 a.h. (Pack 94)
Test Temperature: 0° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: Continued

Notes

1. Cycles 727, 1506, 2173, 2908: Capacity Check.

FIGURE 11(d)



Cell Number	Cycle Failed

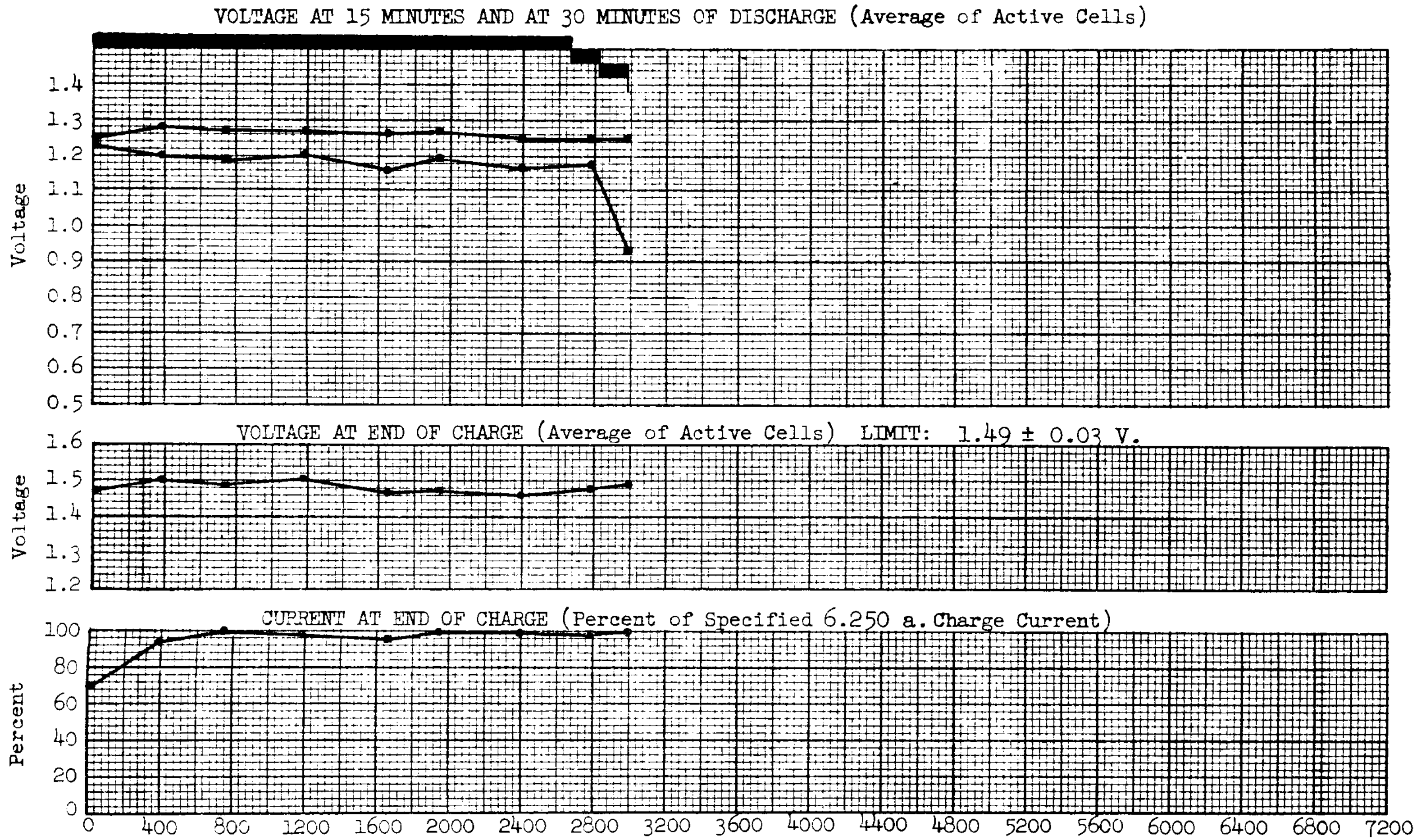
GOULD 20 a.h. (Pack 94)
Test Temperature: 0° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: 5 cells cycling after 5309 cycles.

Notes

1. Cycles 3605, 4352, 4915: Capacity Check:

FIGURE 11(d) (Contd)



Cell Number	Cycle Failed
69	2672
R36	2826
5	2980

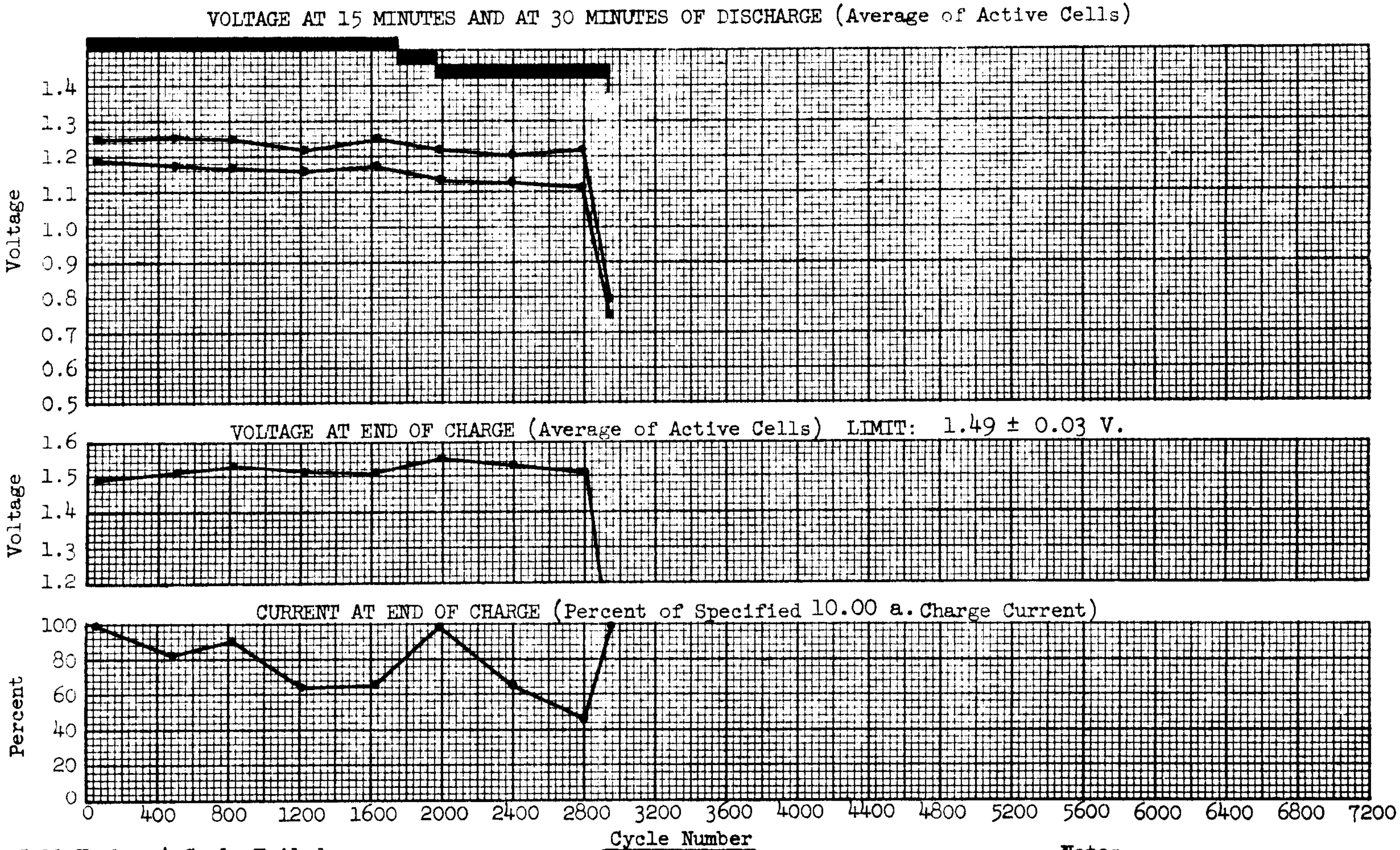
GOULD 20 a.h. (Pack 104)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: Pack Failed: Cycle 2980

Notes

1. Cycles 1360, 2802: Capacity Check.

FIGURE 11(e)



Cell Number	Cycle Failed
61	1747
R91	1963
92	2937

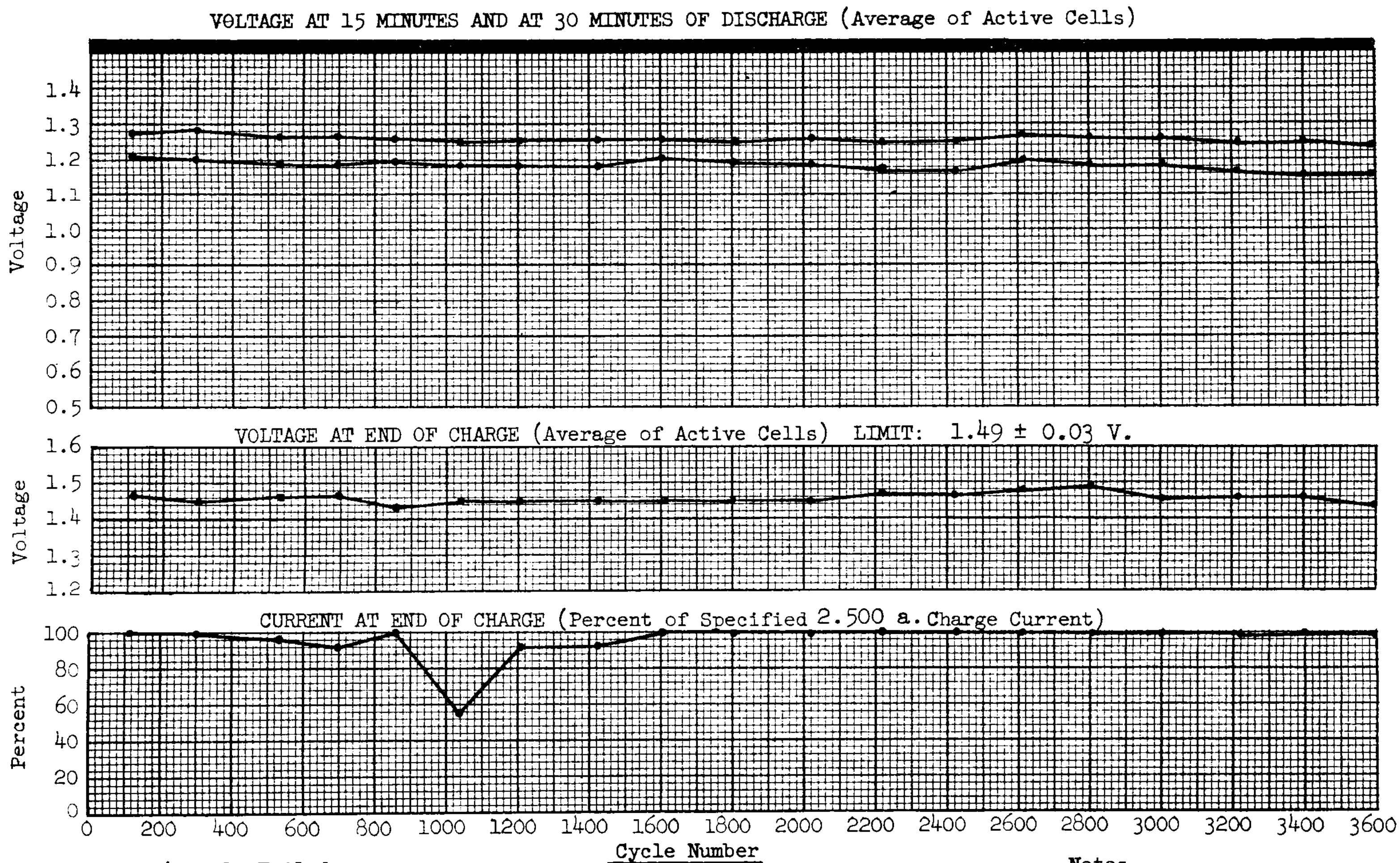
GOULD 20 a.h. (Pack 118)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 40%

Status: Pack Failed: Cycle 2937

Notes

1. Cycle 1358: Capacity Check.

FIGURE 11(f)



Cell Number	Cycle Failed

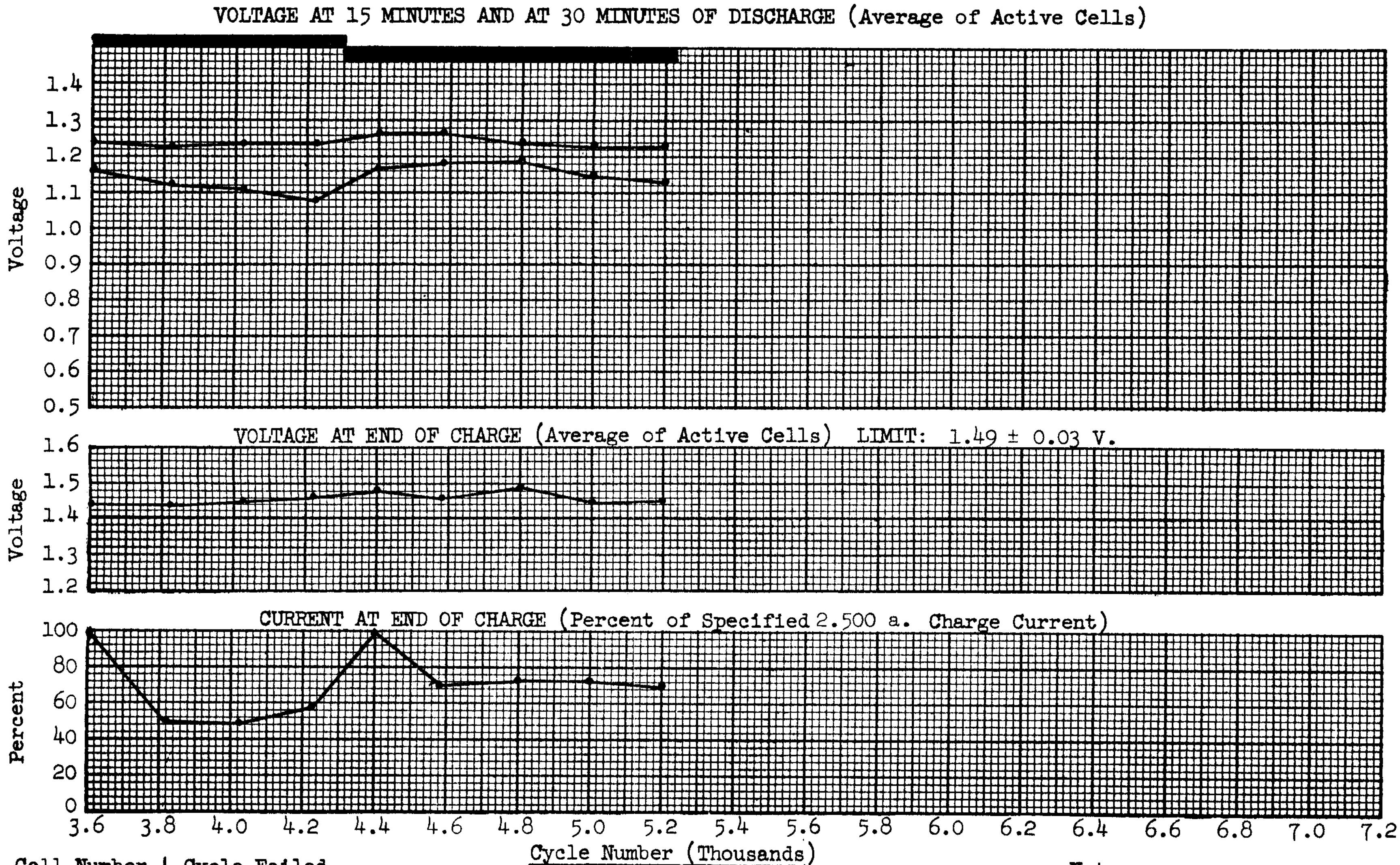
GOULD 20 a.h. (Pack 105)
Test Temperature: 25° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: Continued

Notes

1. Cycles 740, 1577, 2231, 2885, 3543: Capacity Check.

FIGURE 11(g)



Cell Number	Cycle Failed
40	4306

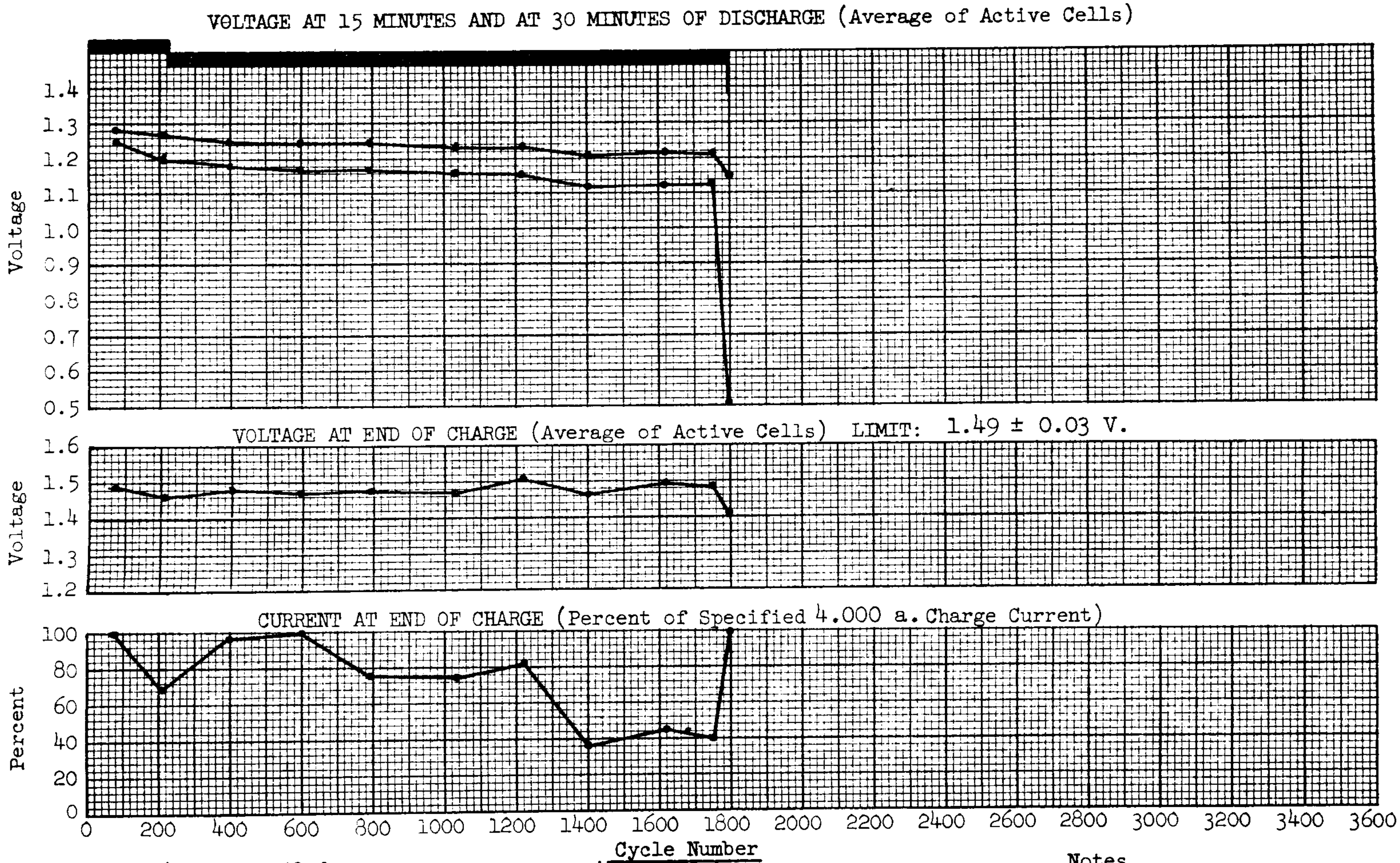
GOULD 20 a.h. (Pack 105)
Test Temperature: 25° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: 4 cells cycling after 5227 cycles.

Notes

1. Cycles 4282: Capacity Check.

FIGURE 11(g) (Contd)



Cell Number	Cycle Failed
73	222
80, 86	1793

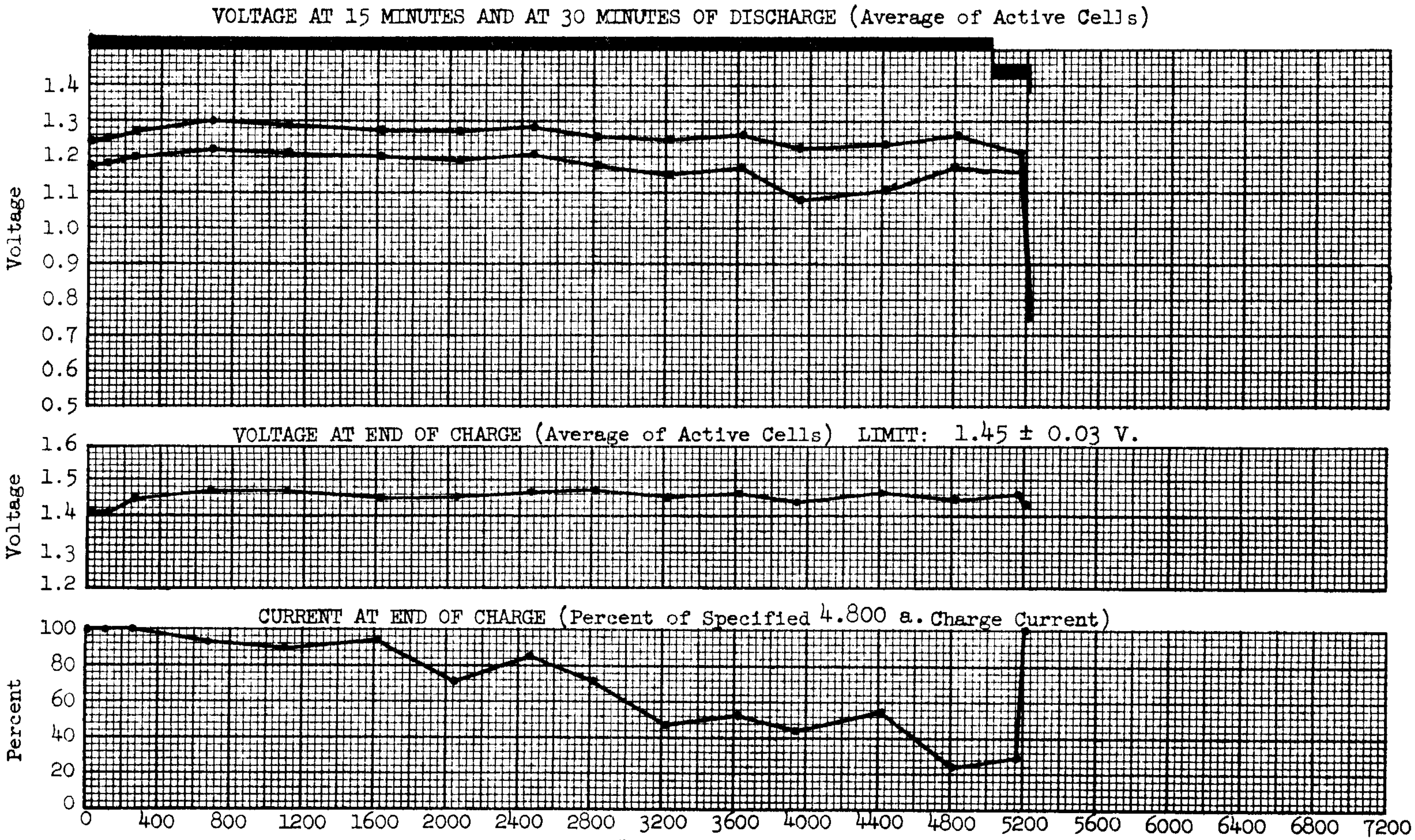
GOULD 20 a.h. (Pack 119)
Test Temperature: 25° C
Orbit Period: 3 hours
Depth of Discharge: 40%

Status: Pack Failed: Cycle 1793

Notes

1. Cycles 726, 1506: Capacity Check.

FIGURE 11(h)



Cell Number	Cycle Failed
17, 25	5005
38	5213

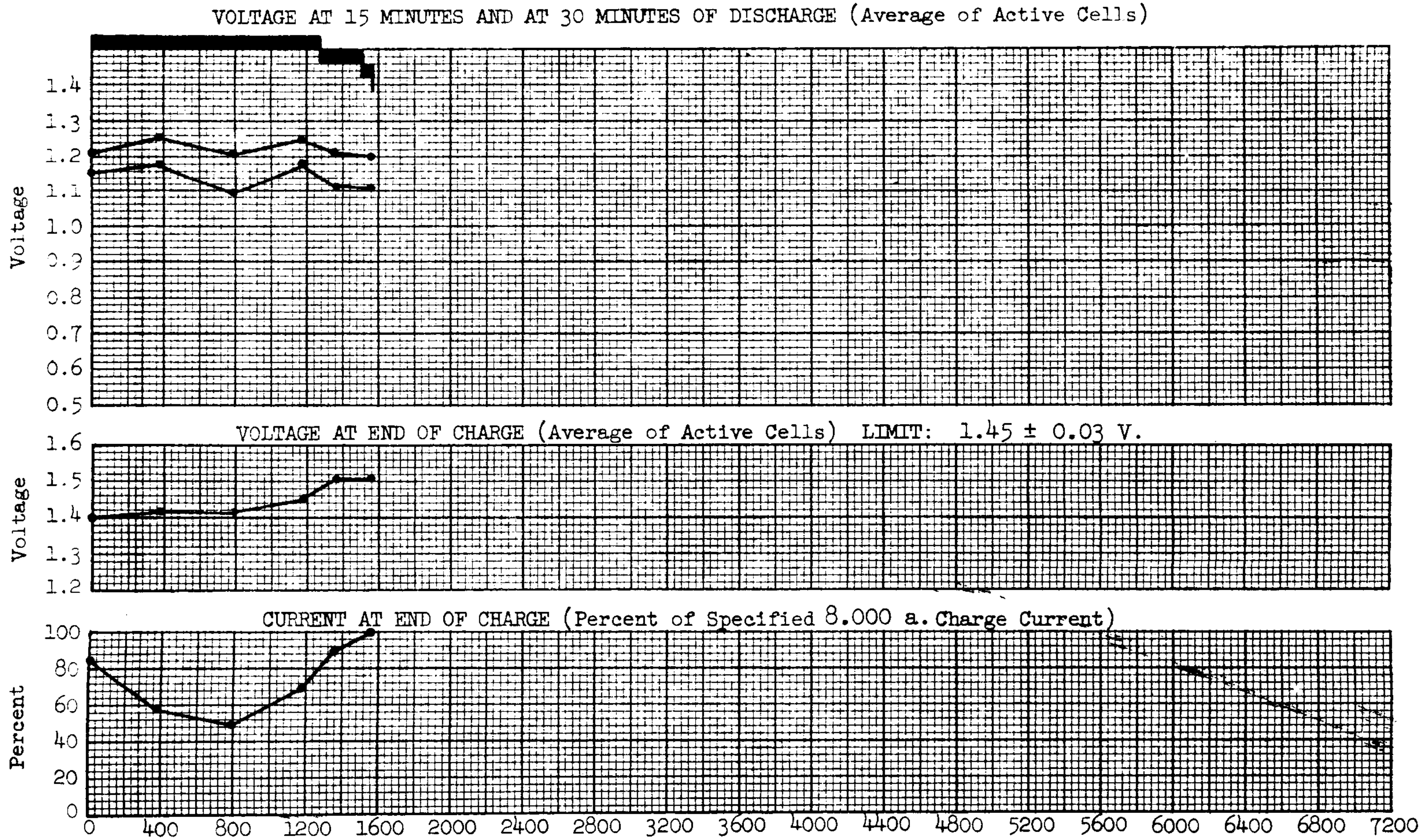
GOULD 20 a.h. (Pack 112)
Test Temperature: 50° - 40° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

Status: Pack Failed: Cycle 5213

Notes

1. Cycle 183: Changed to 40° C.
2. Cycle 485: Voltage limit raised to 1.45 V/cell.
3. Cycles 1395, 2950, 4370, 5203: Capacity Check.

FIGURE 11(i)



Cell Number	Cycle Failed
9	1273
R29	1509
11	1569

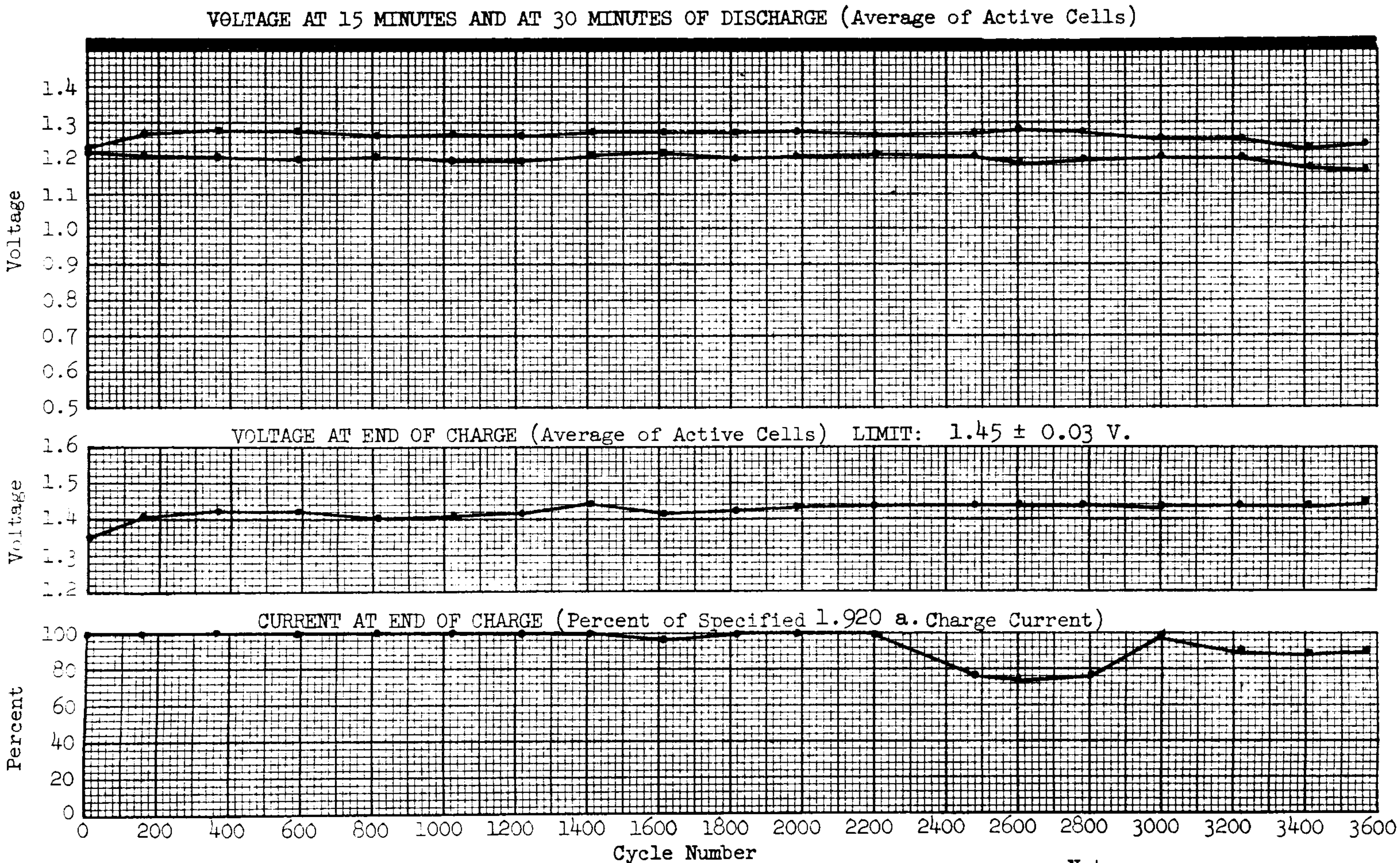
GOULD 20 a.h. (Pack 126)
Test Temperature: 50° - 40° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

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 11(j)



Cell Number	Cycle Failed

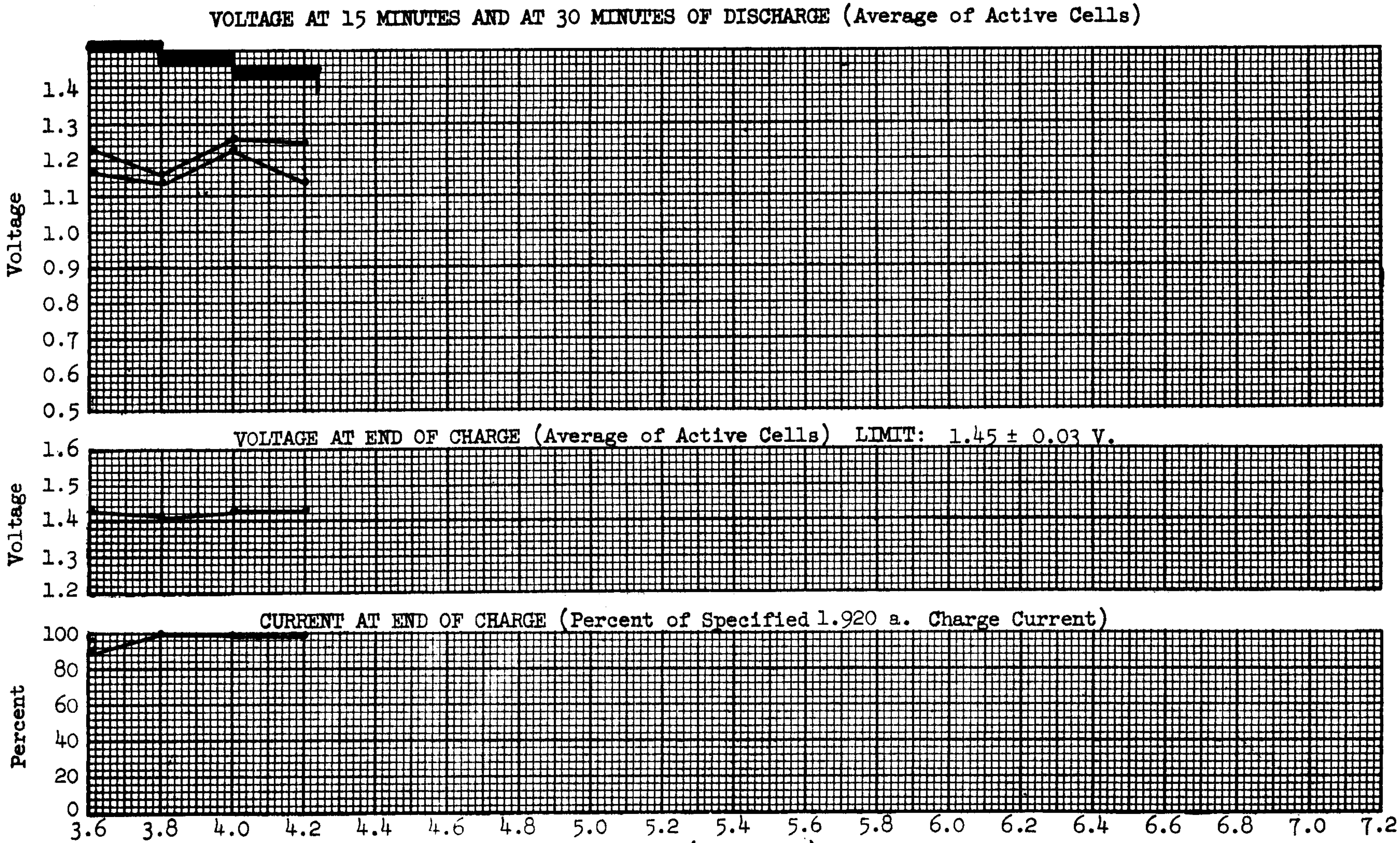
GOULD 20 a.h. (Pack 108)
Test Temperature: 50° - 40° C
Orbit Period: 3 hours
Depth of Discharge: 15%

Status: Continued

Notes

1. Cycle 47: Changed to 40° C.
2. Cycle 206: Voltage limit raised to 1.45 V/cell.
3. Cycles 717, 1544, 2189, 2977: Capacity Check.

FIGURE 11(k)



Cell Number	Cycle Failed
R99	3796
81	4003
82	4233

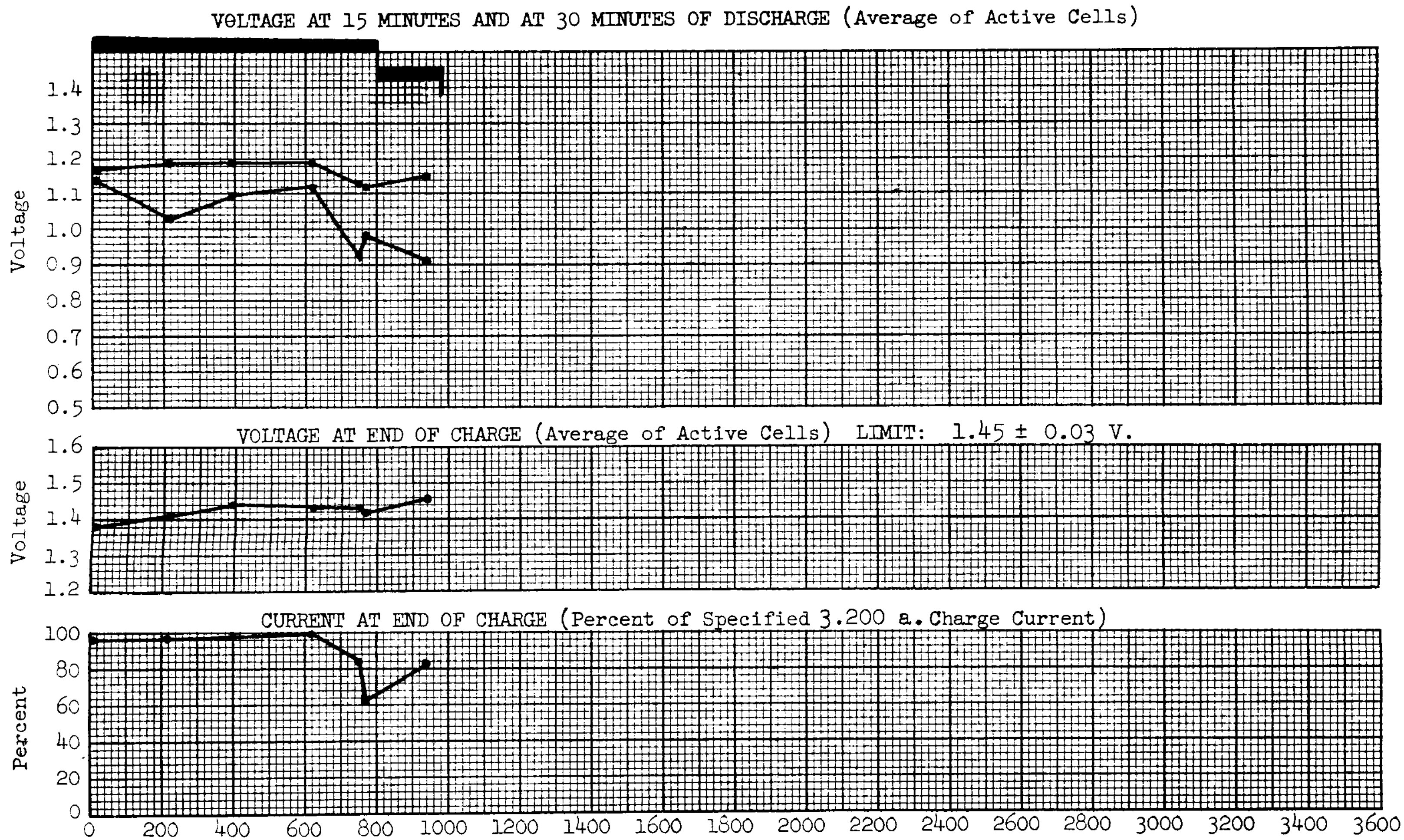
GOULD 20.0 a.h. (Pack 108)
Test Temperature: 50°-40° C
Orbit Period: 3 hours
Depth of Discharge: 15%

Status: Pack Failed: Cycle 4233

Notes

1. Cycles 3677: Capacity Check.

FIGURE 11(k) (Contd)



Cell Number	Cycle Failed
16, 58	801
18	983

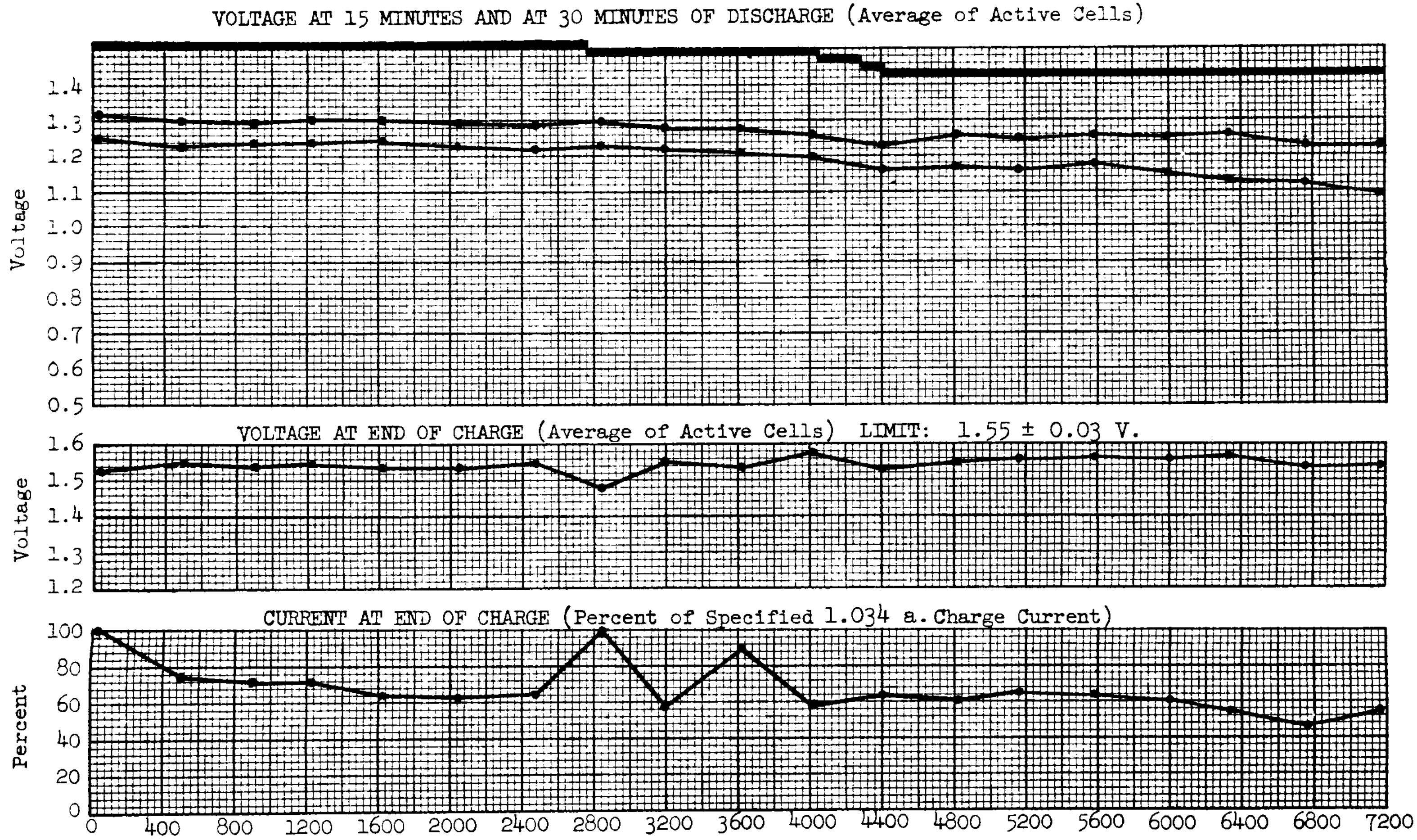
GOULD 20 a.h. (Pack 122)
Test Temperature: 50° - 40° C
Orbit Period: 3 hours
Depth of Discharge: 25%

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 11(1)



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

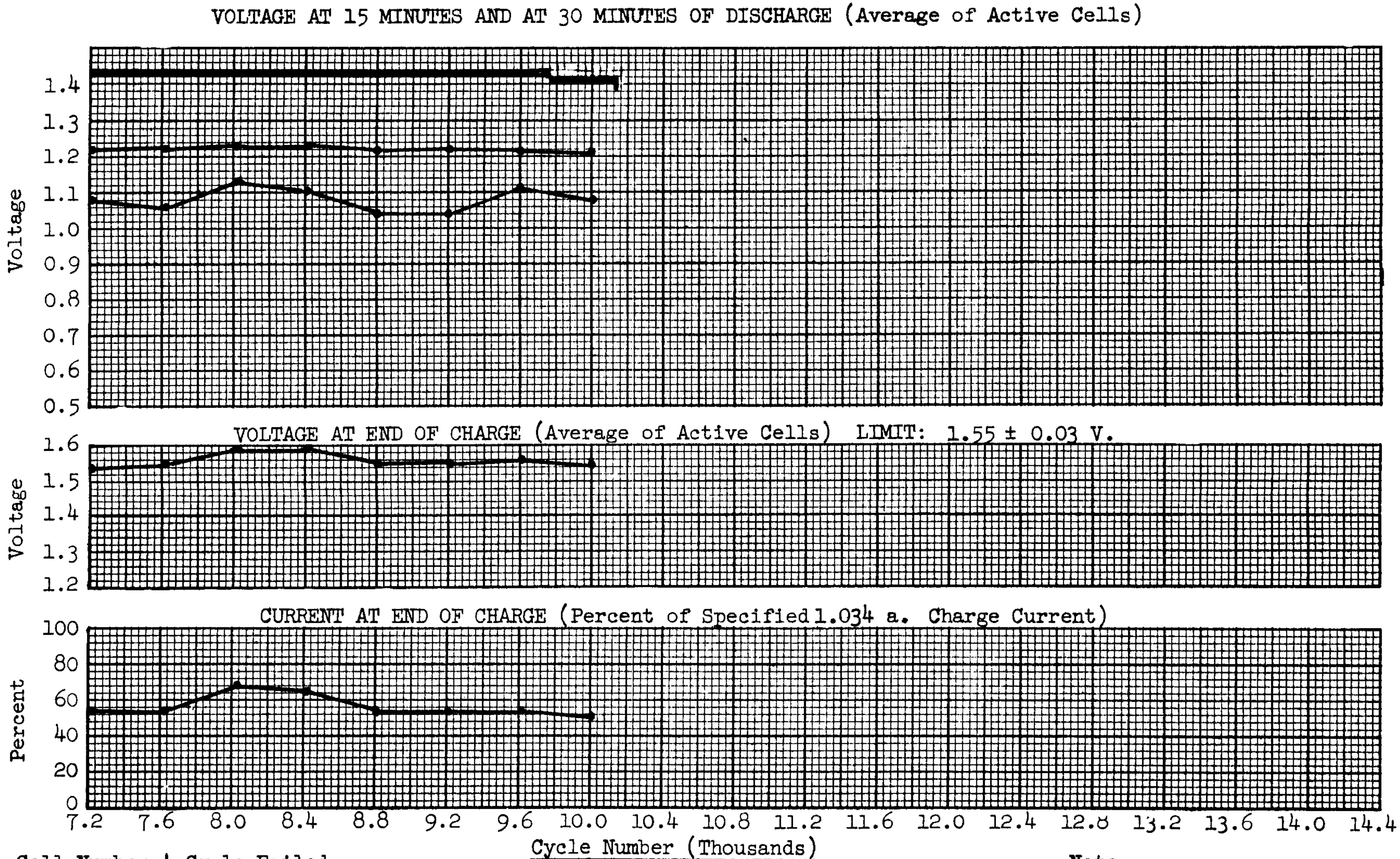
GULTON 6.0 a.h. (Pack 61)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

Status: Continued

Notes

1. Cycles 1467, 2897, 4074, 5493, 6495: Capacity Check.

FIGURE 12(a)



Cell Number	Cycle Failed
1636	9760
1616	10146

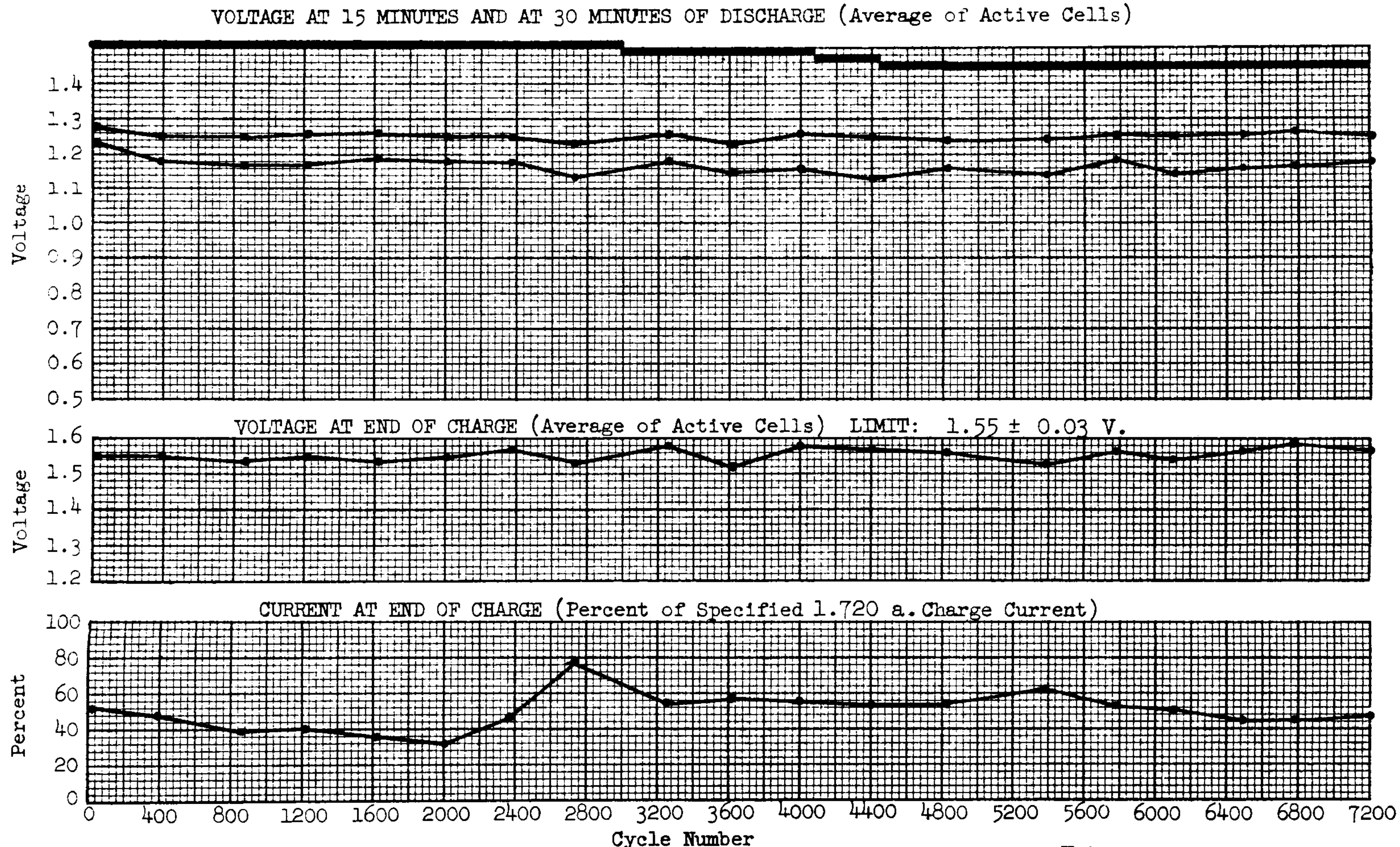
GULTON 6.0 a.h. (Pack 61)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

Status: Pack Failed: Cycle 10146

Notes

1. Cycles 8004, 9160: Capacity Check.

FIGURE 12(a) (Contd)



Cell Number	Cycle Failed
1630	2995
1792	4066
1806	4441

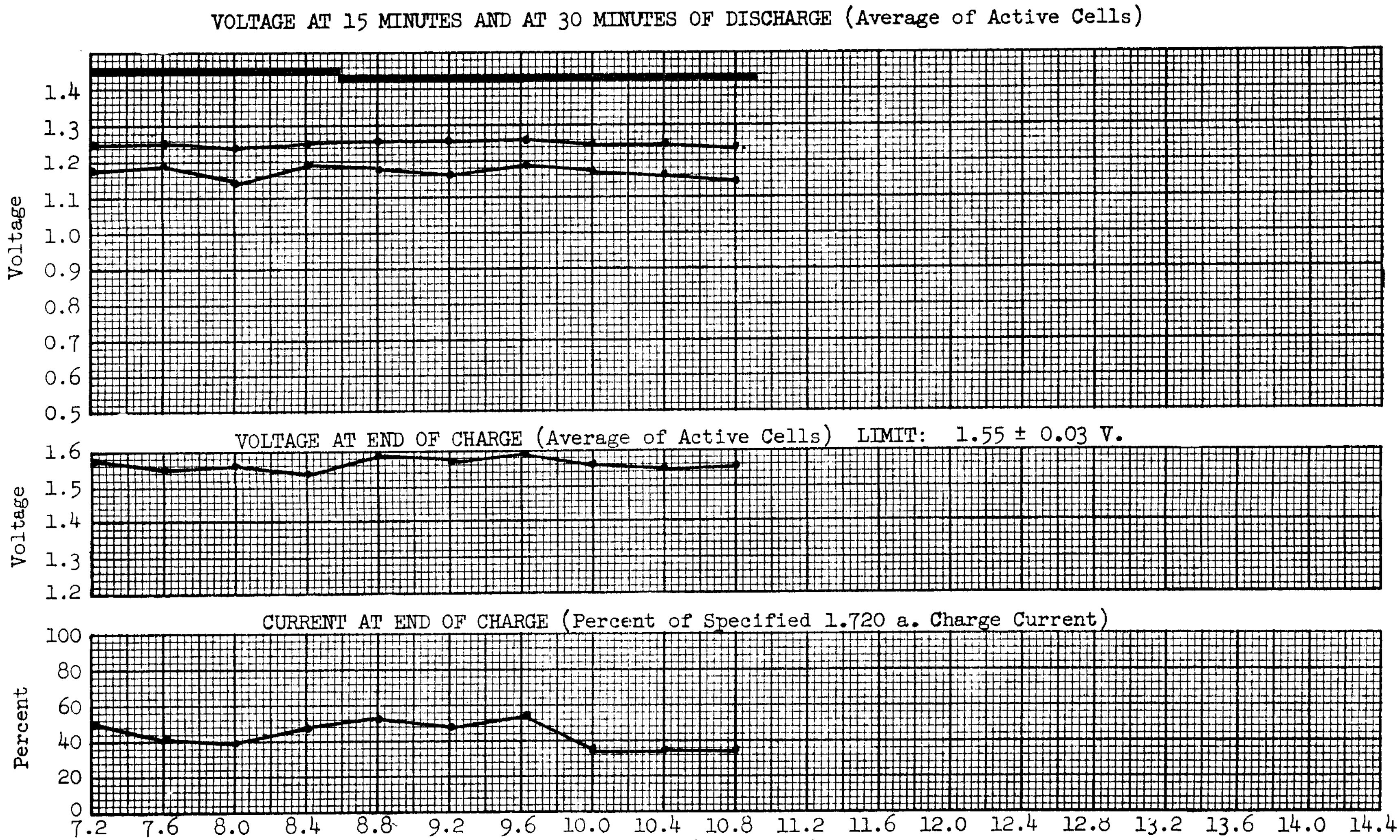
GULTON 6.0 a.h. (Pack 62)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: Continued

Notes

1. Cycles 1386, 2741, 4090, 5647, 7050: Capacity Check.

FIGURE 12(b)



Cell Number	Cycle Failed
2227	8590

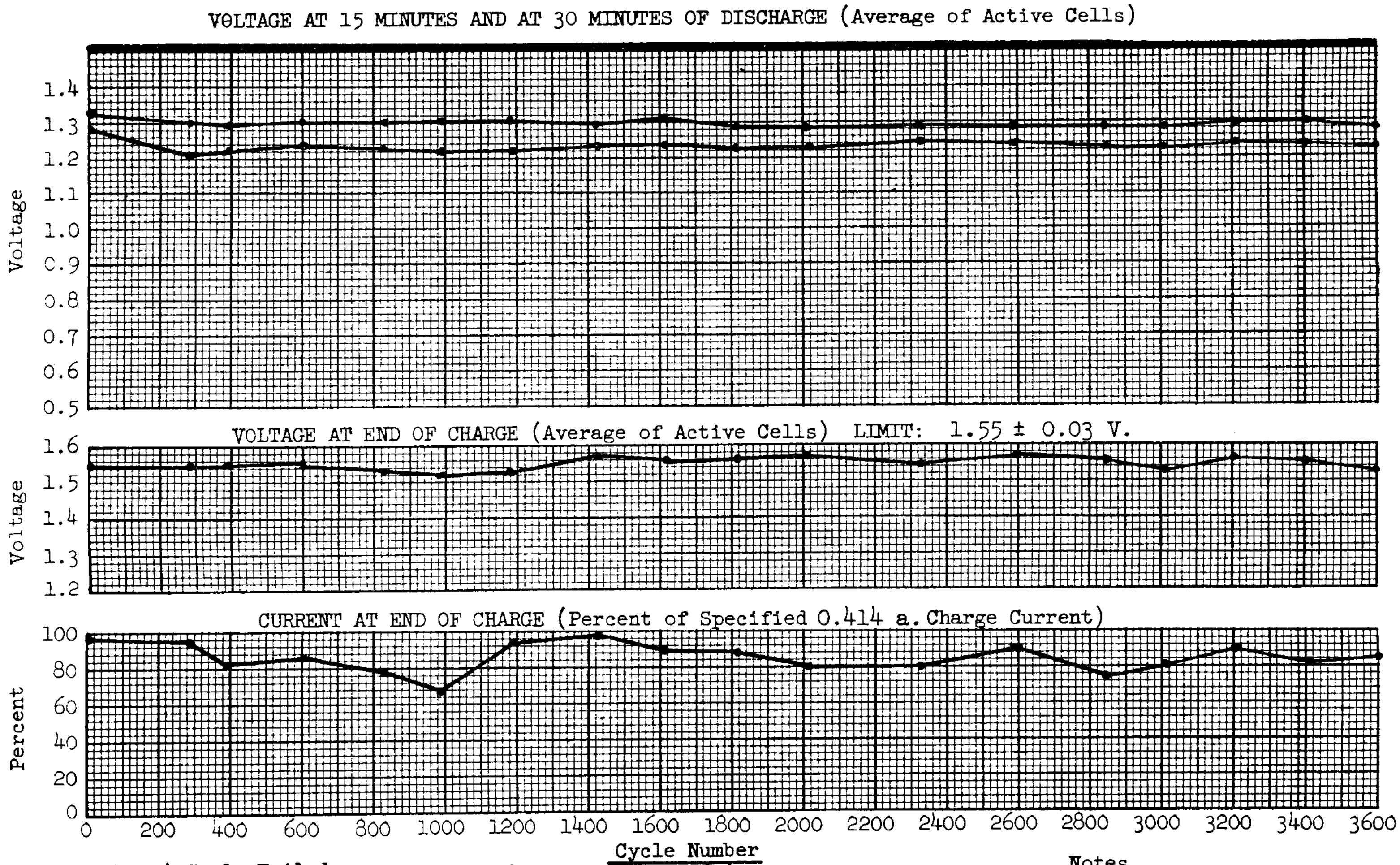
GULTON 6.0 a.h. (Pack 62)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: 6 cells cycling after 10869 cycles.

Notes

1. Cycles 8369, 9547: Capacity Check.

FIGURE 12(b) (Contd)



Cell Number	Cycle Failed

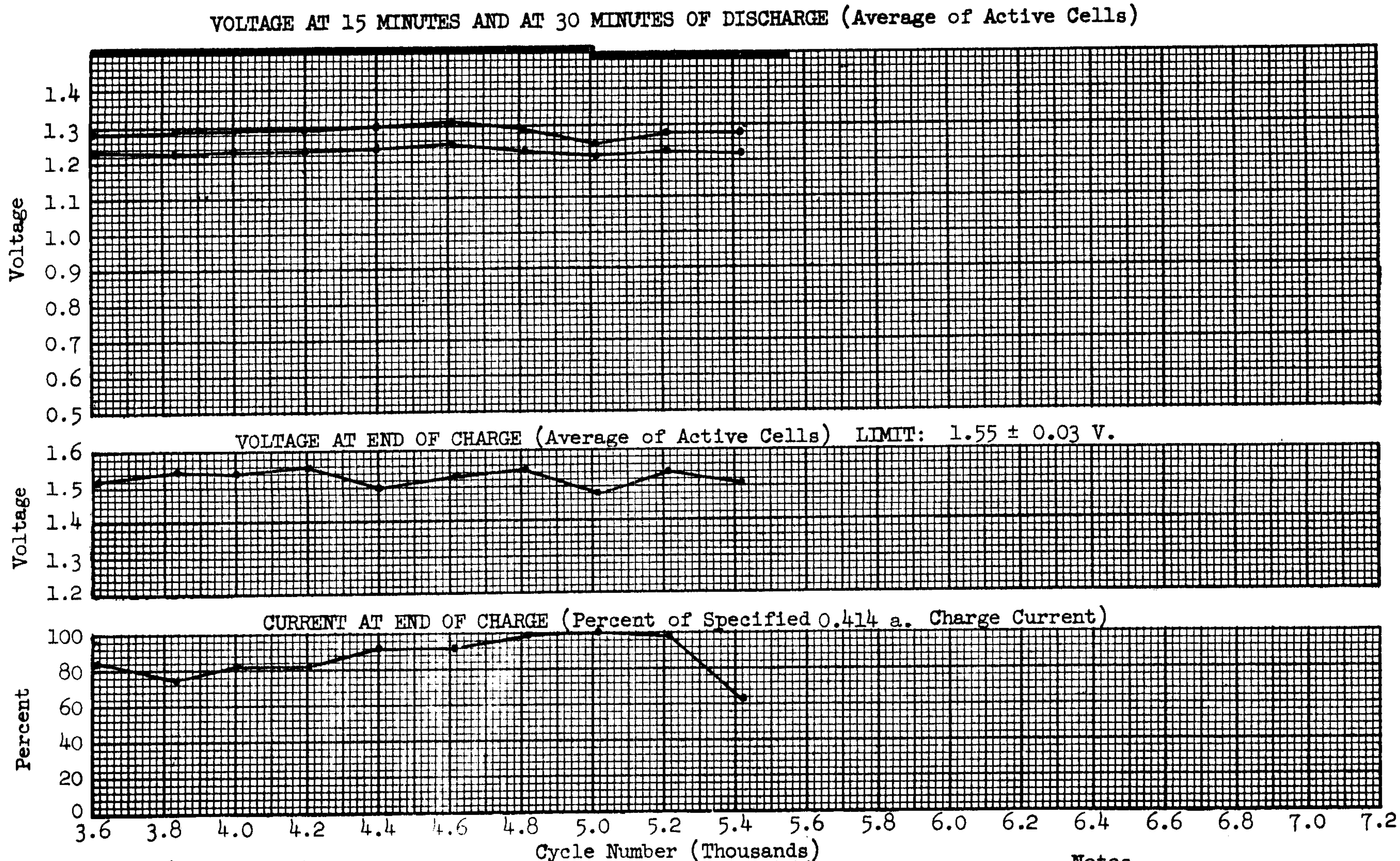
GULTON 6.0 a.h. (Pack 65)
Test Temperature: 0° C
Orbit Period: 3 hours
Depth of Discharge: 15%

Status: Continued

Notes

1. Cycles 694, 1440, 2200, 2899, 3555: Capacity Check.

FIGURE 12(c)



Cell Number	Cycle Failed
1285	5012

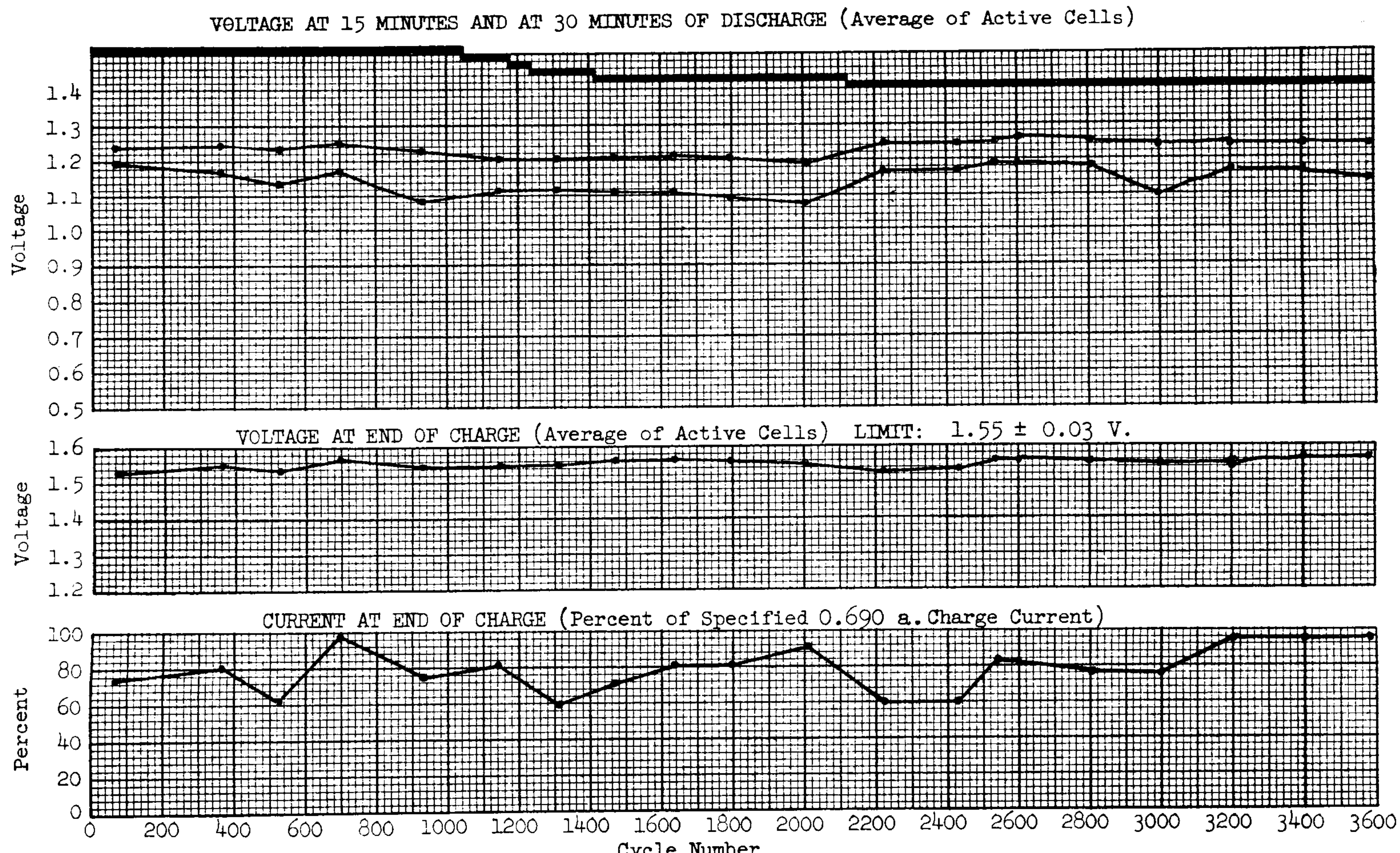
GULTON 6.0 a.h. (Pack 65)
Test Temperature: 0° C
Orbit Period: 3 hours
Depth of Discharge: 15%

Status: 9 cells cycling after 5549 cycles.

Notes

1. Cycles 4404, 4986: Capacity Check.

FIGURE 12(c) (Contd)



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

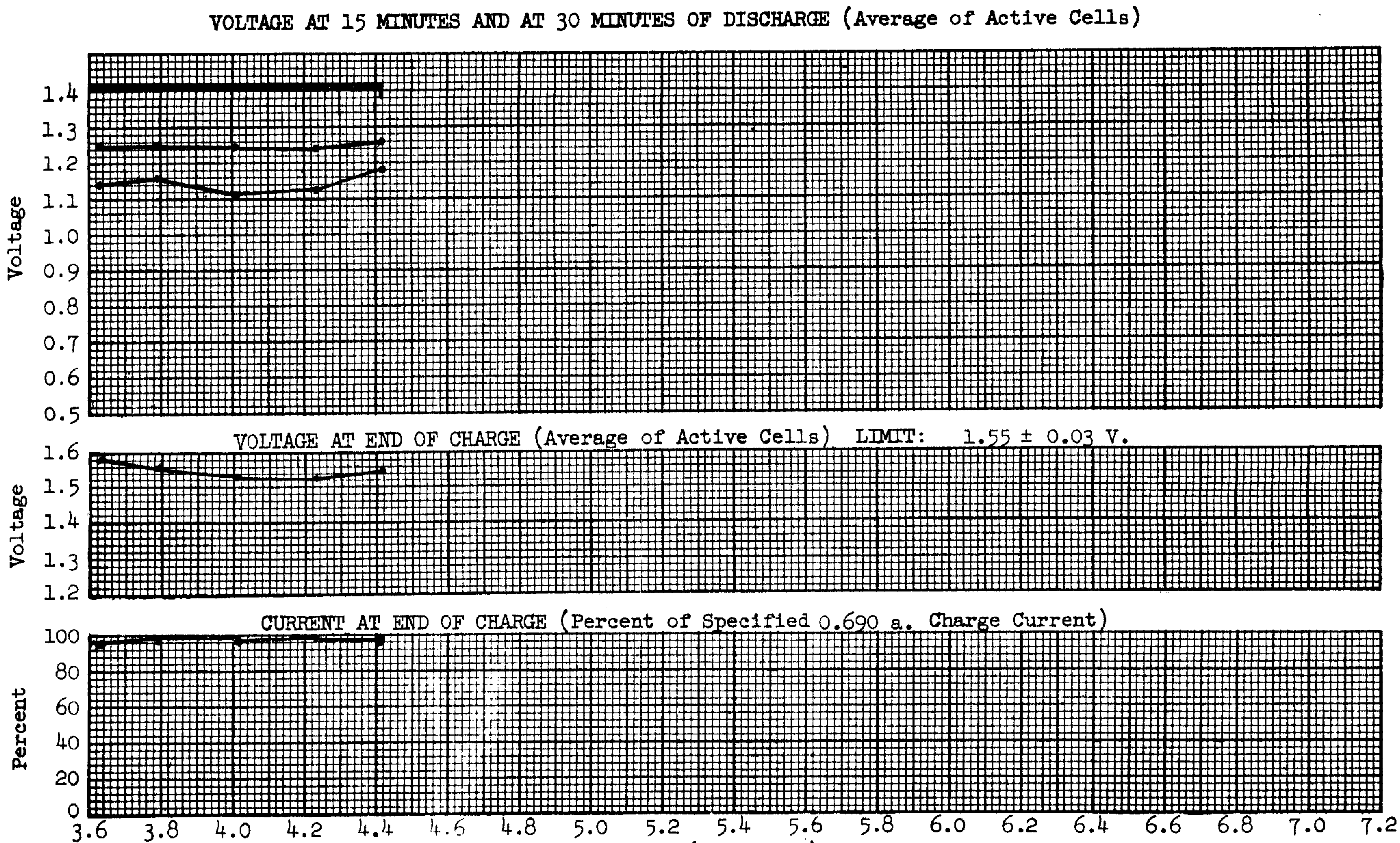
GULTON 6.0 a.h. (Pack 66)
Test Temperature: 0° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: Continued

Notes

1. Cycles 701, 1292, 1911, 2503, 3255: Capacity Check.

FIGURE 12(d)



Cell Number	Cycle Failed
1591	4414

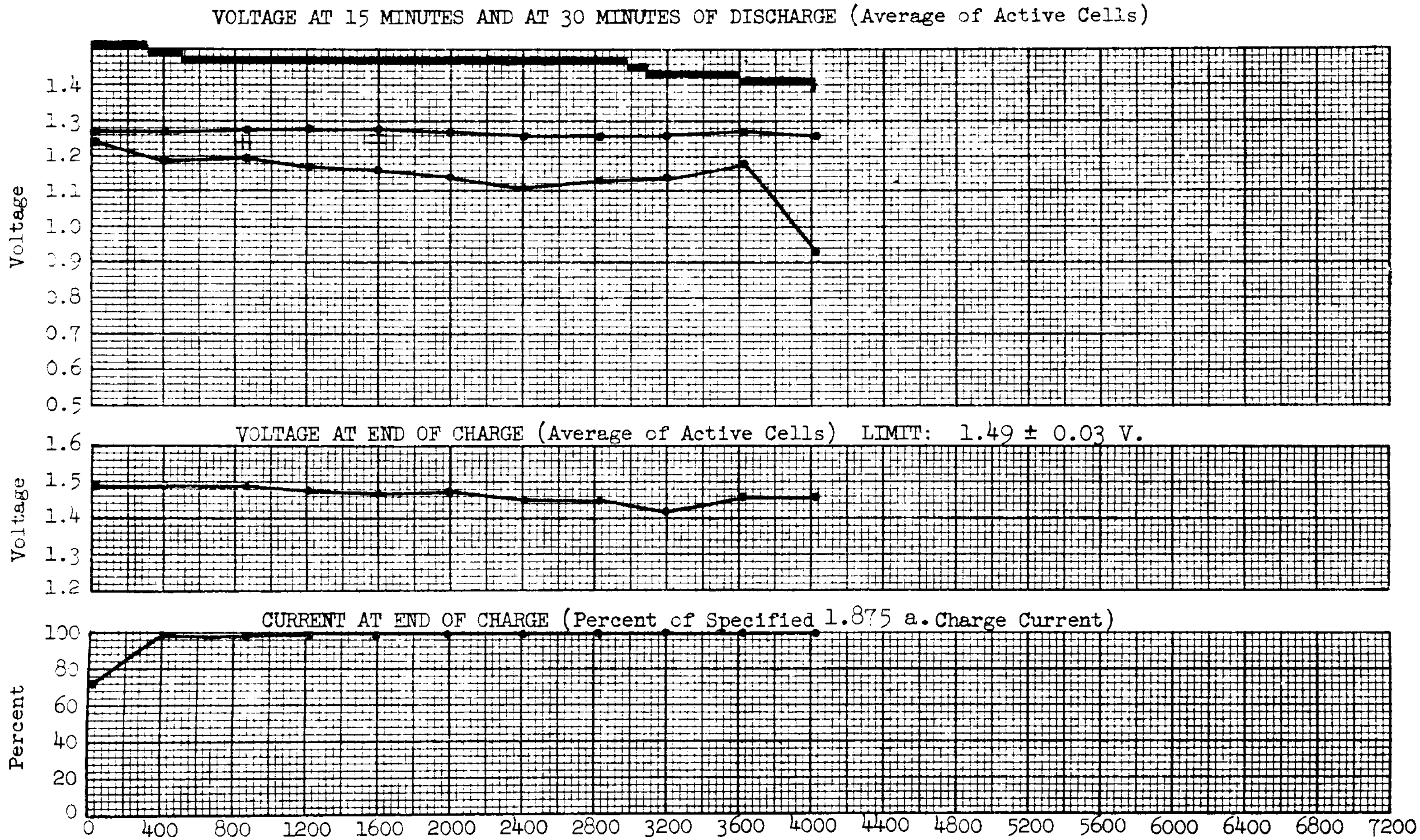
GULTON 6.0 a.h. (Pack 66)
Test Temperature: 0° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: Pack Failed: Cycle 4414

Notes

1. Cycles 4064: Capacity Check.

FIGURE 12(d) (Contd)



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

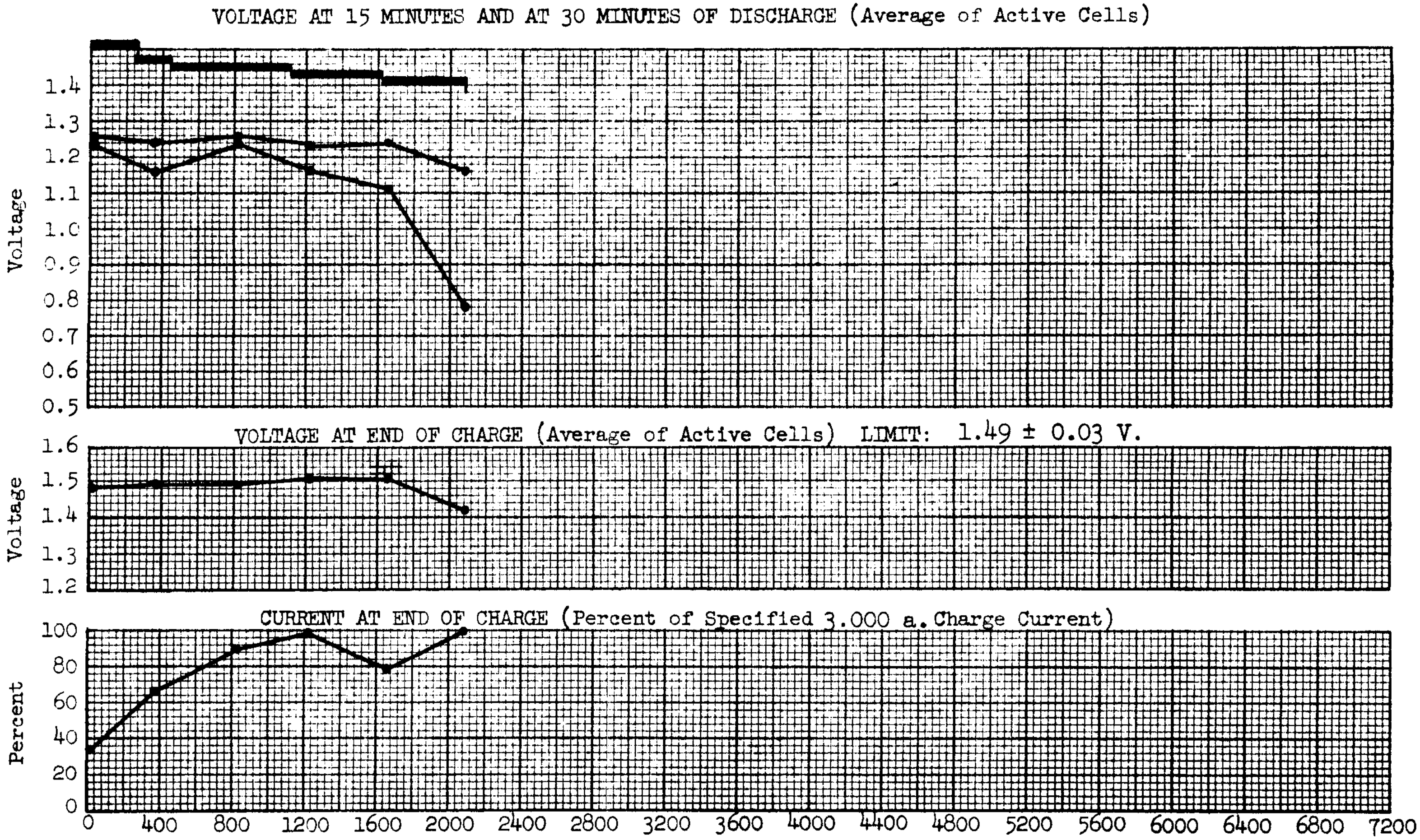
GULTON 6.0 a.h. (Pack 13)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: Pack Failed: Cycle 4021

Notes

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

FIGURE 12(e)



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

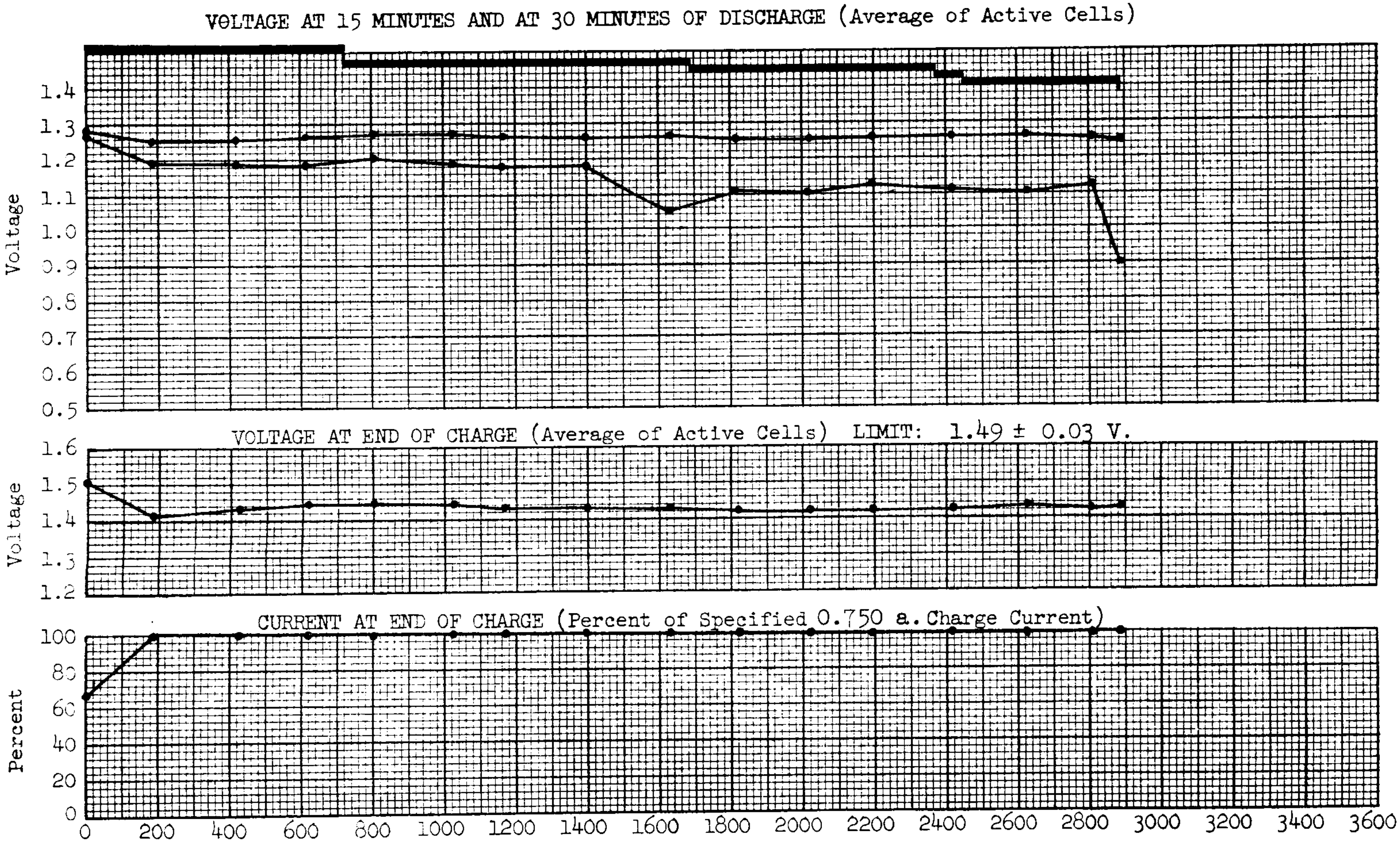
GULTON 6.0 a.h. (Pack 14)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 40%

Status: Pack Failed: Cycle 2086

Notes

1. Cycle 1368: Capacity Check.

FIGURE 12(f)



Cell Number	Cycle Failed
1823, 1862	721
2348	1688
1757	2375
1598	2449
2347	2885

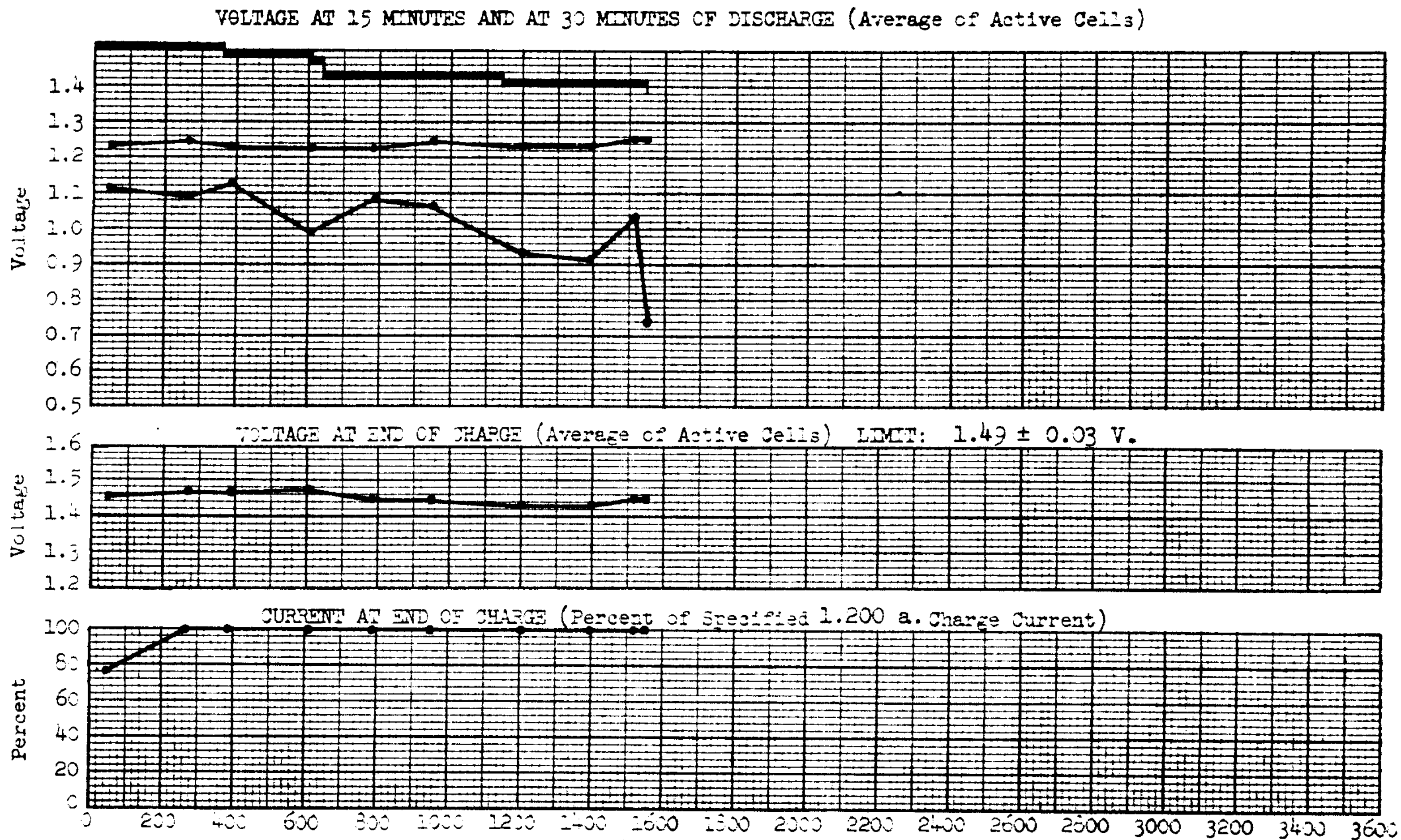
GULTON 6.0 a.h. (Pack 17)
Test Temperature: 25° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: Pack Failed: Cycle 2885

Notes

1. Cycles 702, 1317, 2075, 2711: Capacity Check.

FIGURE 12(g)



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

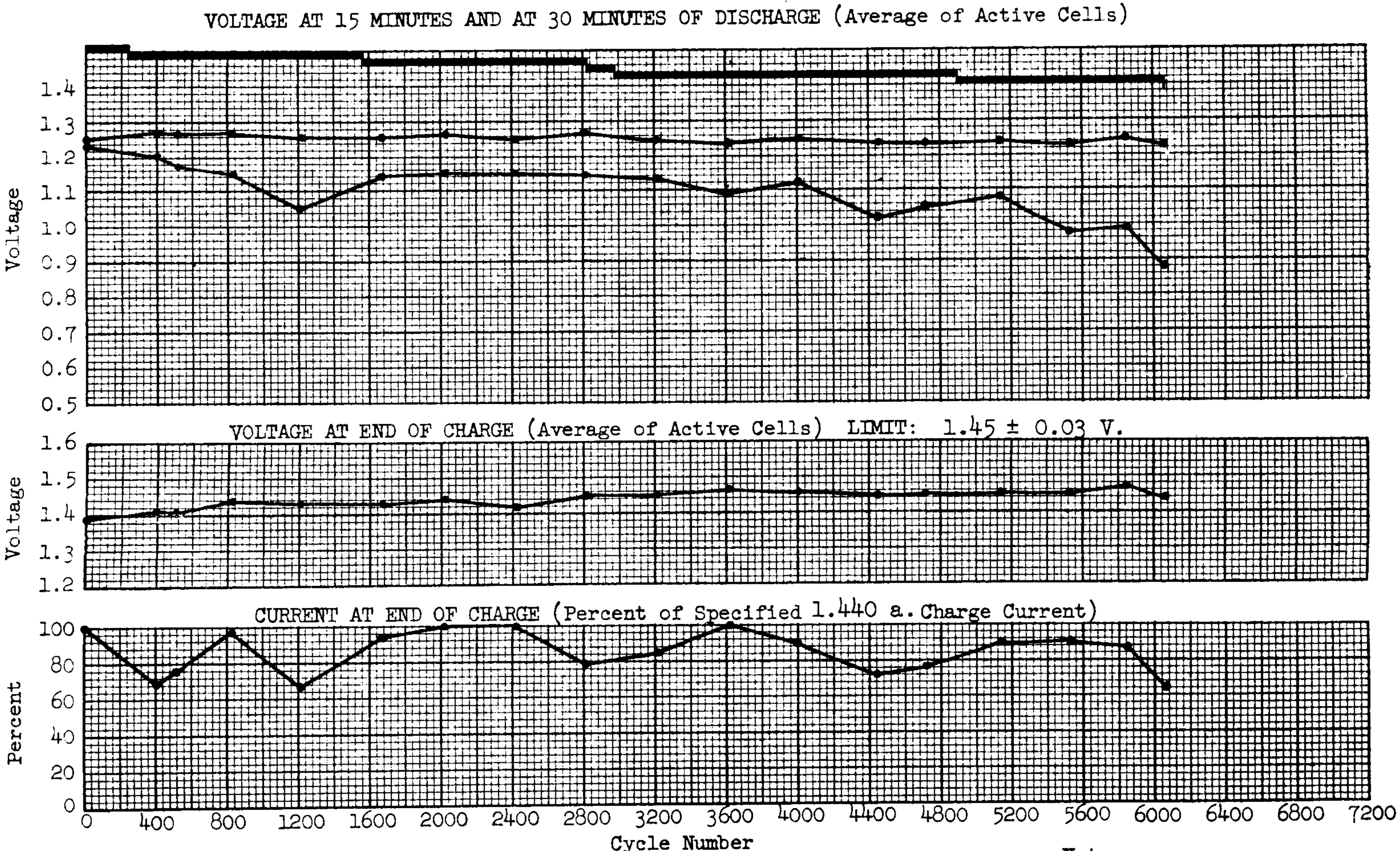
GULTON 6.0 a.h. (Pack 18)
Test Temperature: 25° C
Orbit Period: 3 hours
Depth of Discharge: 40%

Status: Pack Failed: Cycle 1550

Notes

1. Cycles 637, 1357: Capacity Check.

FIGURE 12(h)



Cell Number	Cycle Failed
1764	238
1784	1566
1802	2819
2333	2981
1769	4897
1814	6064

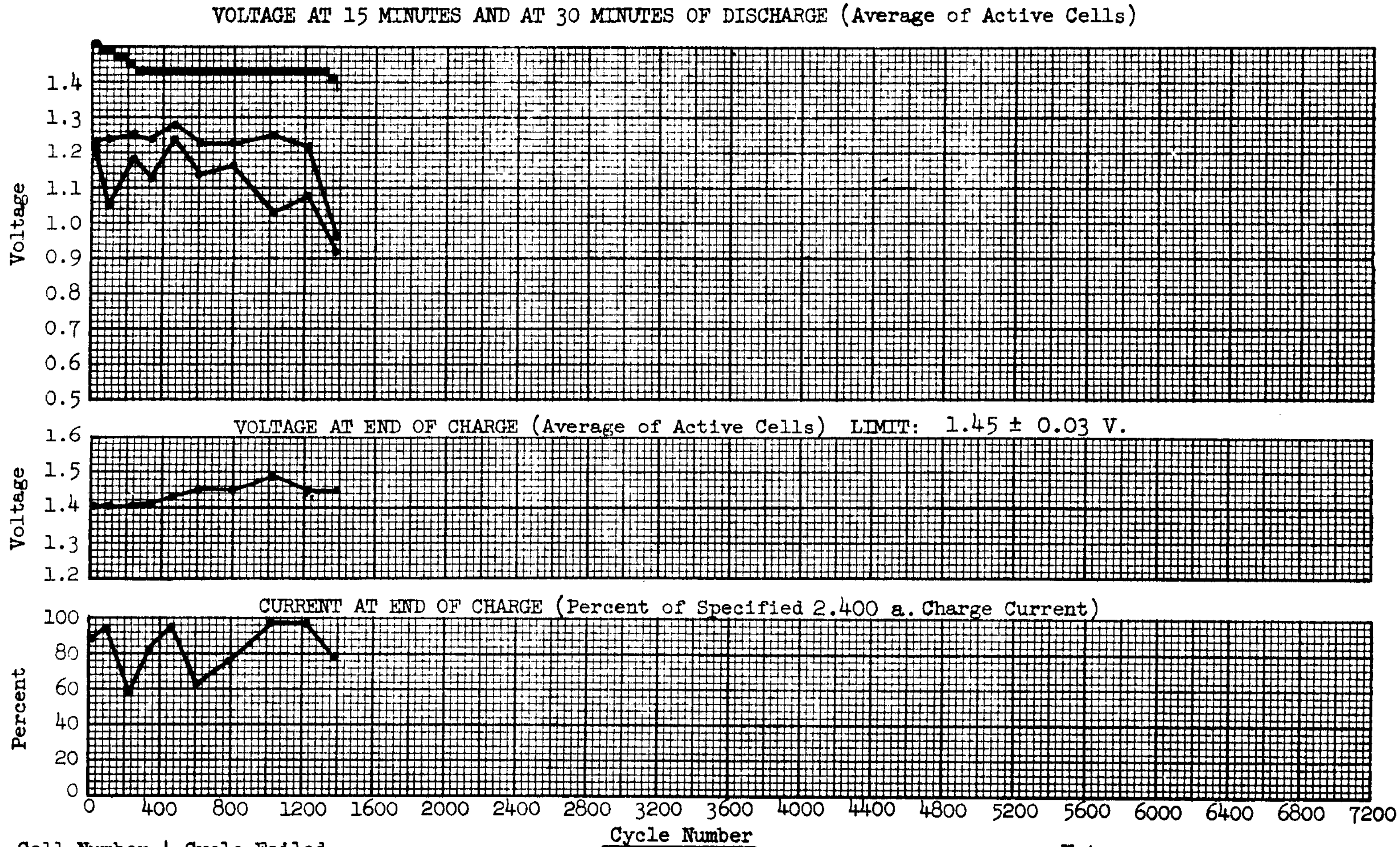
GULTON 6.0 a.h. (Pack 37)
Test Temperature: 50° - 40° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

Status: Pack Failed: Cycle 6064

Notes

1. Cycle 239: Changed to 40° C.
2. Cycle 527: Voltage limit raised to 1.45 V/cell.
3. Cycles 1441, 2819, 3810, 4988: Capacity Check.

FIGURE 12(i)



Cell Number	Cycle Failed
1454	37
1815	114
1853	187
1627	225
2405	1333
1625	1377

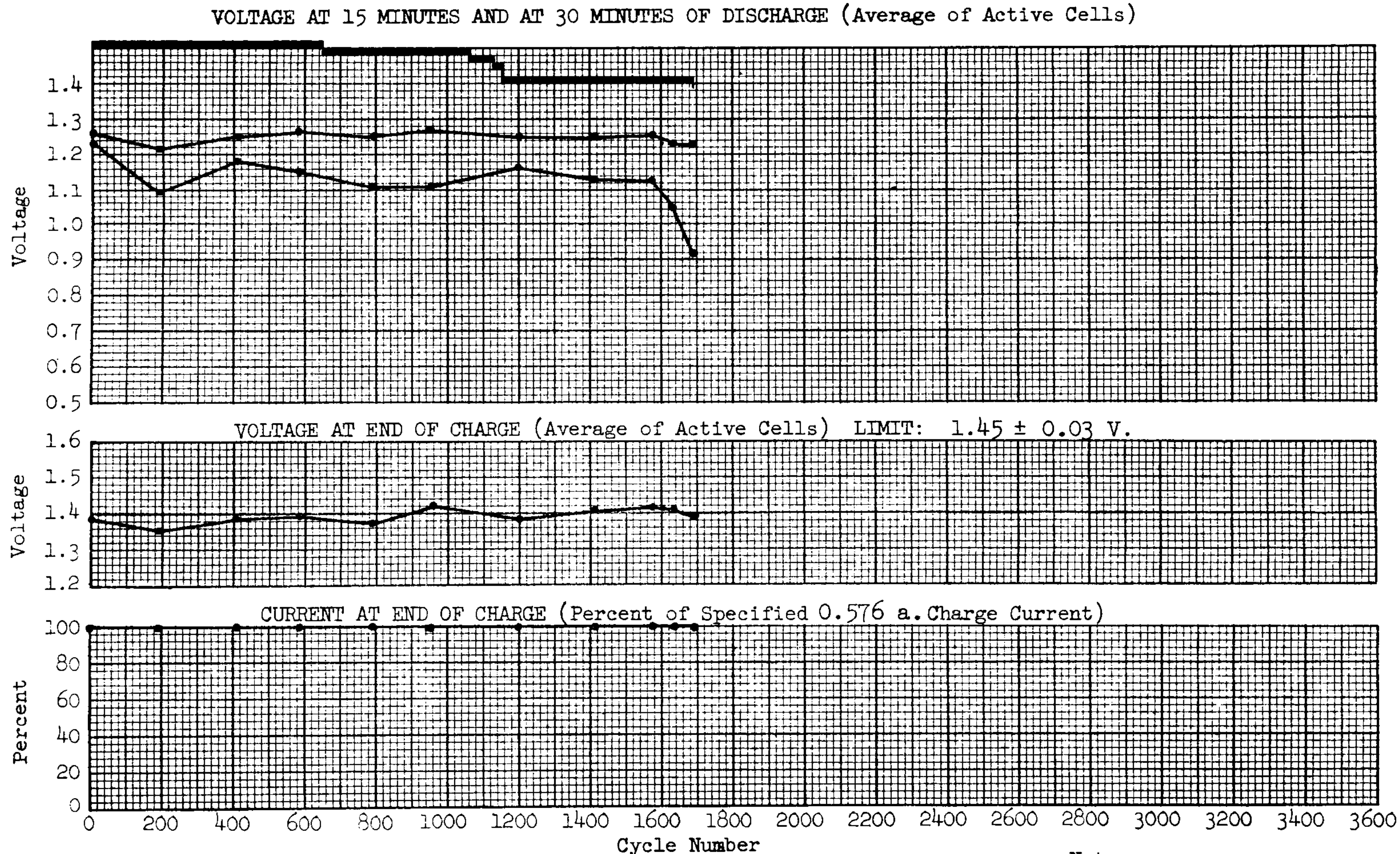
GULTON 6.0 a.h. (Pack 38)
Test Temperature: 50° - 40° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

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 12(j)



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

GULTON 6.0 a.h. (Pack 41)

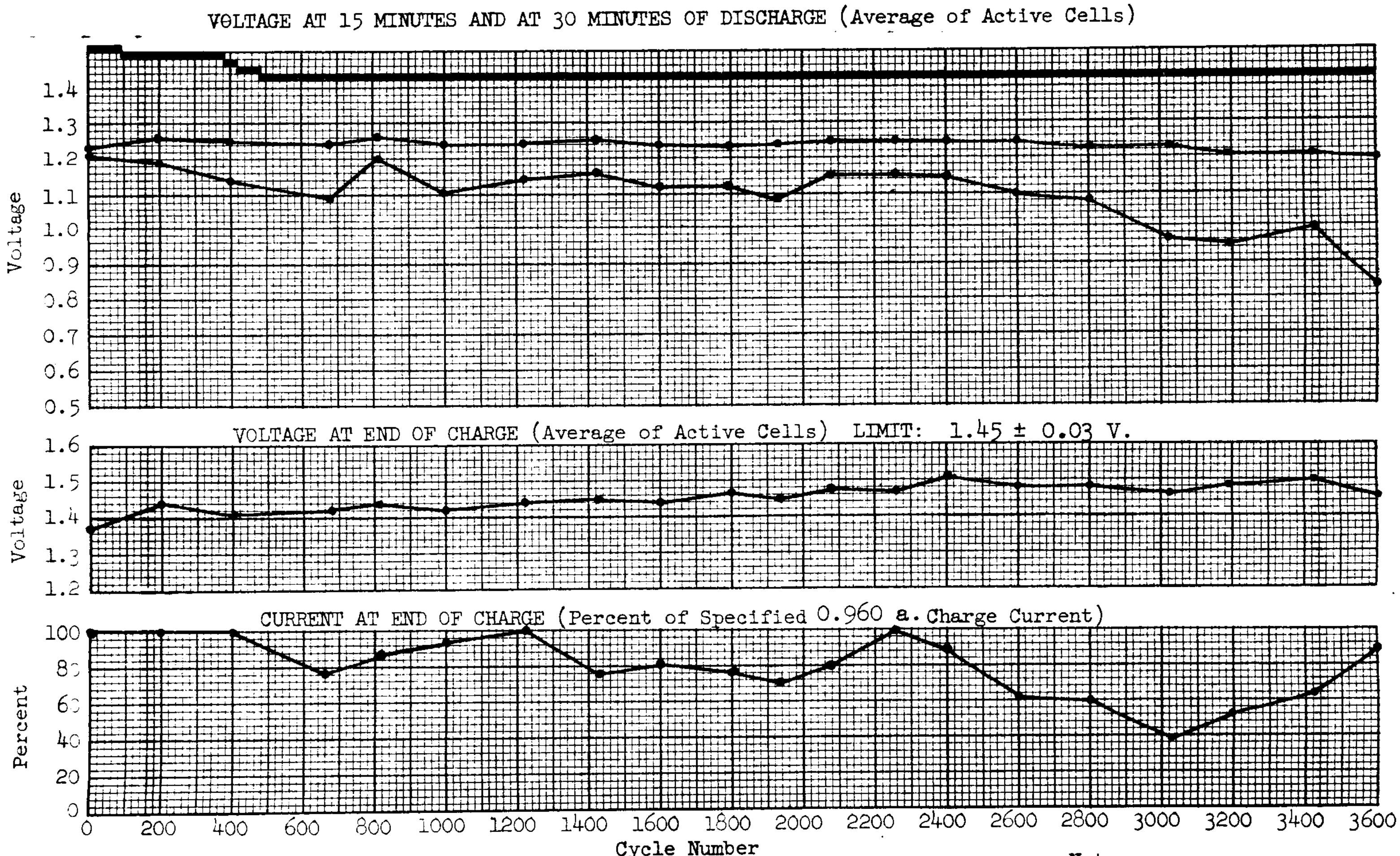
Test Temperature: 50° - 40° C
Orbit Period: 3 hours
Depth of Discharge: 15%

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 12(k)



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

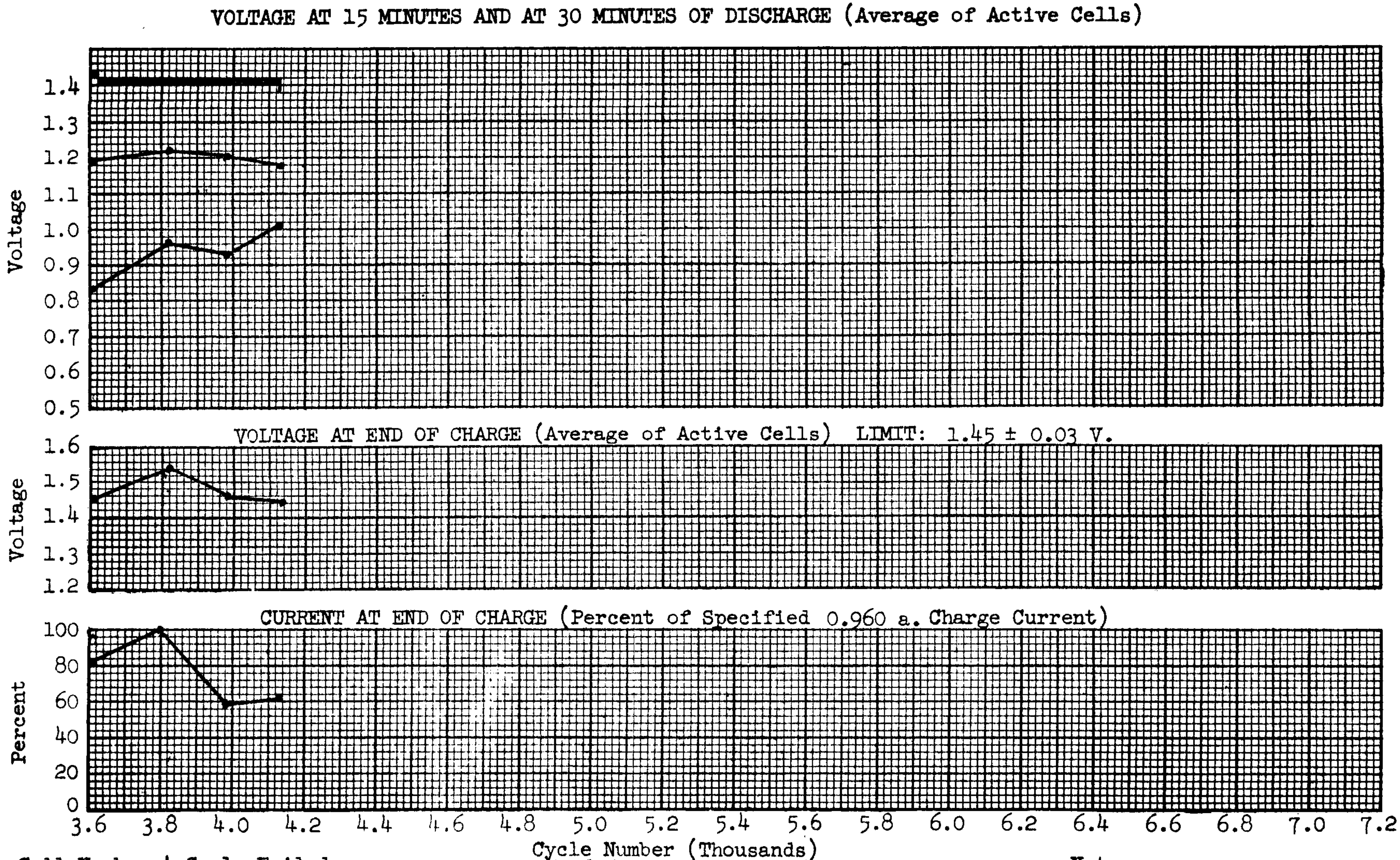
GULTON 6.0 a.h. (Pack 42)
Test Temperature: 50° - 40° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: Continued

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, 2817, 3460: Capacity Check.

FIGURE 12(1)



Cell Number	Cycle Failed
2340	3619
2334	4133

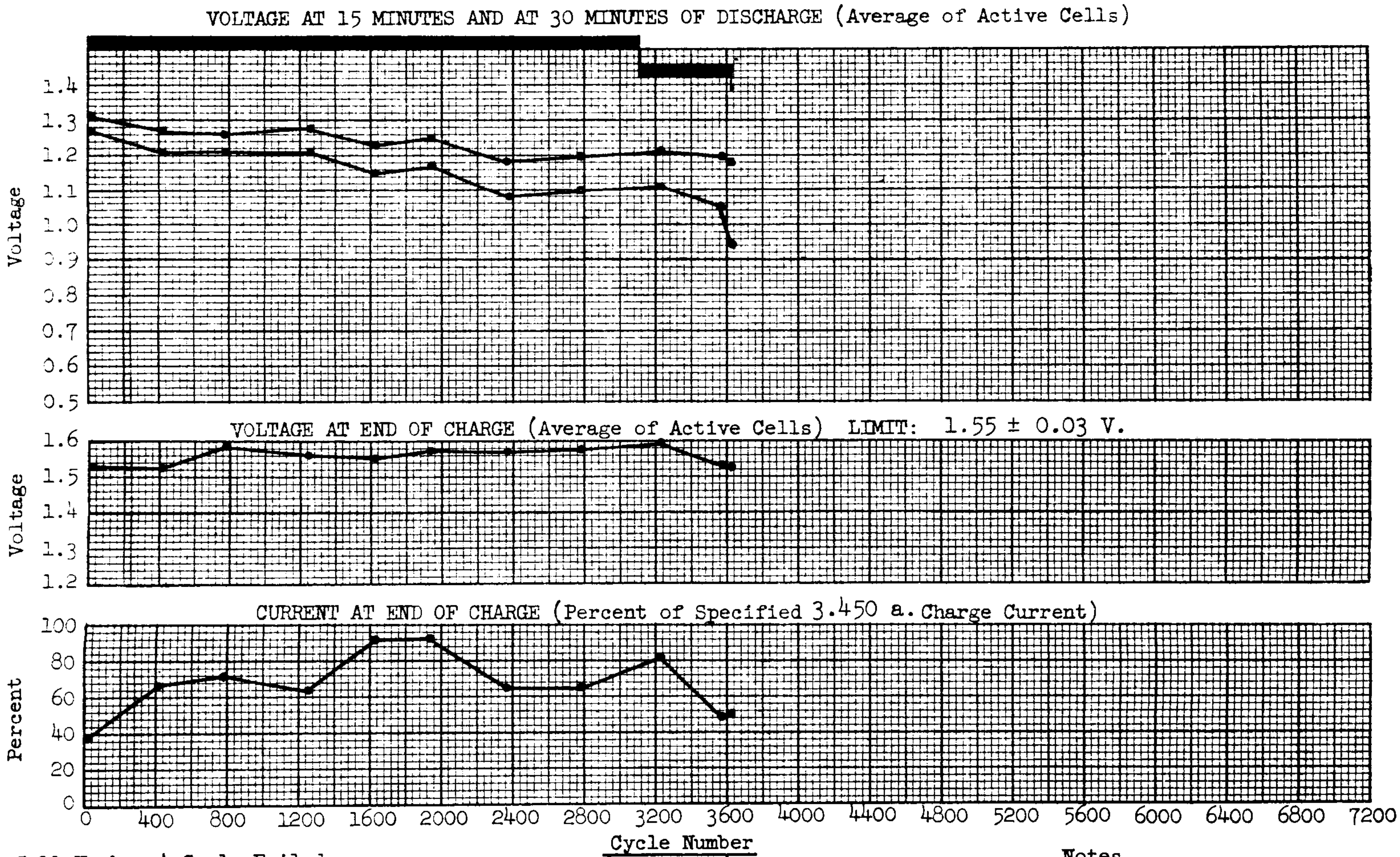
GULTON 6.0 a.h. (Pack 42)
Test Temperature: 50° -40° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: Pack Failed: Cycle 4133

Notes

1. Cycles 4106: Capacity Check.

FIGURE 12(1) (Contd)



Cell Number	Cycle Failed
435, 407	3111
438	3629

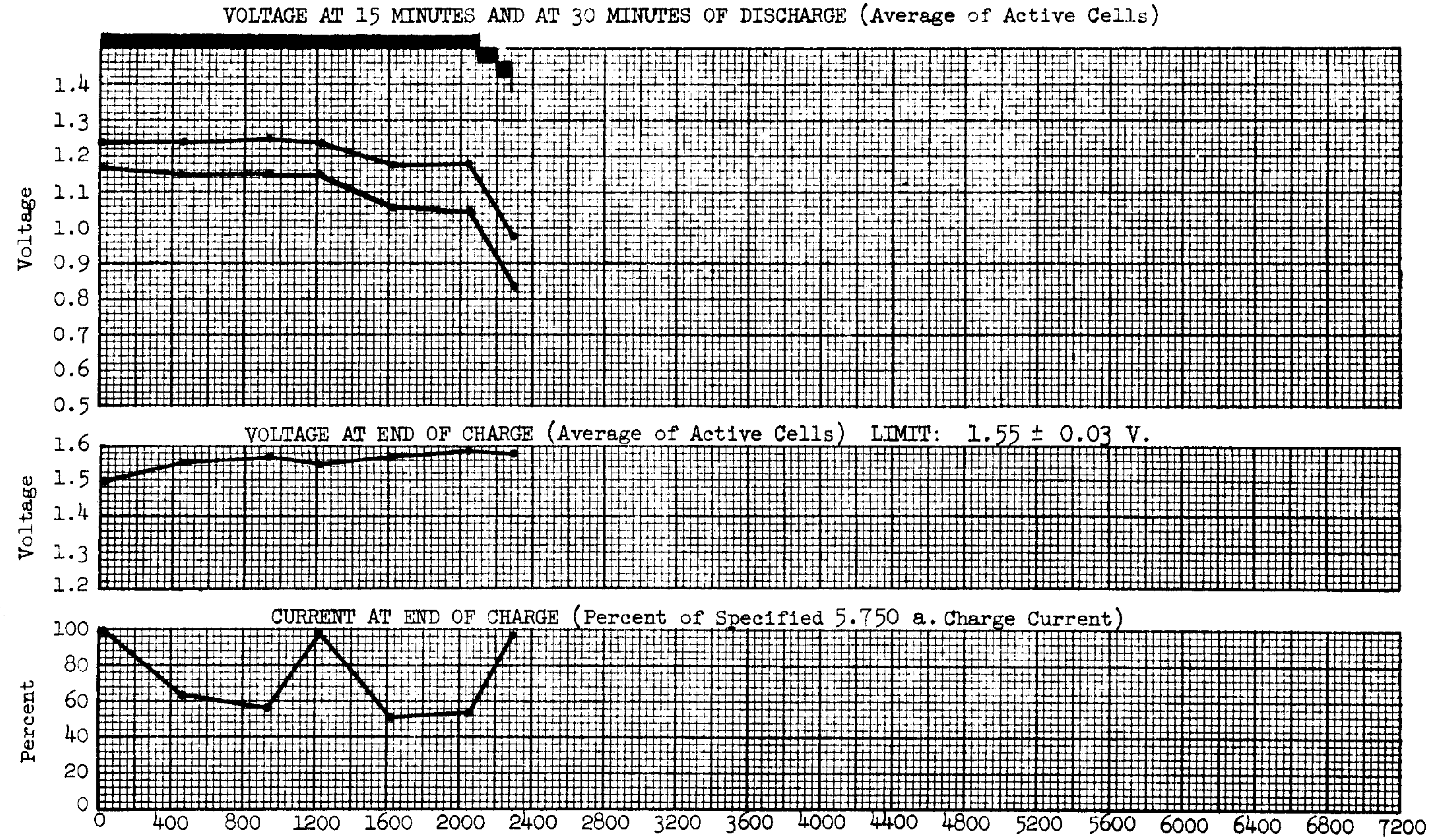
GULTON 20 a.h. (Pack 101)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

Status: Pack Failed: Cycle 3629

Notes

1. Cycles 1406, 3024: Capacity Check.

FIGURE 13(a)



Cell Number	Cycle Failed
490	2107
508	2203
467	2291

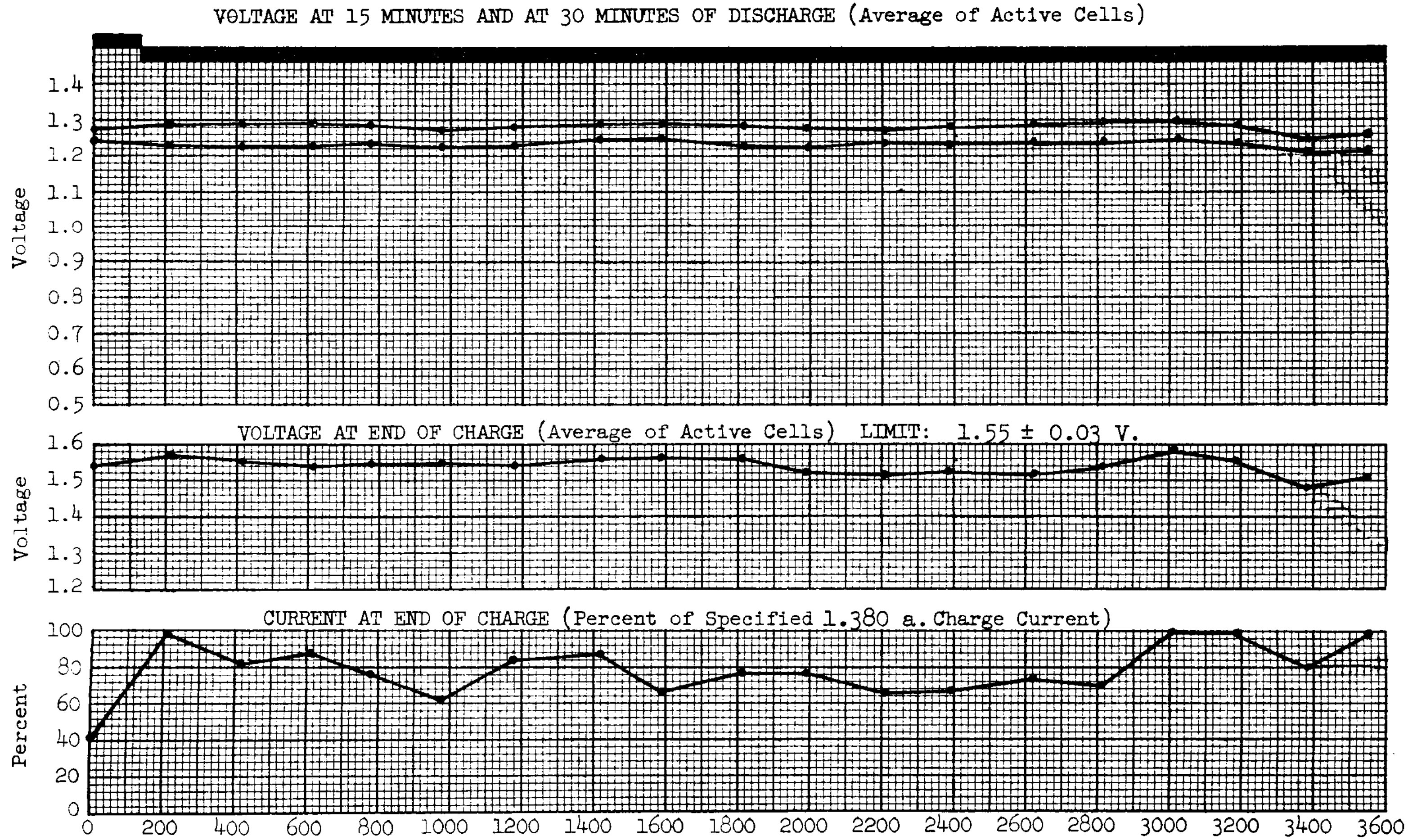
GULTON 20 a.h. (Pack 115)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: Pack Failed: Cycle 2291

Notes

1. Cycle 1408: Capacity Check.

FIGURE 13(b)



Cell Number	Cycle Failed
449	135

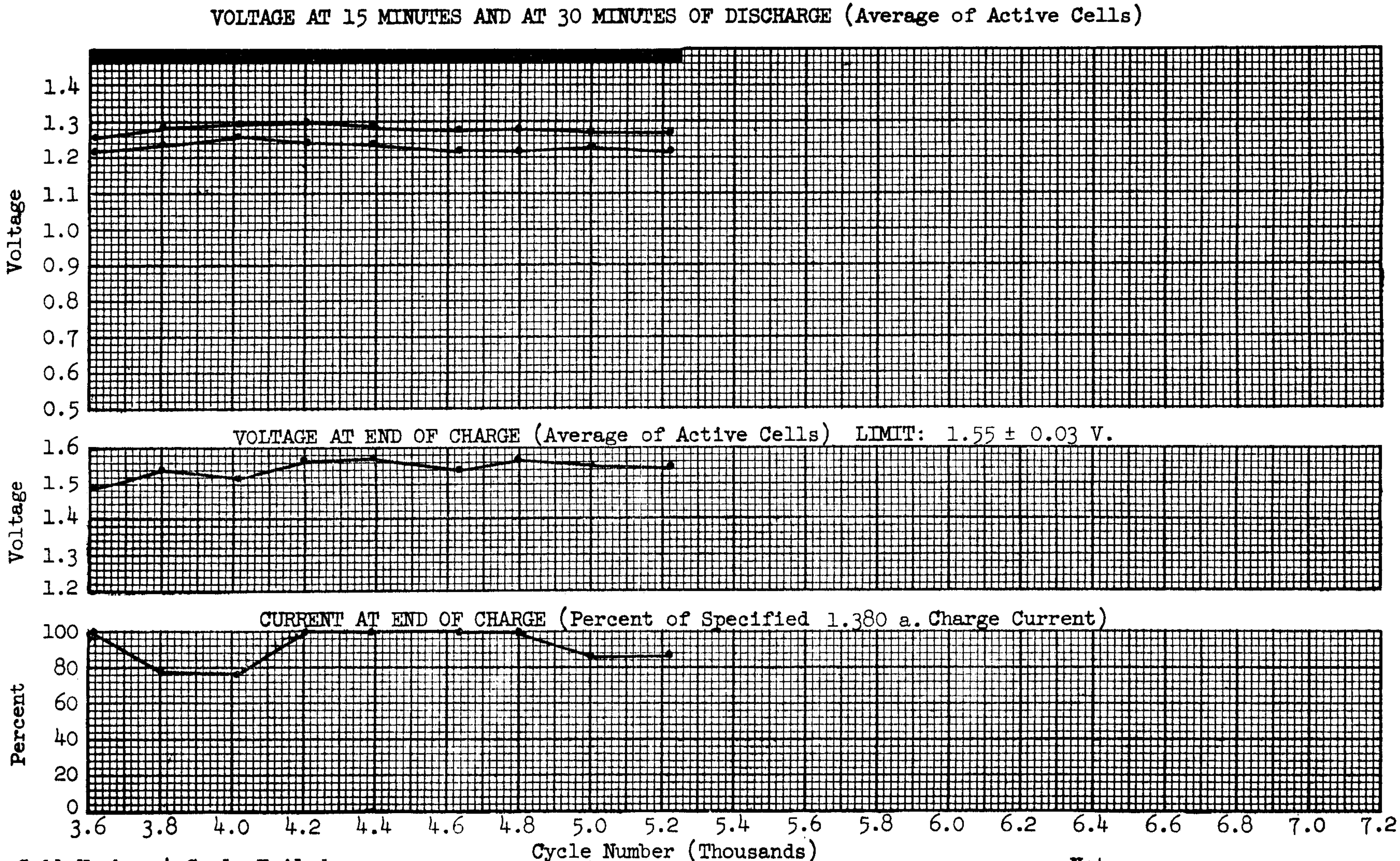
GULTON 20 a.h. (Pack 102)
Test Temperature: 0° C
Orbit Period: 3 hours
Depth of Discharge: 15%

Status: Continued

Notes

1. Cycles 716, 1437, 2104, 2839, 3536: Capacity Check.

FIGURE 13(c)



Cell Number	Cycle Failed

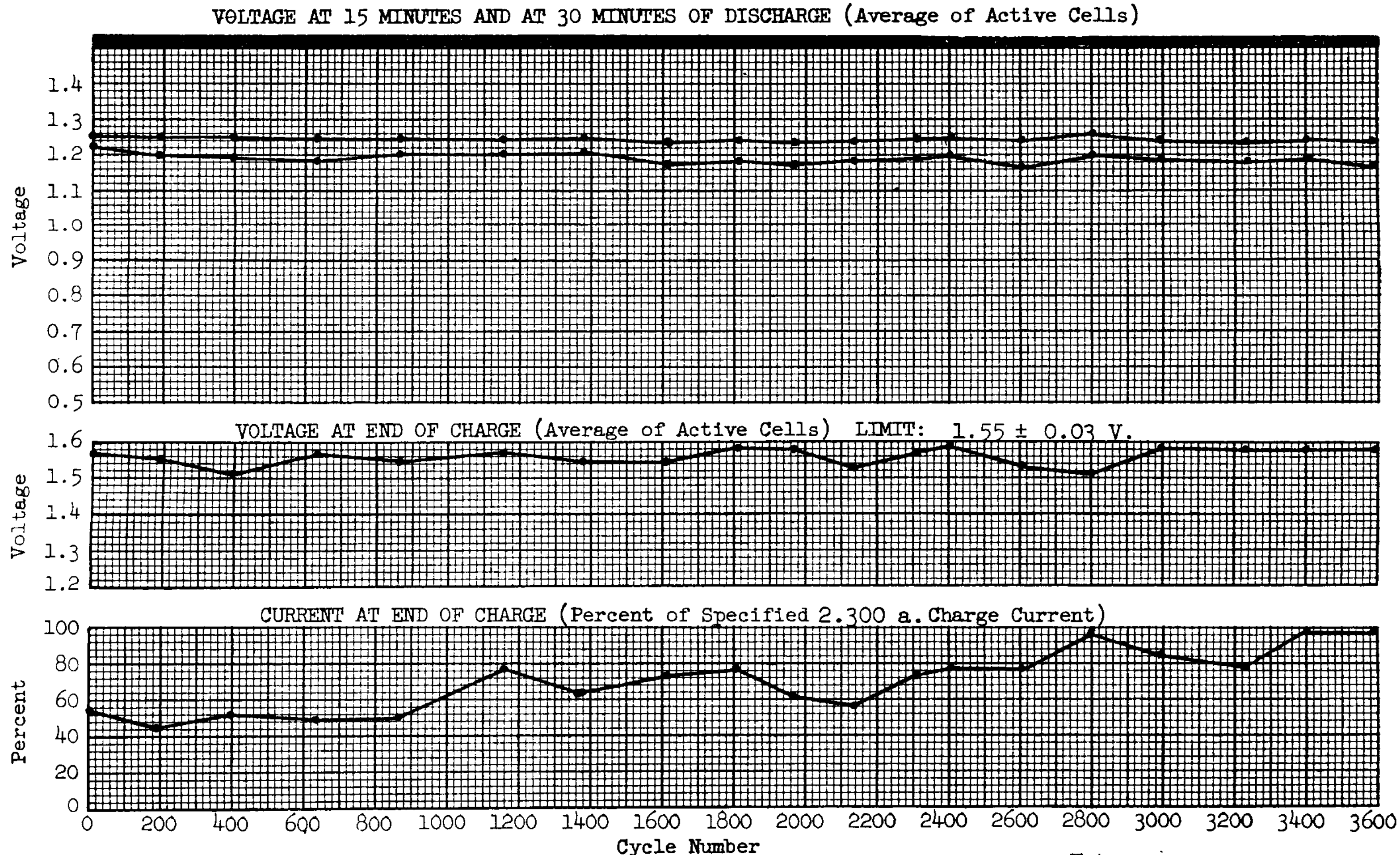
GULTON 20 a.h. (Pack 102)
Test Temperature: 0° C
Orbit Period: 3 hours
Depth of Discharge: 15%

Status: 4 cells cycling after 5255 cycles.

Notes

1. Cycles 4364, 4971: Capacity Check.

FIGURE 13(c) (Contd)



Cell Number	Cycle Failed

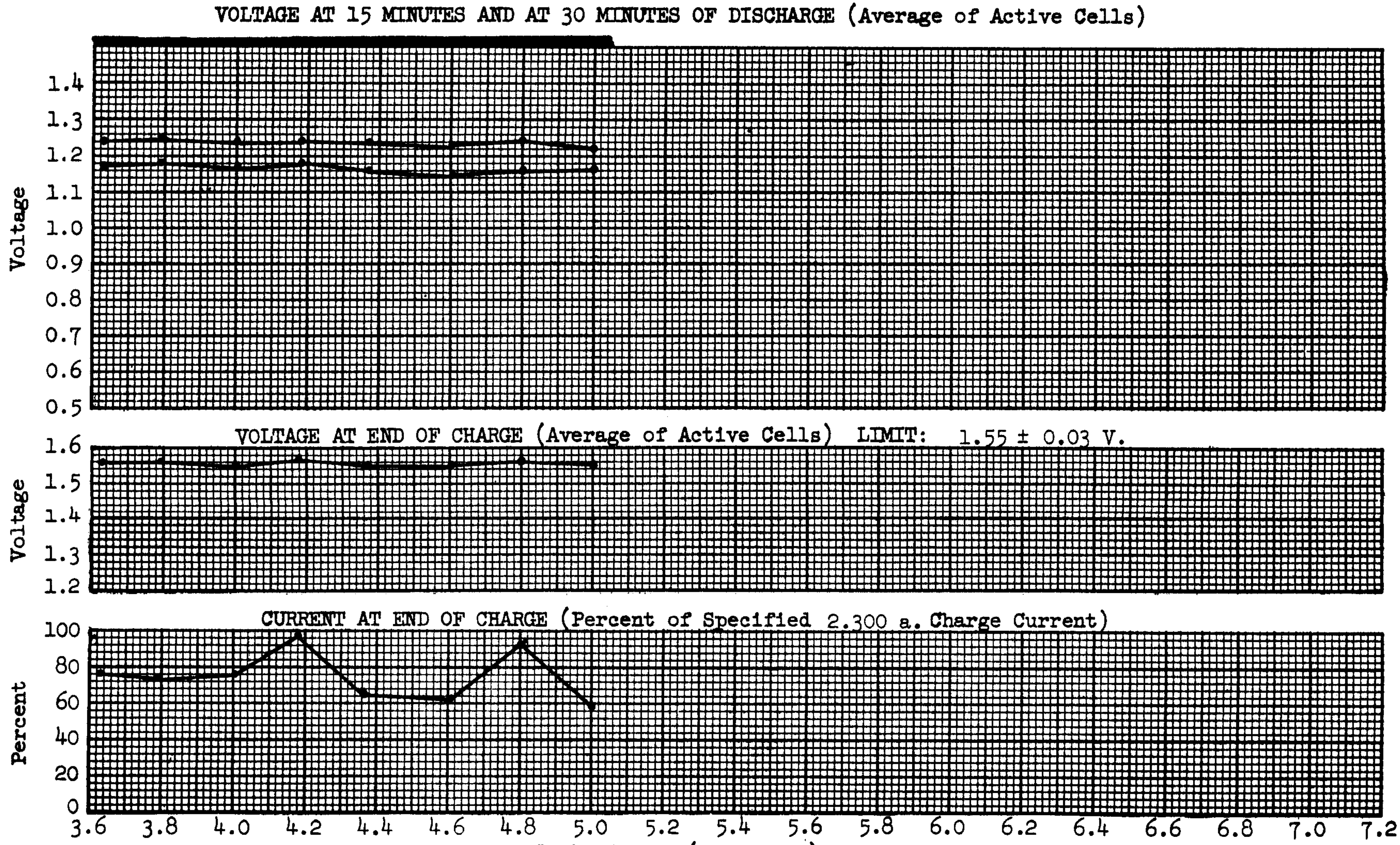
GULTON 20 a.h. (Pack 116)
Test Temperature: 0° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: Continued

Notes

1. Cycles 760, 1357, 2017, 2750, 3393: Capacity Check.

FIGURE 13(d)



Cell Number	Cycle Failed

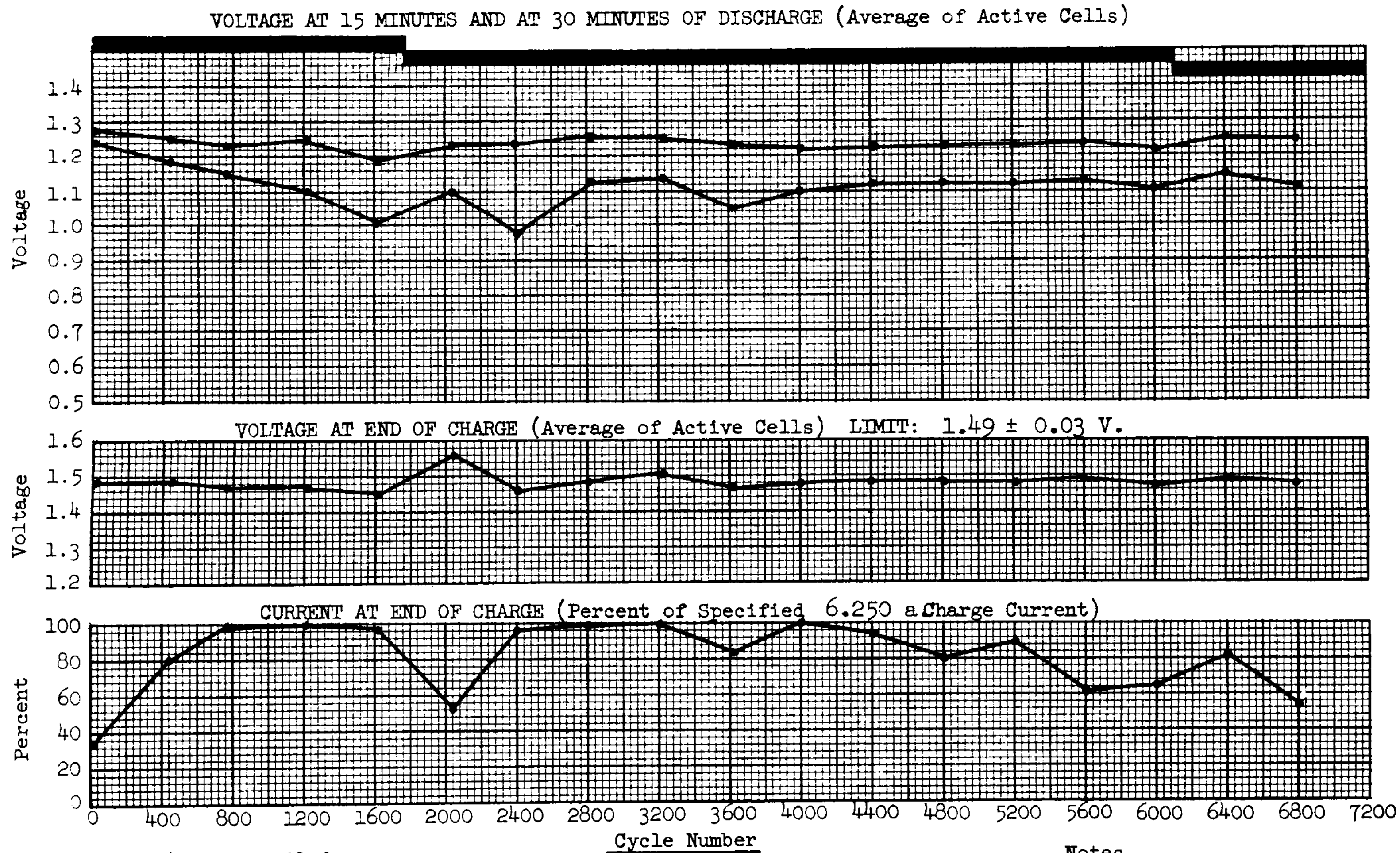
GULTON 20 a.h. (Pack 116)
Test Temperature: 0° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: 5 cells cycling after 5097 cycles.

Notes

1. Cycles 4147, 4703: Capacity Check.

FIGURE 13(d) (Contd)



Cell Number	Cycle Failed
396	1776
387	6120

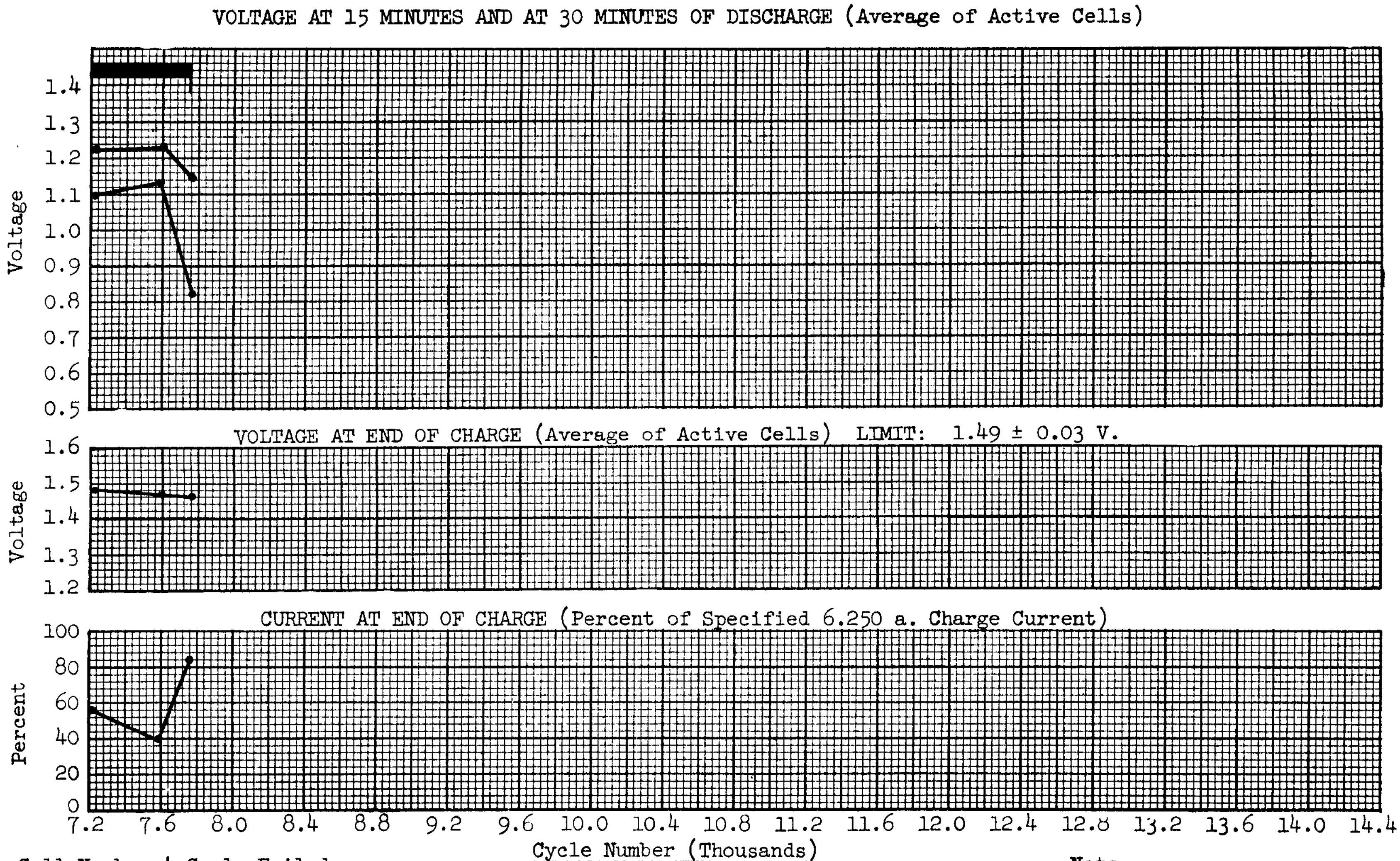
GULTON 20 a.h. (Pack 73)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: Continued

Notes

1. Cycles 1358, 2663, 4242, 5670, 6679: Capacity Check.

FIGURE 13(e)



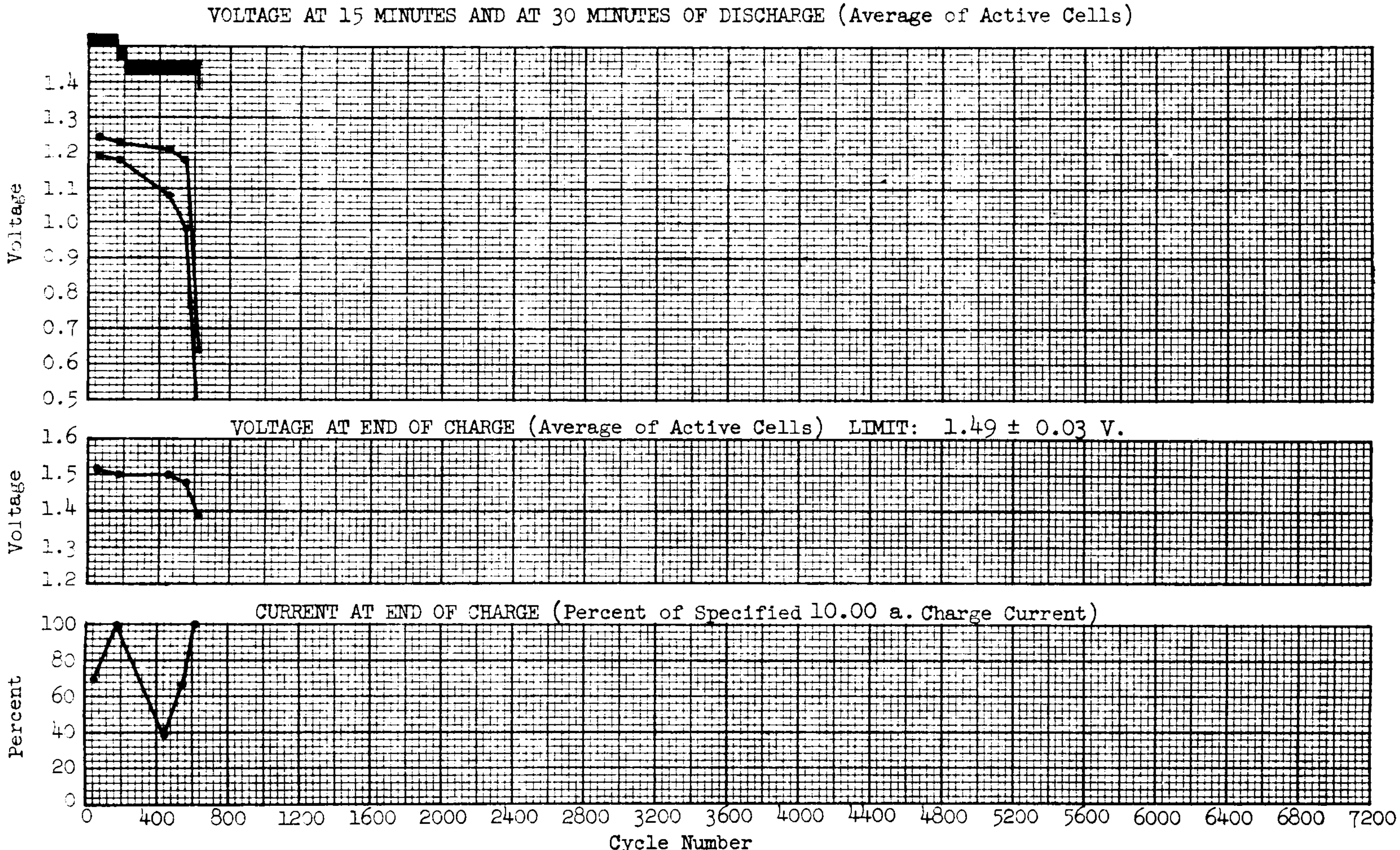
Cell Number	Cycle Failed
465	7763

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

Notes

Status: Pack Failed: Cycle 7763

FIGURE 13(e) (Contd)



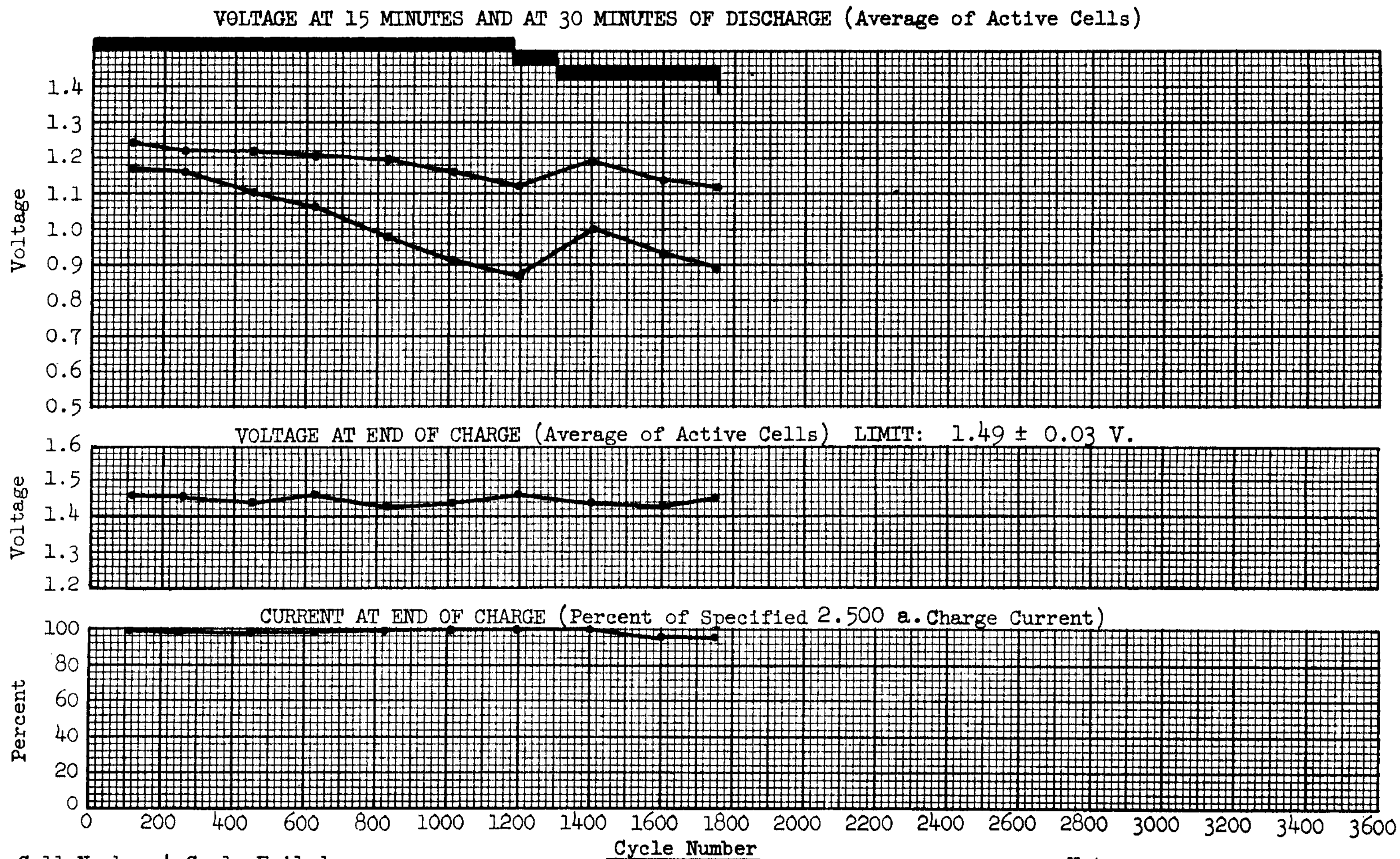
Cell Number	Cycle Failed
468	163
388	208
386, 394 & 454	627

GULTON 20 a.h. (Pack 87)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 40%

Status: Pack Failed: Cycle 627

Notes

FIGURE 13(f)



Cell Number	Cycle Failed
458	1184
419	1302
440	1754

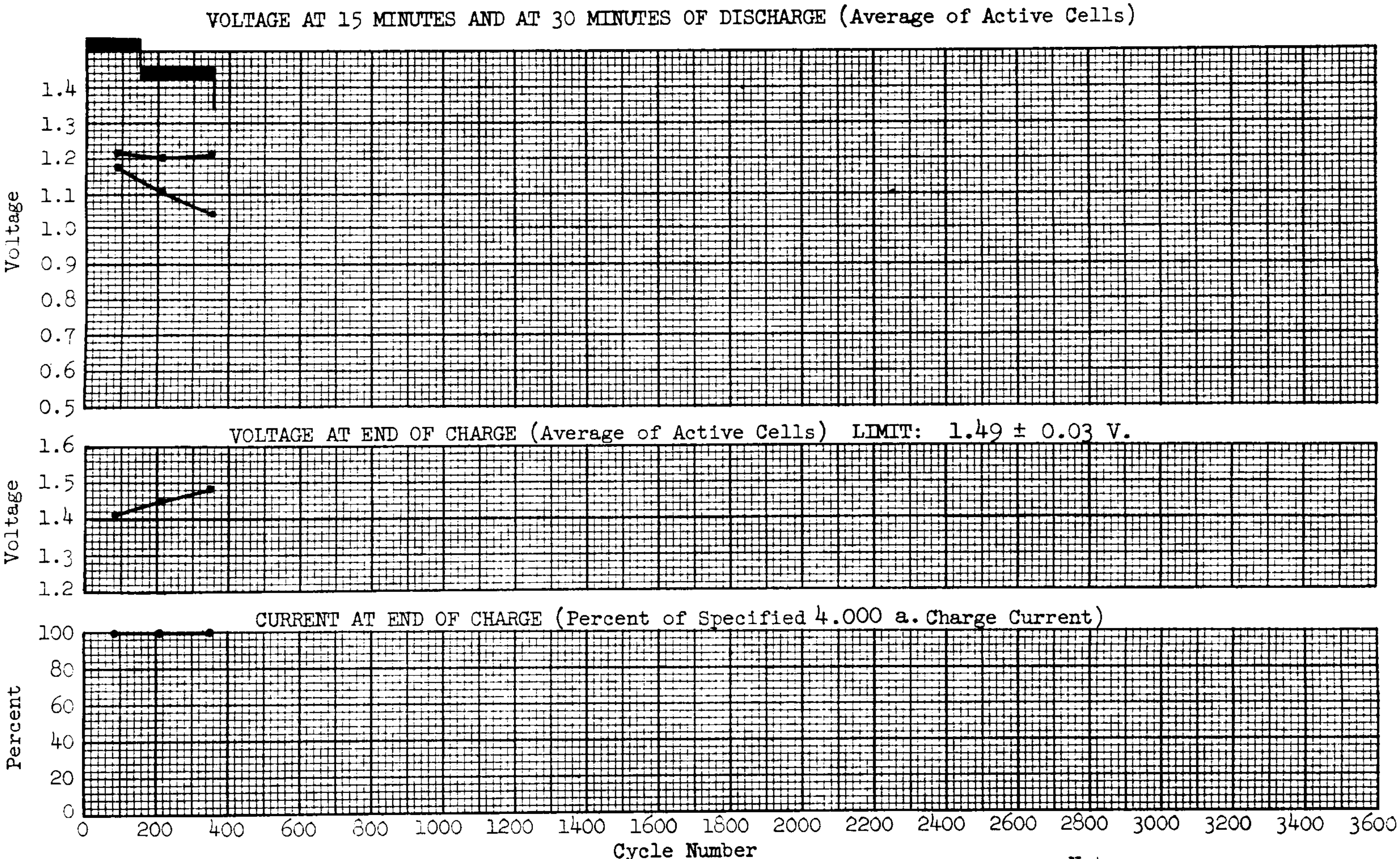
GULTON 20 a.h. (Pack 74)
Test Temperature: 25° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: Pack Failed: Cycle 1754

Notes

1. Cycles 739, 1427: Capacity Check.

FIGURE 13(g)



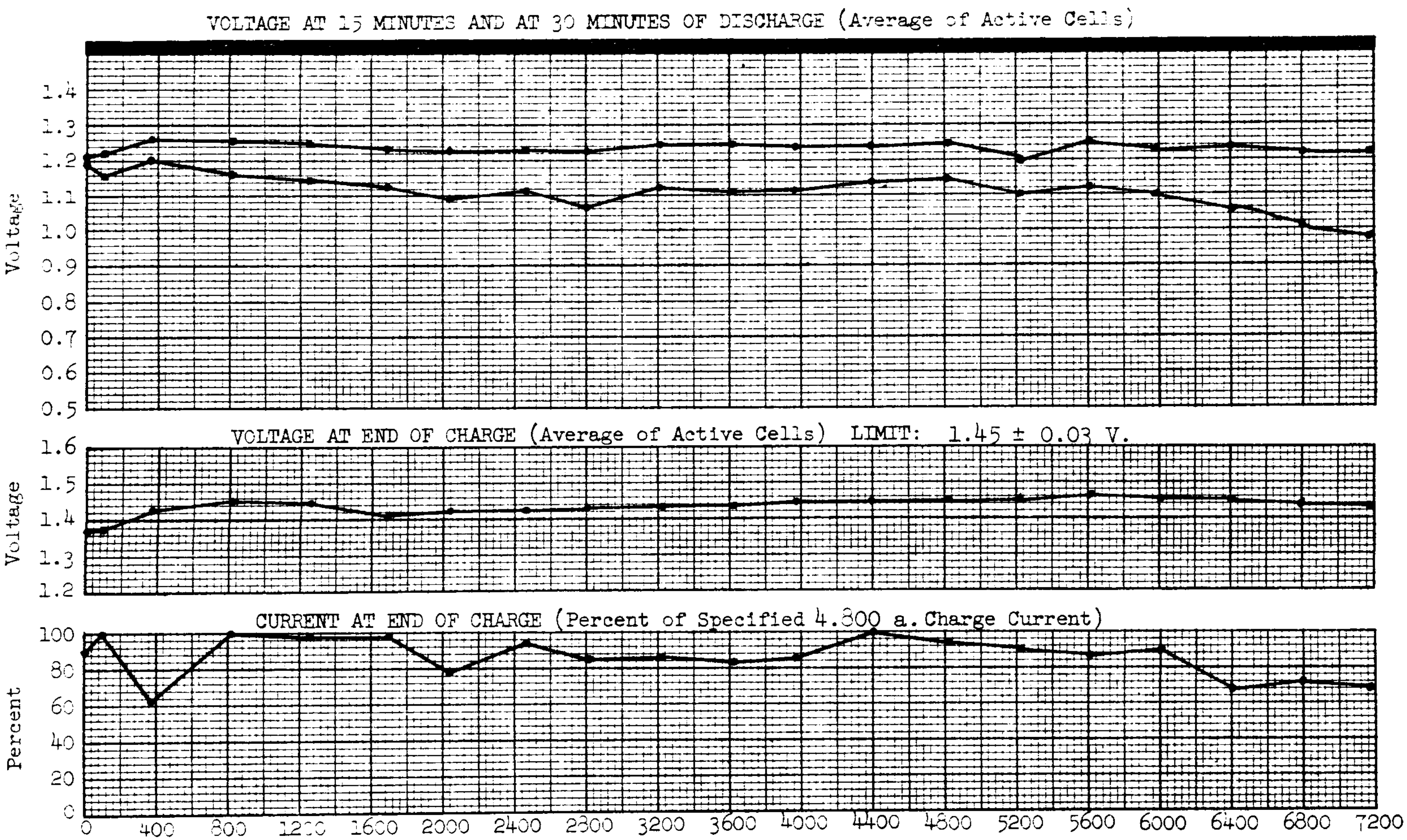
Cell Number	Cycle Failed
404, 422	151
466, 429	358

GULTON 20 a.h. (Pack 88)
Test Temperature: 25° C
Orbit Period: 3 hours
Depth of Discharge: 40%

Status: Pack Failed: Cycle 358

Notes

FIGURE 13(h)



Cell Number	Cycle Failed

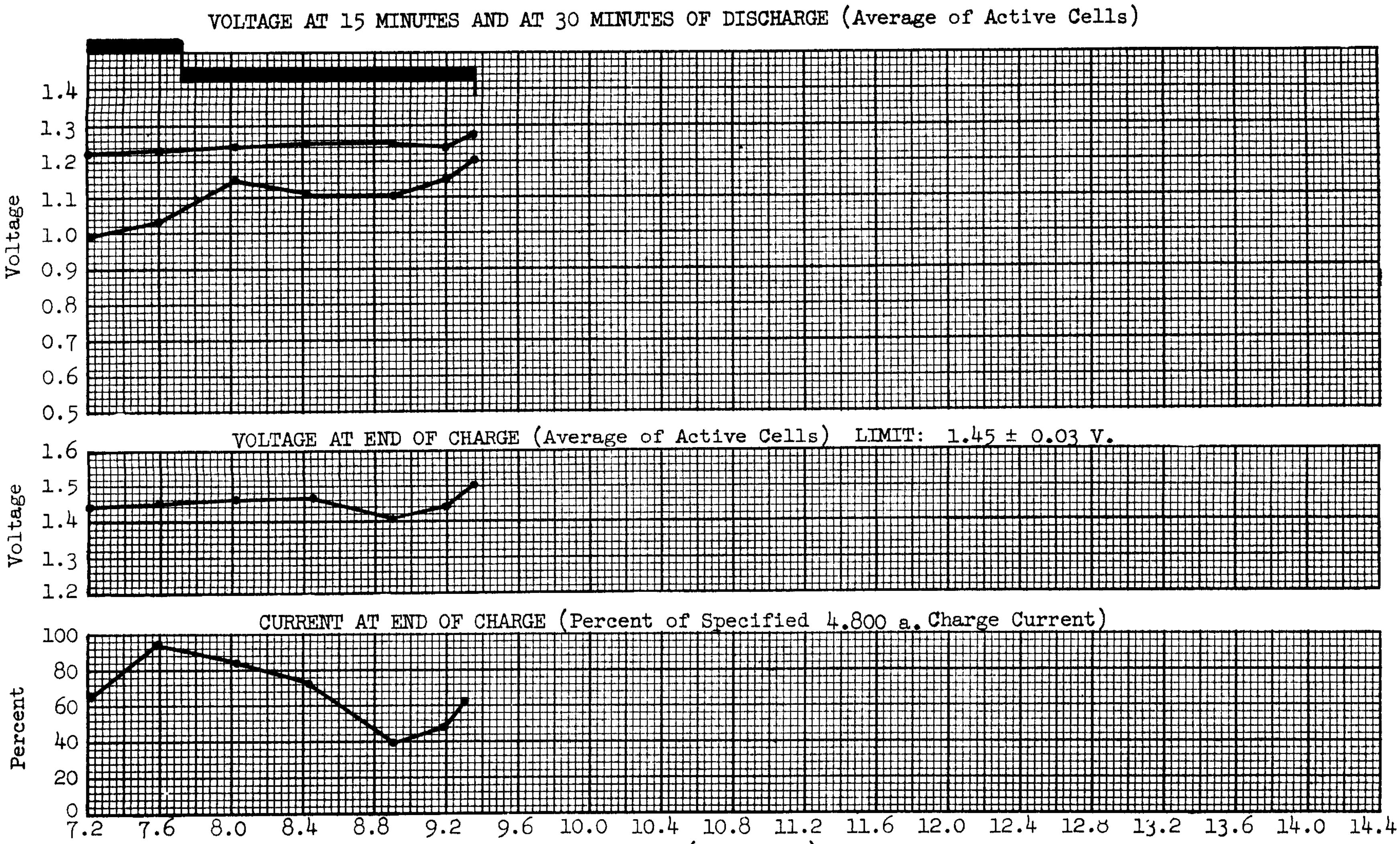
GULTON 20 a.h. (Pack 76)
Test Temperature: 50° - 40° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

Status: Continued

Notes

1. Cycle 172: Changed to 40° C.
2. Cycle 474: Voltage limit raised to 1.45 V/cell.
3. Cycles 1338, 2911, 4326, 5701, 7098: Capacity Check.

FIGURE 13(i)



Cell Number	Cycle Failed
453	7697
431	7698
455	9348

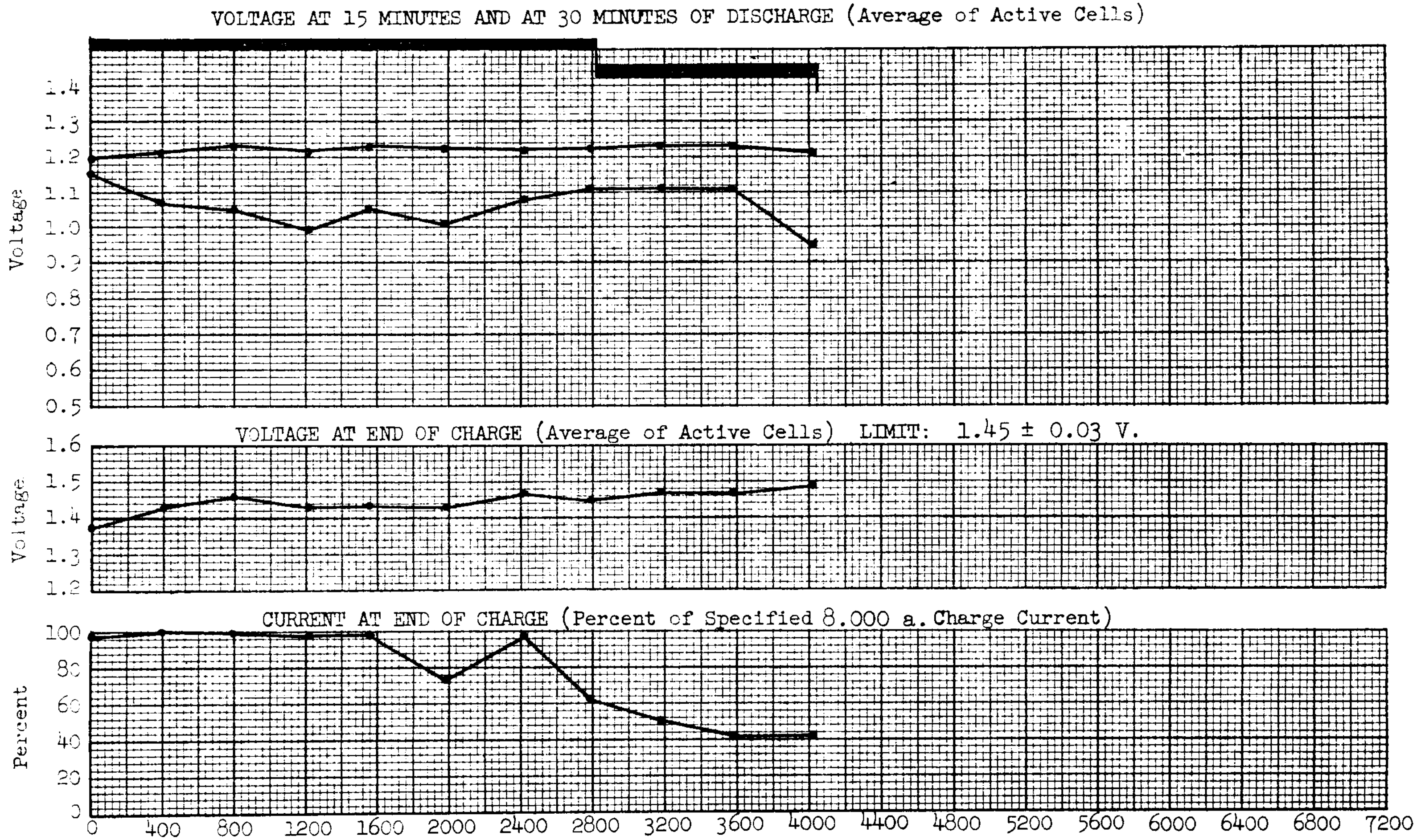
GULTON 20 a.h. (Pack 76)
Test Temperature: 50°-40° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

Status: Pack Failed: Cycle 9348

Notes

1. Cycles 8507: Capacity Check.

FIGURE 13(i) (Contd)



Cell Number	Cycle Failed
452, 457	2824
378	4045

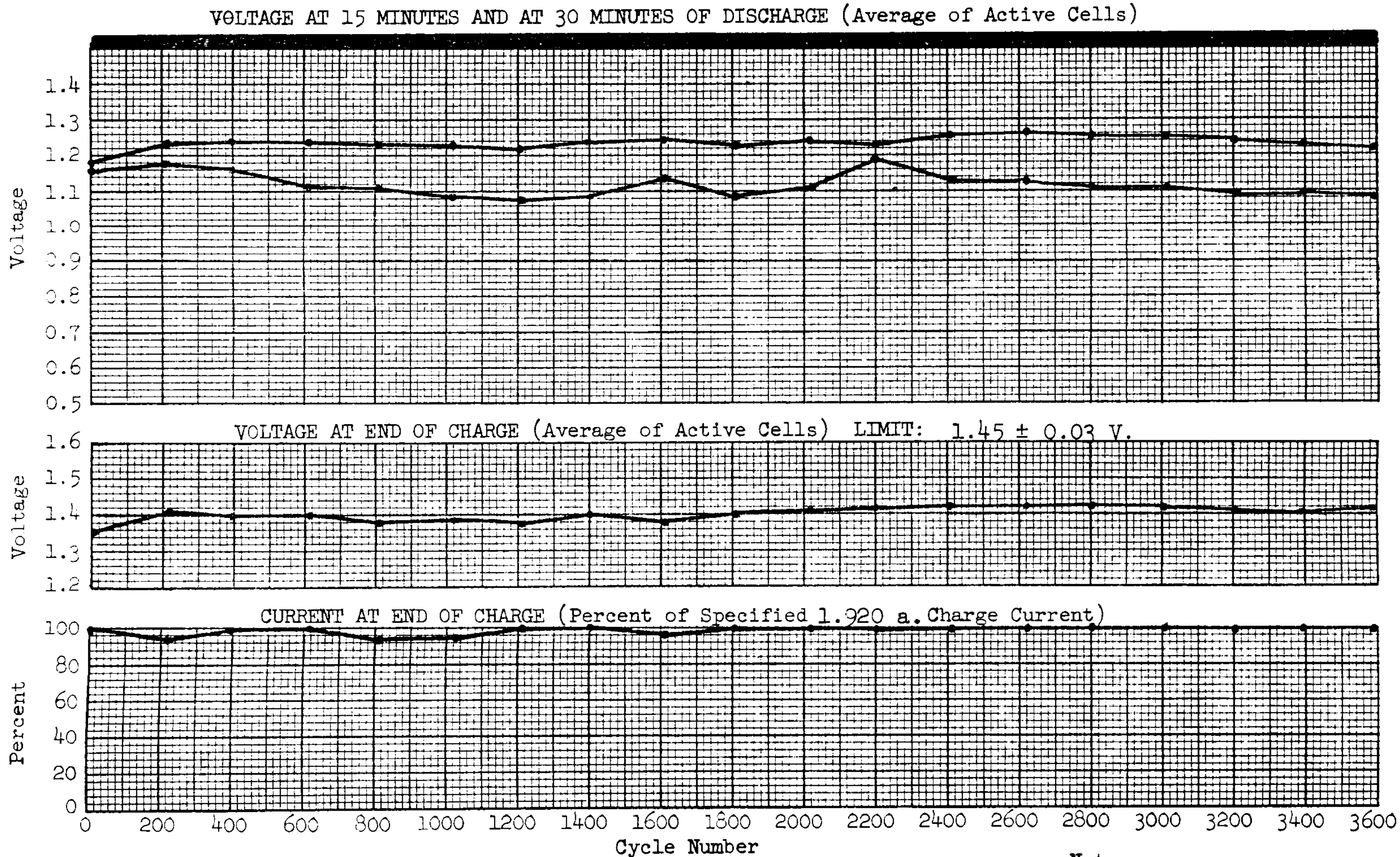
GULTON 20 a.h.
Test Temperature: 50° - 40° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

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 13(j)



Cell Number	Cycle Failed

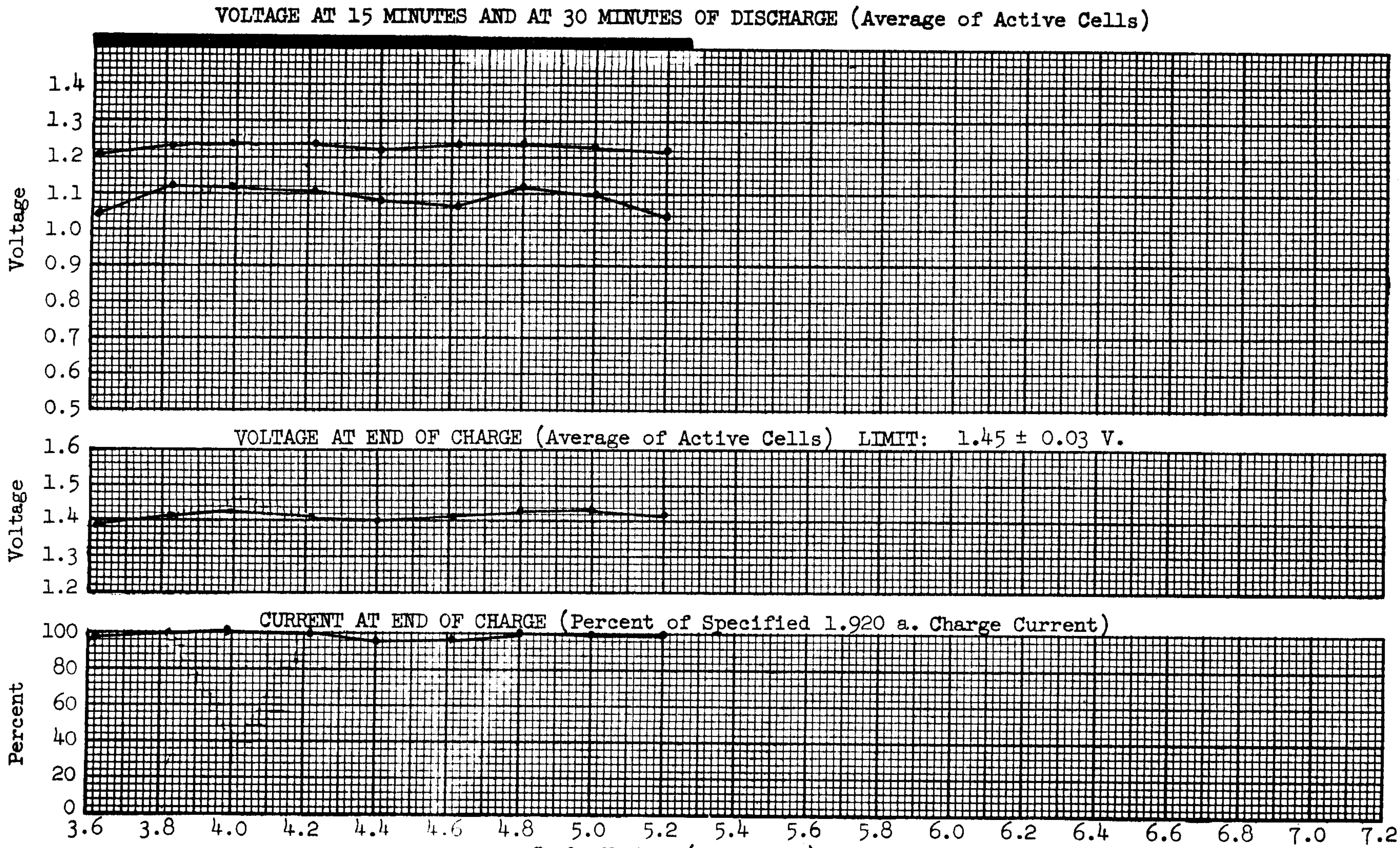
GULTON 20 a.h. (Pack 77)
Test Temperature: 50° - 40° C
Orbit Period: 3 hours
Depth of Discharge: 15%

Status: Continued

Notes

1. Cycle 71: Changed to 40° C.
2. Cycle 231: Voltage limit raised to 1.45 V/cell.
3. Cycles 740, 1550, 2198, 2903, 3600: Capacity Check.

FIGURE 13(k)



Cell Number	Cycle Failed

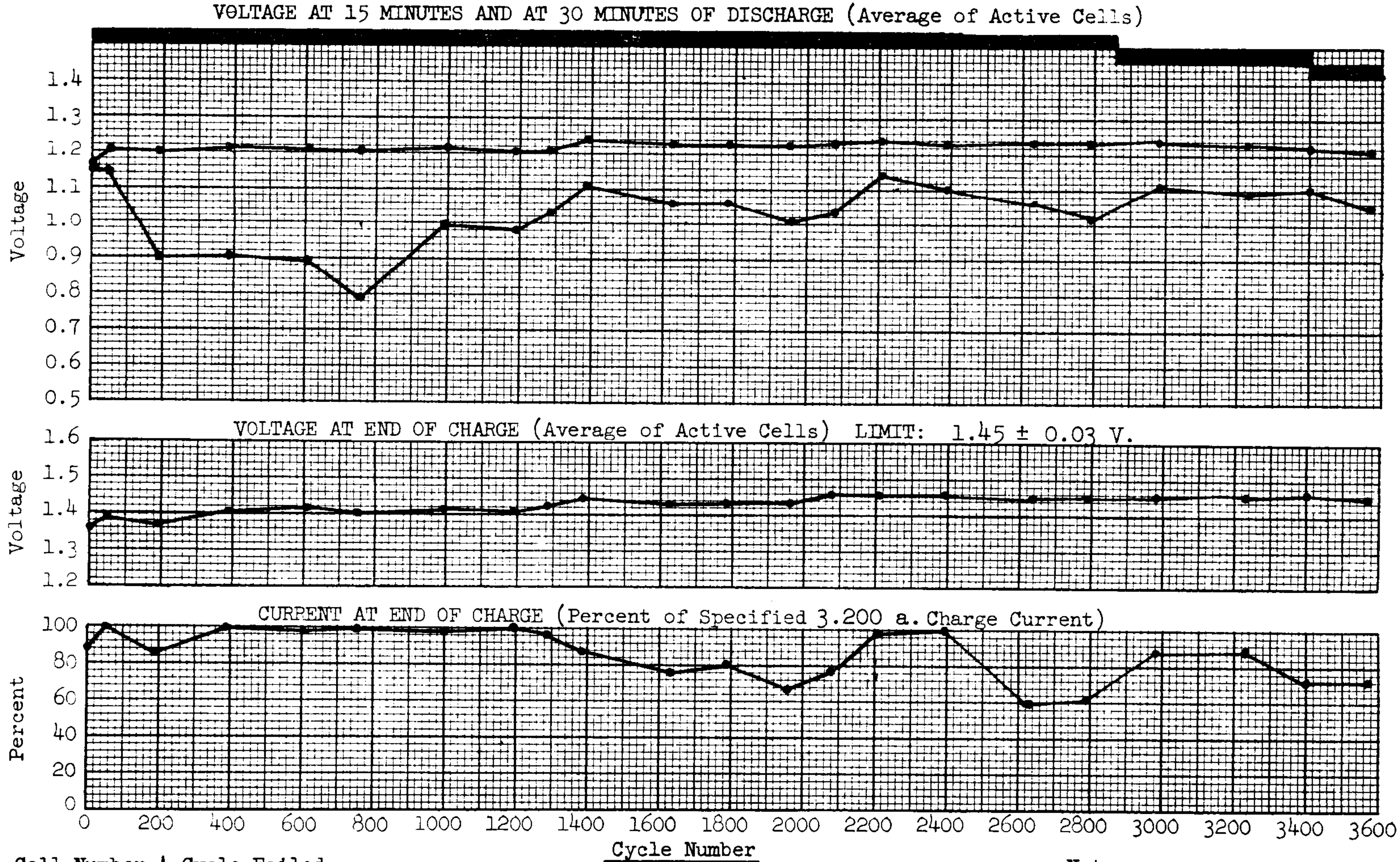
GULTON 20 a.h. (Pack 77)
Test Temperature: 50°-40° C
Orbit Period: 3 hours
Depth of Discharge: 15%

Status: 5 cells cycling after 5264 cycles.

Notes

1. Cycles 4357, 4978: Capacity Check.

FIGURE 13(k) (Contd)



Cell Number	Cycle Failed
395	2862
412	3385

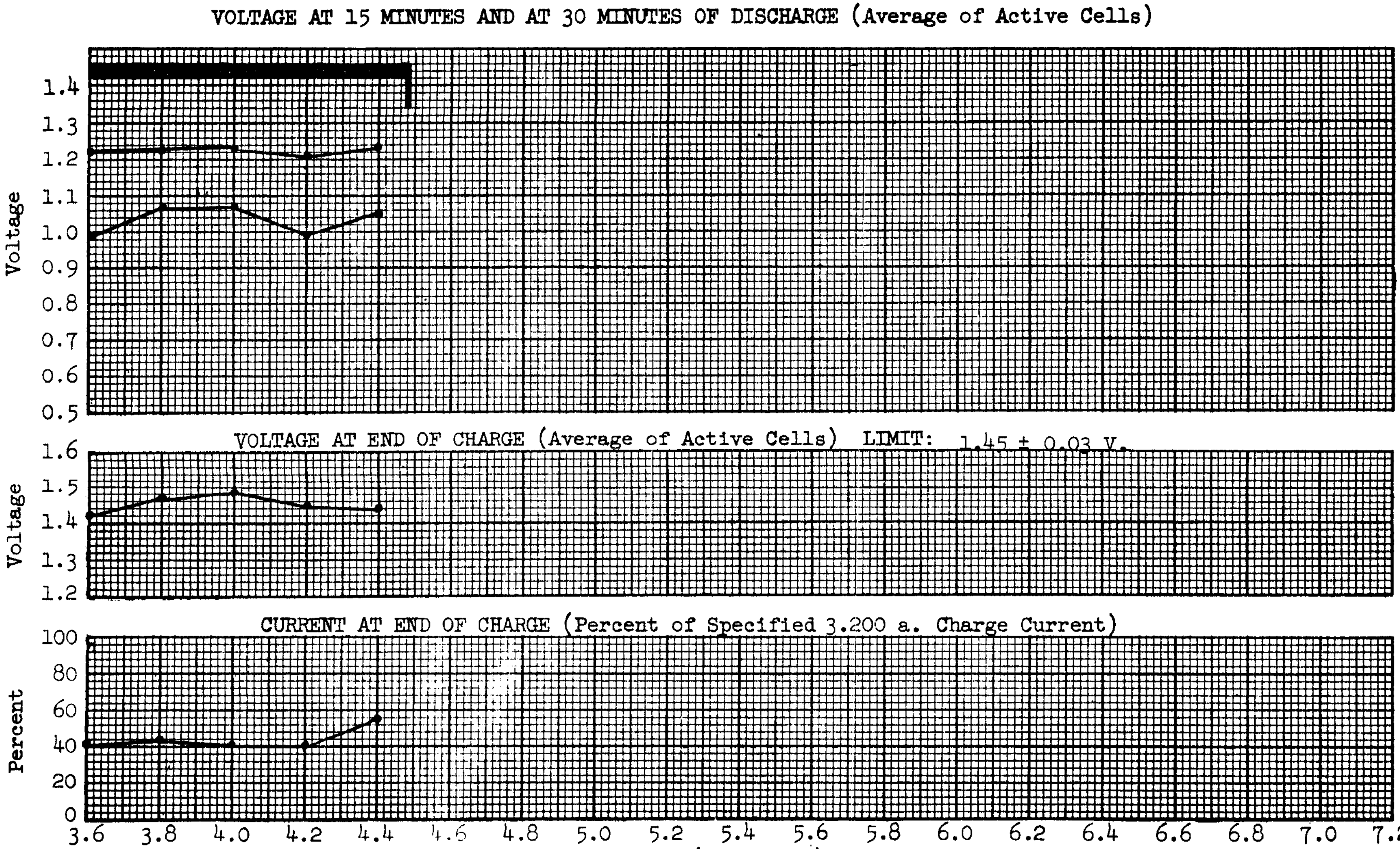
GULTON 20 a.h. (Pack 91)
Test Temperature: 50° - 40° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: Continued

Notes

1. Cycle 47: Changed to 40° C.
2. Cycle 207: Voltage limit raised to 1.45 V/cell.
3. Cycles 741, 1465, 2111, 2861, 3417: Capacity Check.

FIGURE 13(1)



Cell Number	Cycle Failed
489	4480
447	4480

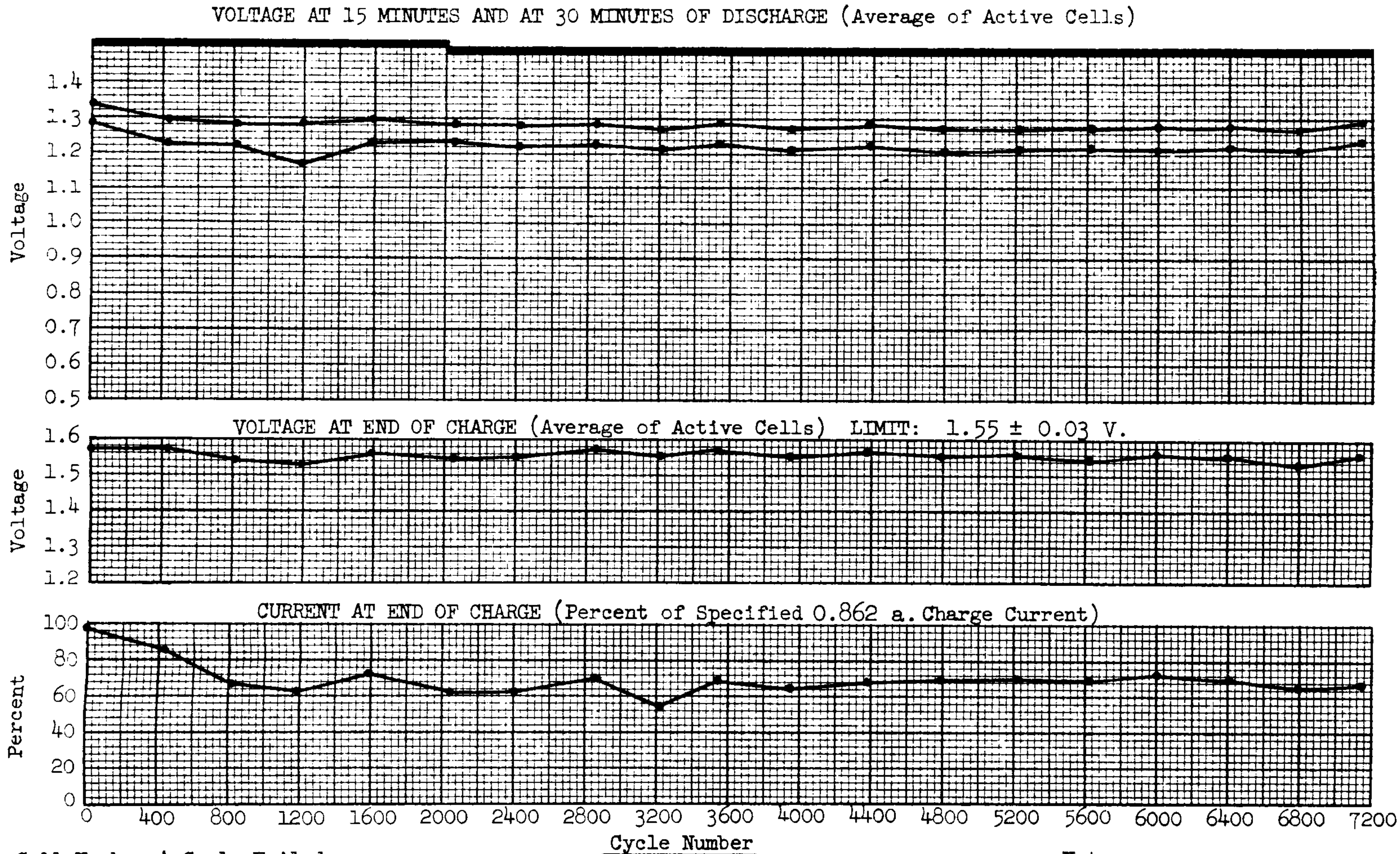
GULTON 20 a.h. (Pack 91)
Test Temperature: 50°-40° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: Pack Failed: Cycle 4480

Notes

1. Cycles 4173: Capacity Check.

FIGURE 13(1) (Contd)



Cell Number	Cycle Failed
6887	2010

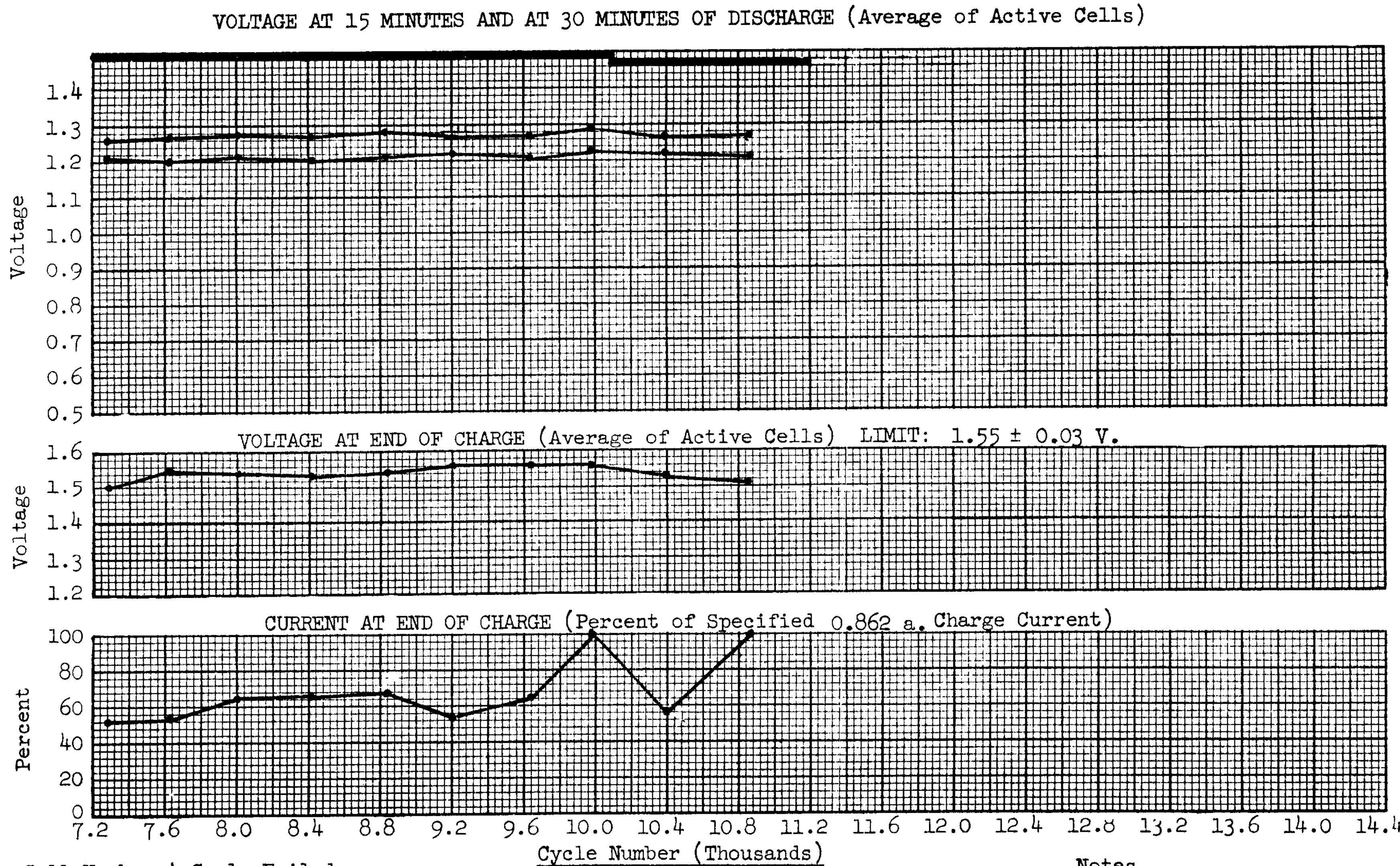
SONOTONE 5.0 a.h. (Pack 49)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: Continued

Notes

1. Cycles 1405, 2691, 3965, 5395, 6895: Capacity Check.

FIGURE 14(a)



Cell Number	Cycle Failed
4370	10073

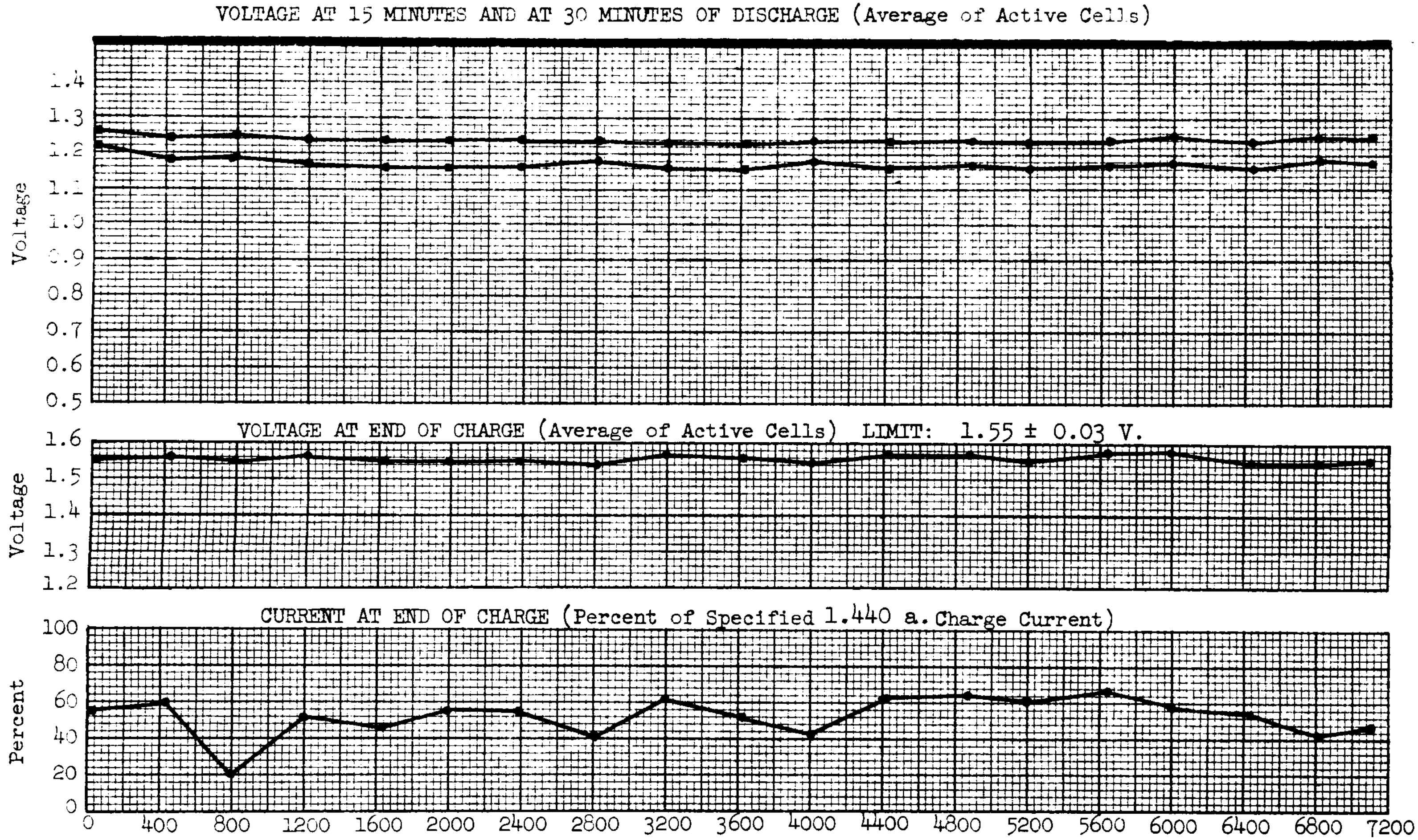
SONOTONE 5.0 a.h. (Pack 49)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: 8 cells cycling after 11191 cycles.

Notes

1. Cycles 8864, 10010: Capacity Check.

FIGURE 14(a) (Contd)



Cell Number	Cycle Failed
	.

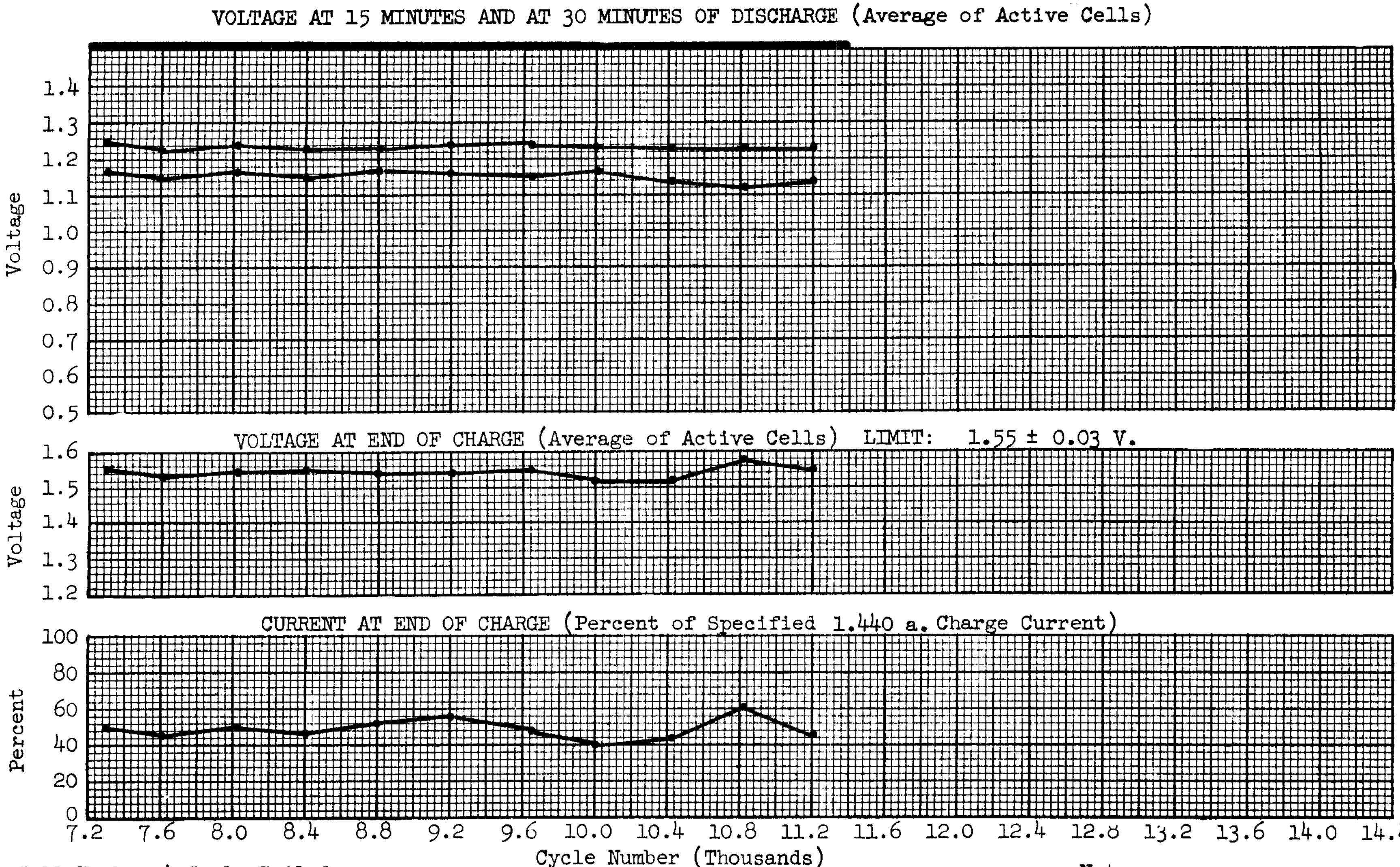
SONOTONE 5.0 a.h (Pack 50)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: Continued

Notes

1. Cycles 1435, 2648, 3921, 5351, 6782: Capacity Check.

FIGURE 14(b)



Cell Number	Cycle Failed

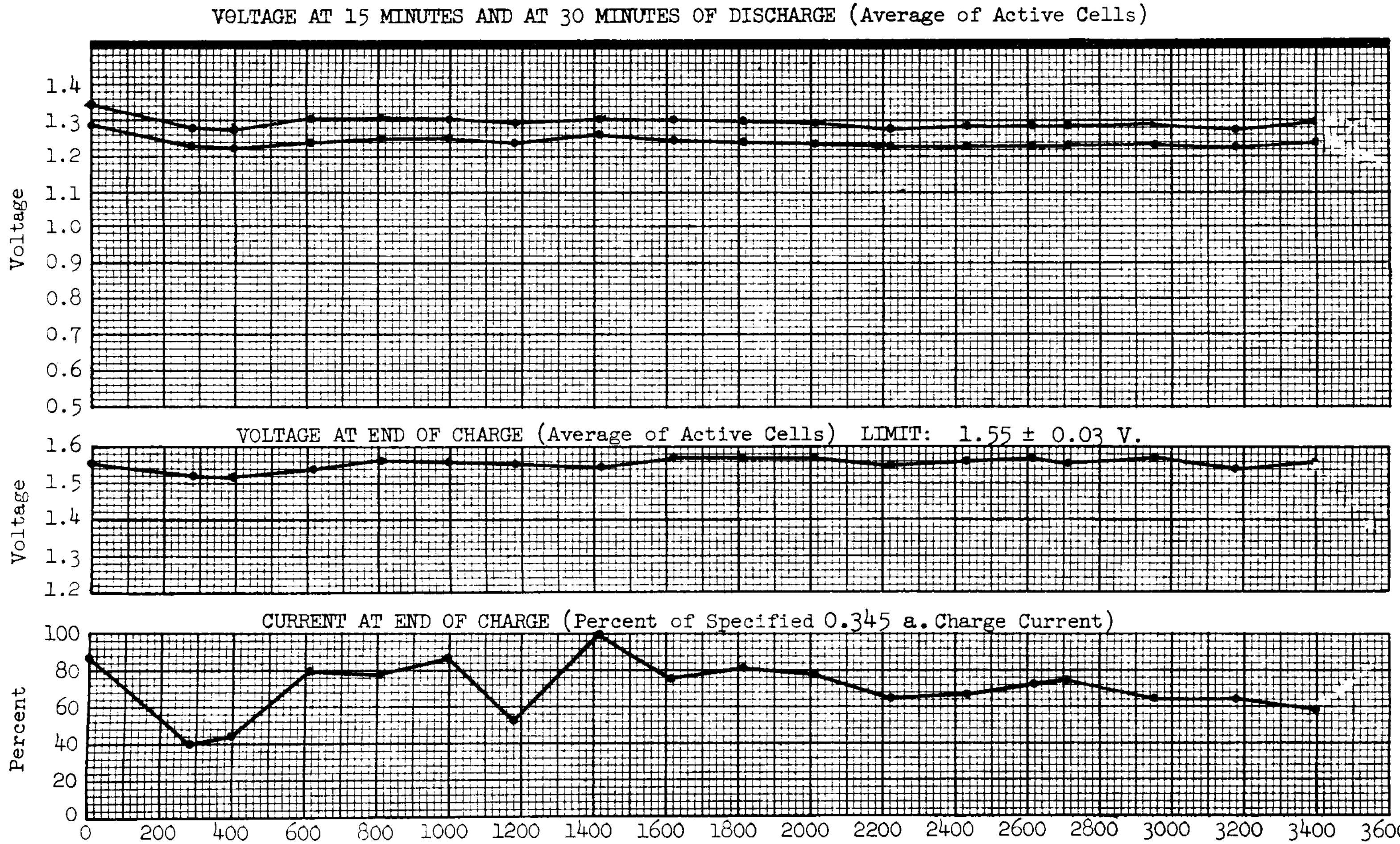
SONOTONE 5.0 a.h. (Pack 50)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: **10 cells cycling after 11300 cycles.**

Notes

1. **Cycles** 8739, 9978: Capacity Check.

FIGURE 14(b) (Contd)



Cell Number	Cycle Failed

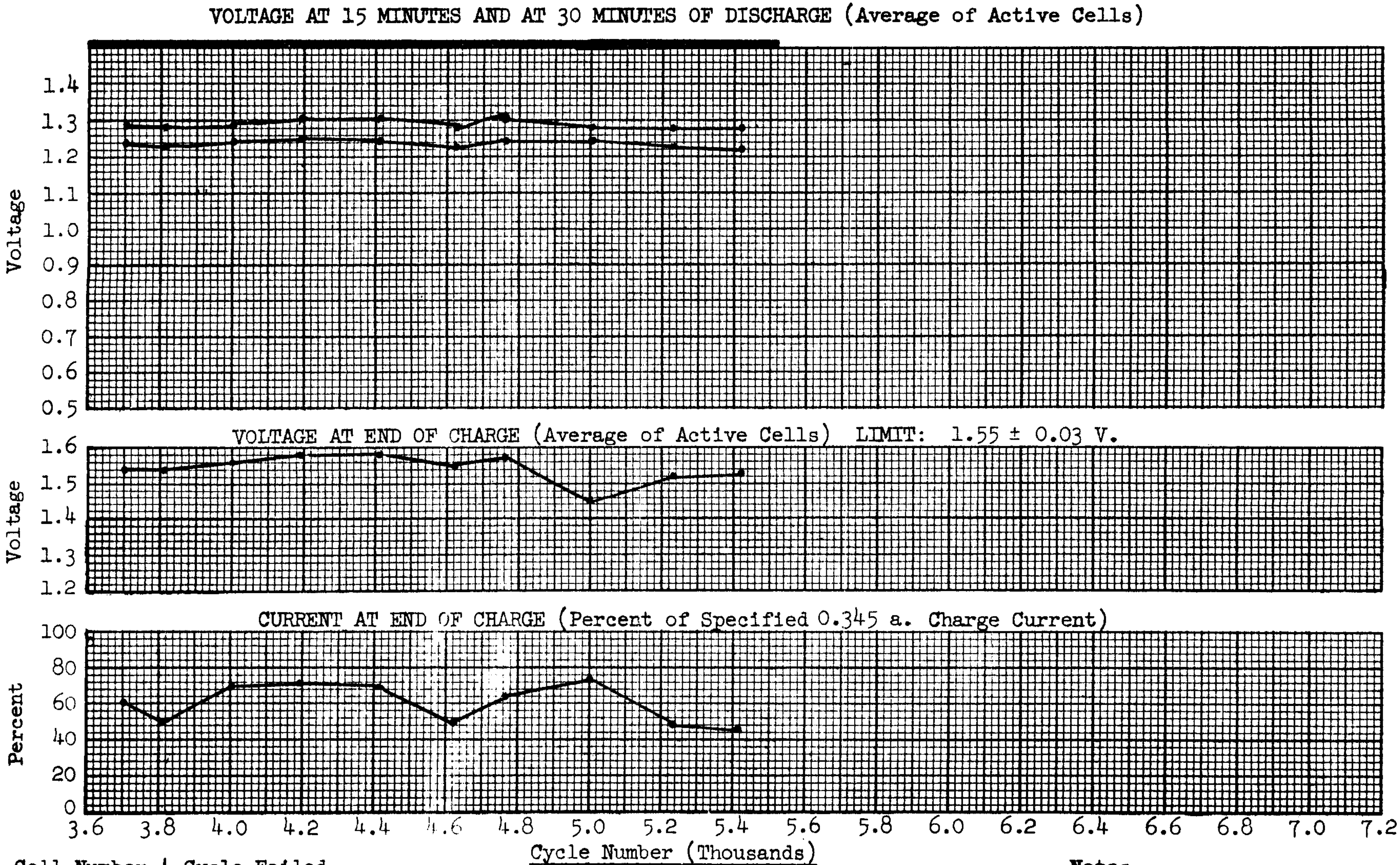
SONOTONE 5.0 a.h. (Pack 53)
Test Temperature: 0° C
Orbit Period: 3 hours
Depth of Discharge: 15%

Status: Continued

Notes

1. Cycles 702, 1332, 2068, 2767, 3423: Capacity Check.

FIGURE 14(c)



Cell Number	Cycle Failed

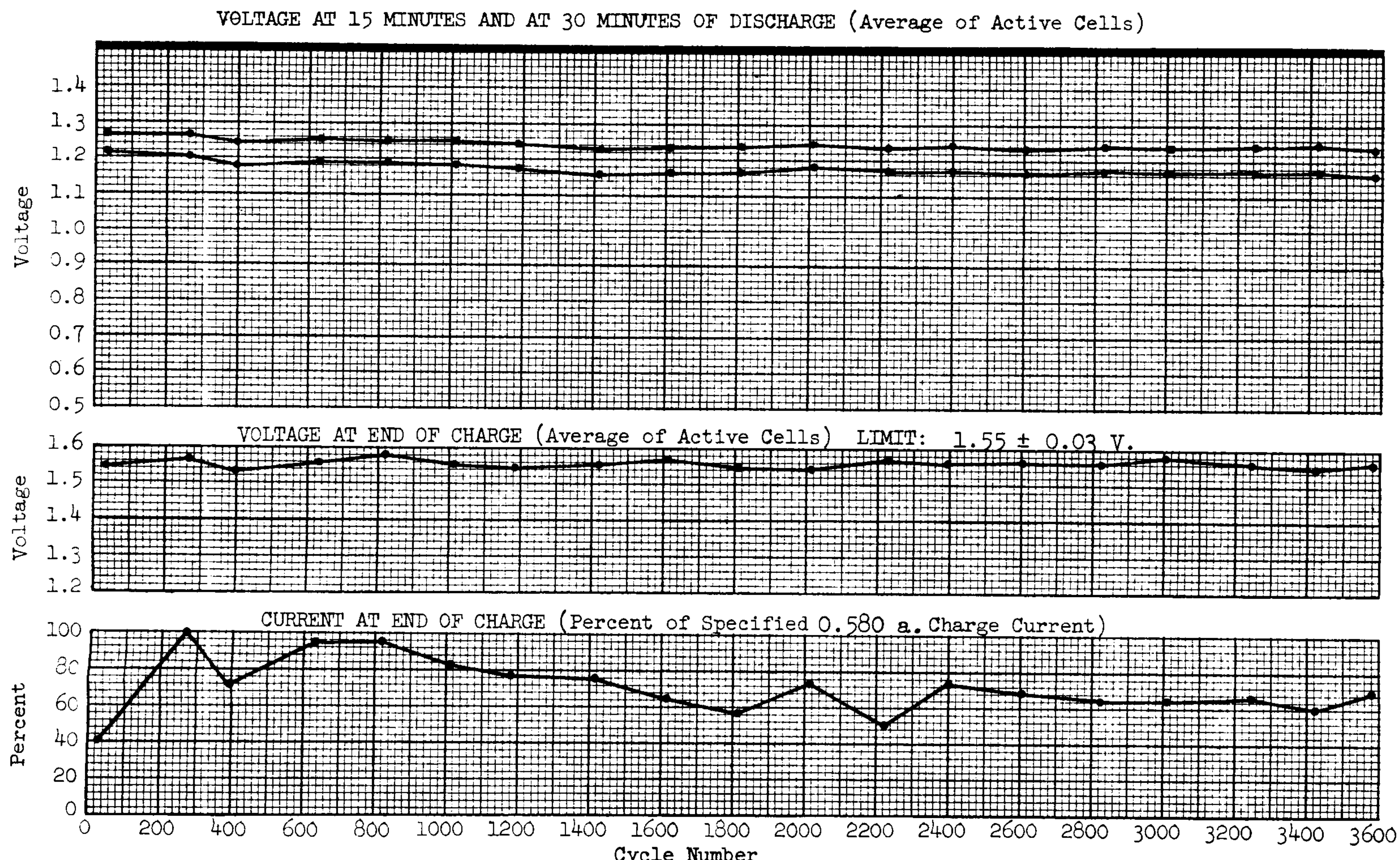
SONOTONE 5.0 a.h. (Pack 53)
Test Temperature: 0° C
Orbit Period: 3 hours
Depth of Discharge: 15%

Status: 10 cells cycling after 5521 cycles.

Notes

1. Cycles 4272, 4854: Capacity Check.

FIGURE 14(c) (Contd)



Cell Number	Cycle Failed

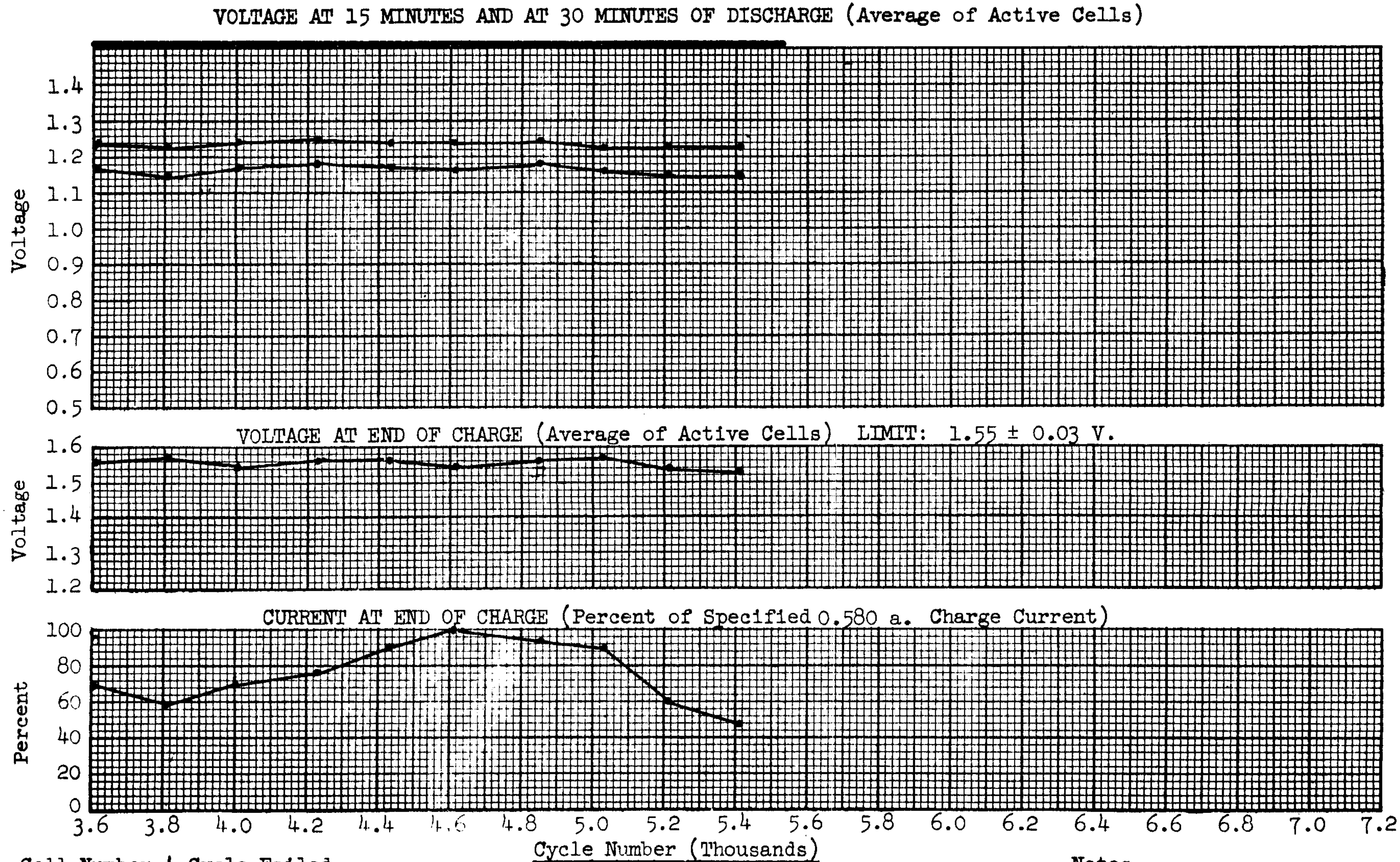
SONOTONE 5.0 a.h. (Pack 54)
Test Temperature: 0° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: Continued

Notes

1. Cycles 701, 1310, 1984, 2681, 3433: Capacity Check.

FIGURE 14(d)



Cell Number	Cycle Failed

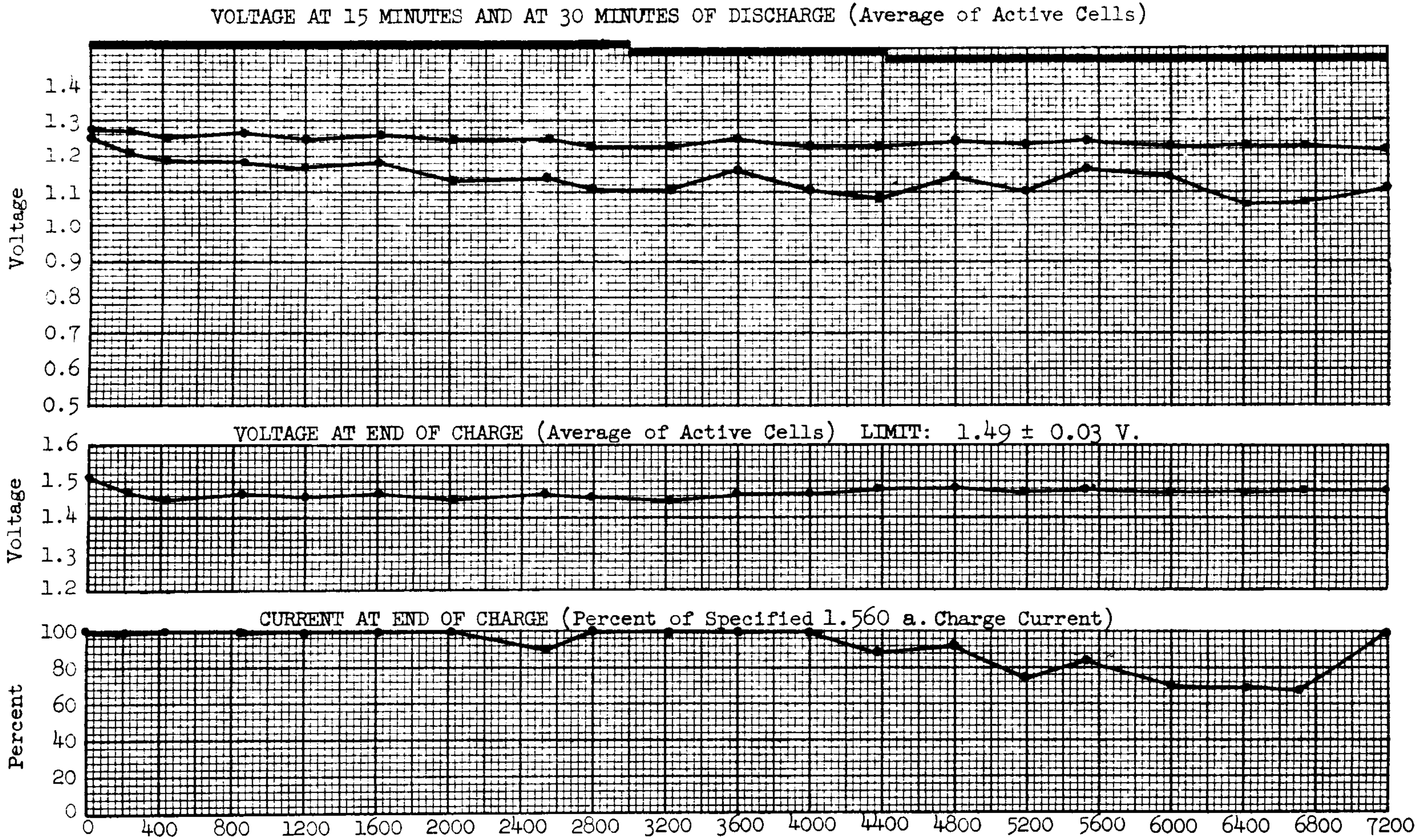
SONOTONE 5.0 a.h. (Pack 54)
Test Temperature: 0° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: 10 cells cycling after 5539 cycles.

Notes

1. Cycles 4242, 4876: Capacity Check:

FIGURE 14(d) (Contd)



Cell Number	Cycle Failed
4361	2995
4335	4423

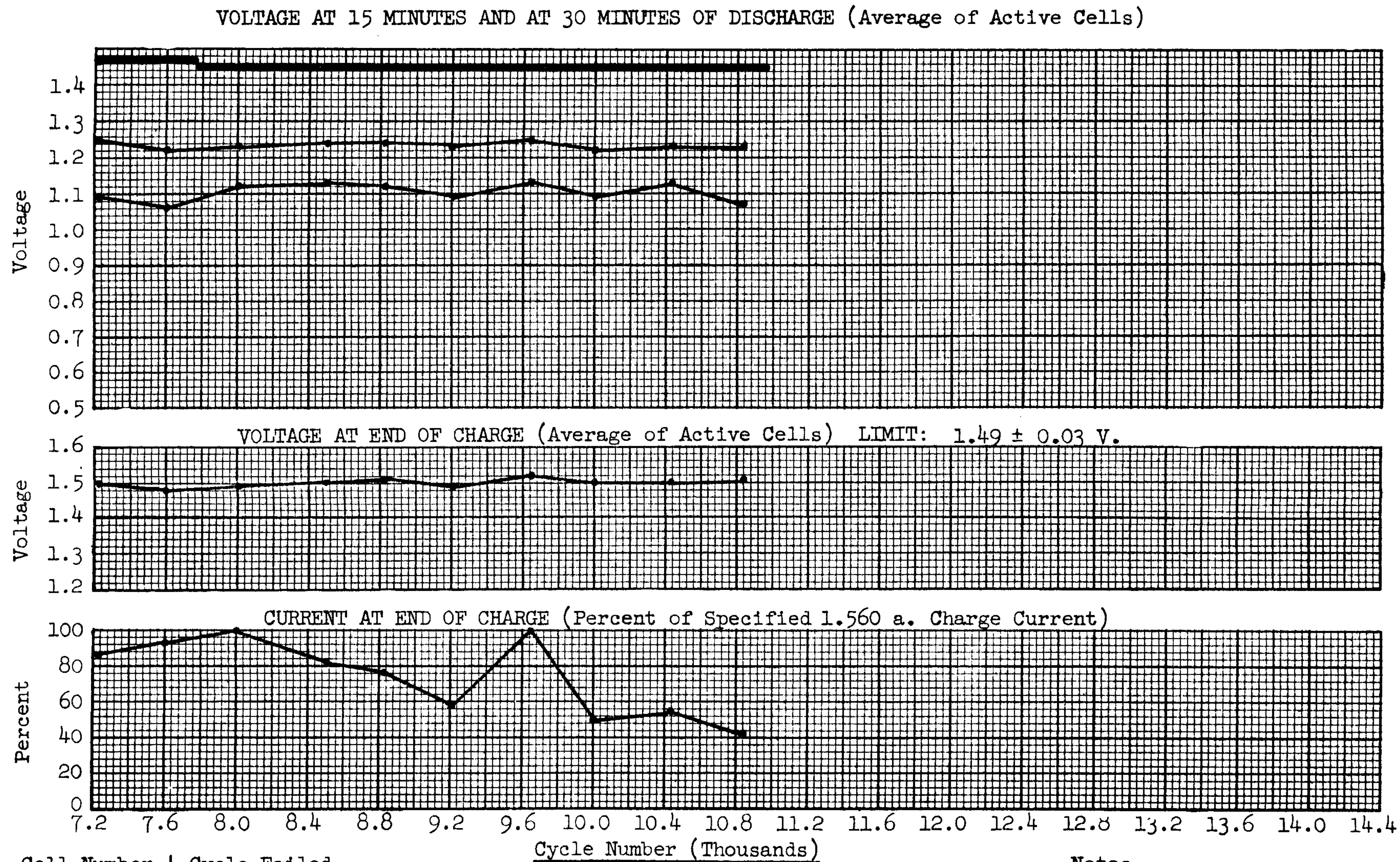
SONOTONE 5.0 a.h. (Pack 1)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: Continued

Notes

1. Cycles 1387, 2686, 3786, 5349, 6752: Capacity Check.

FIGURE 14(e)



Cell Number	Cycle Failed
4878	7782

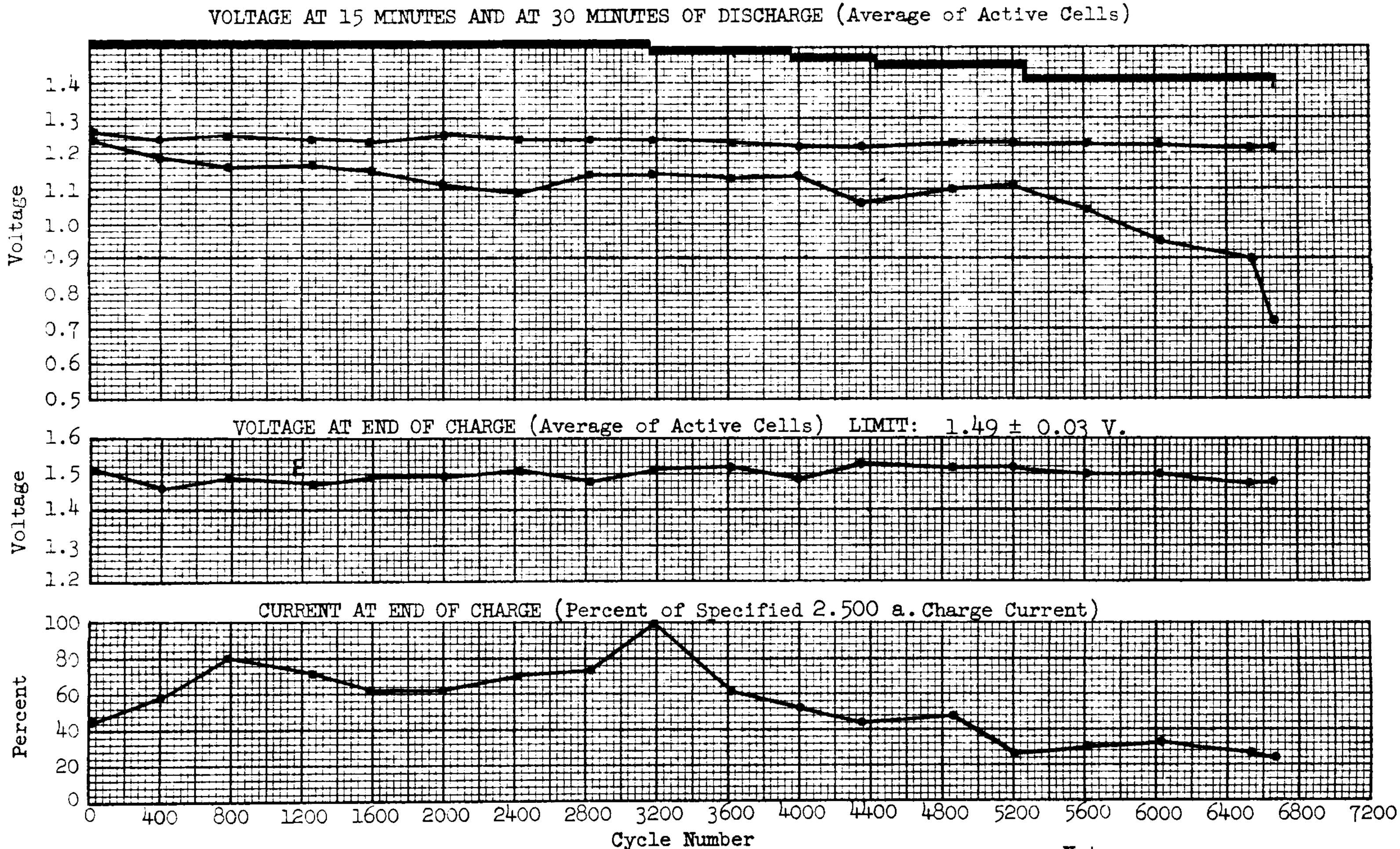
SONOTONE 5.0 a.h. (Pack 1)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: **7 cells cycling after 10971 cycles.**

Notes

1. Cycles 8213, 9258, 10545: Capacity Check.

FIGURE 14(e) (Contd)



Cell Number	Cycle Failed
811	3155
3628	3992
3613	4411
3630	5262
3631	5262
3611	6672

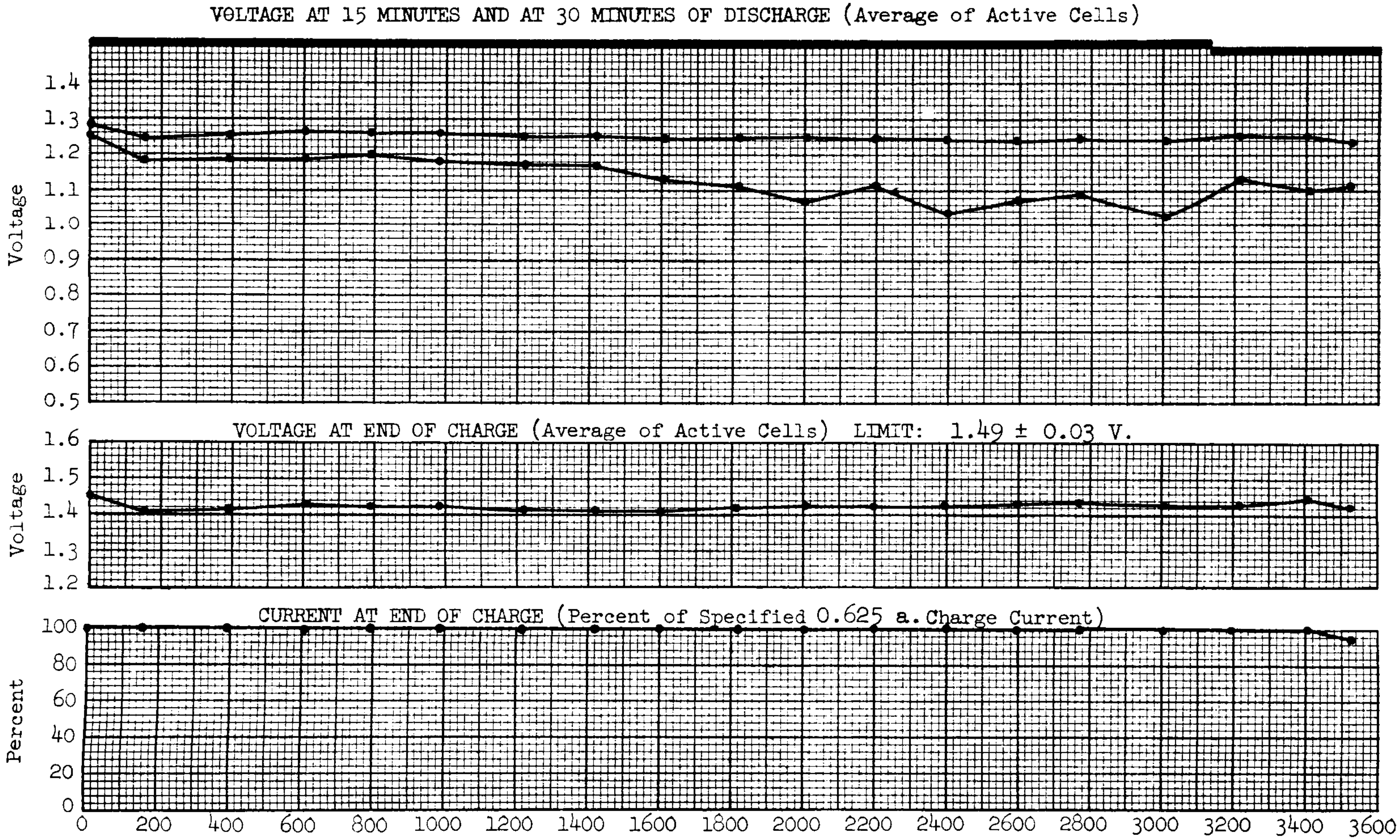
SONOTONE 5.0 a.h. (Pack 2)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 40%

Status: Pack Failed: Cycle 6672

Notes

1. Cycles 1400, 2697, 4015, 5502: Capacity Check.

FIGURE 14(f)



Cell Number	Cycle Failed

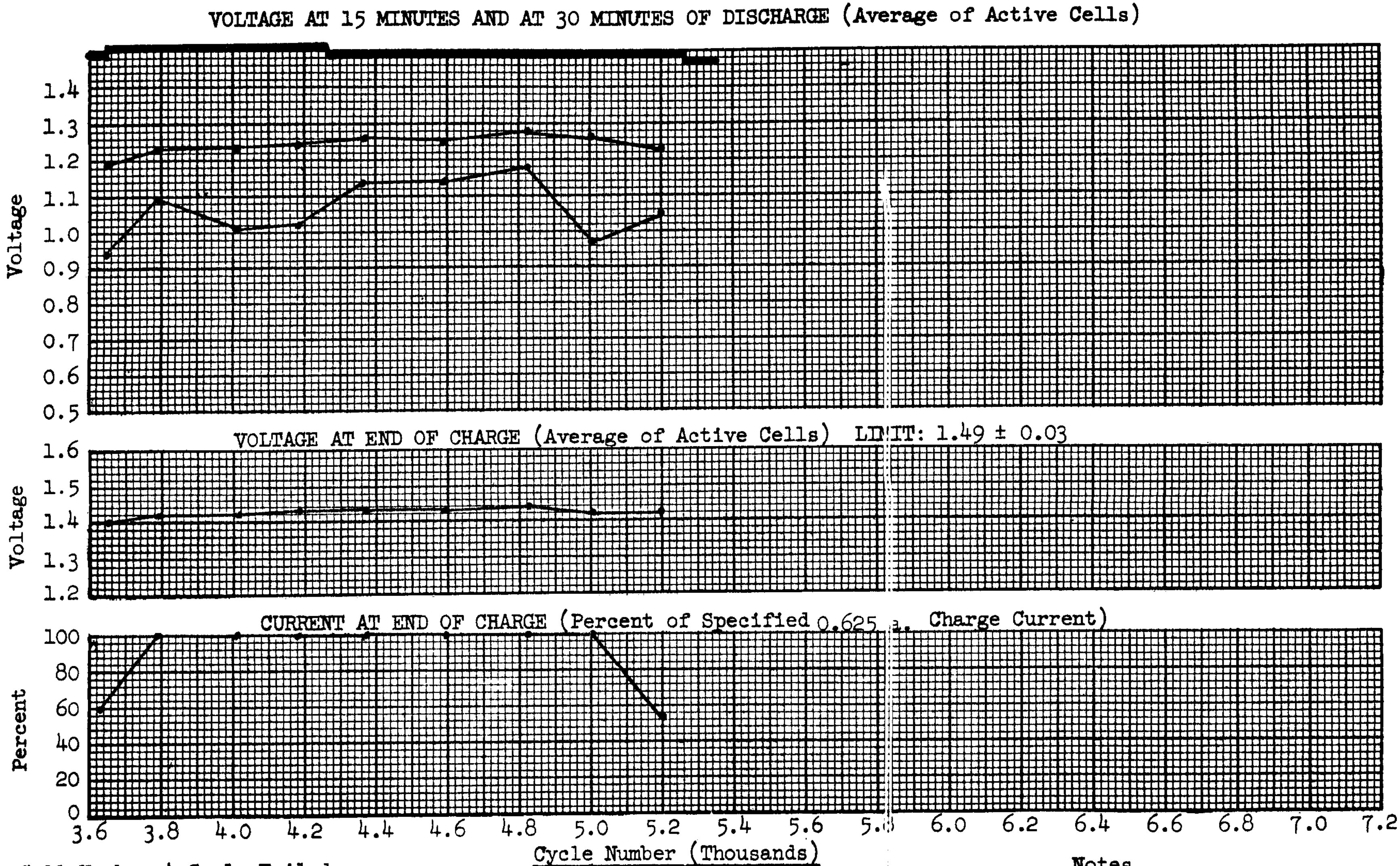
SONOTONE 5.0 a.h. (Pack 5)
Test Temperature: 25° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: Continued

Notes

1. Cycles 702, 1368, 2125, 2823, 3437: Capacity Check.

FIGURE 14(g)



Cell Number	Cycle Failed
4351	3771
4354	5272

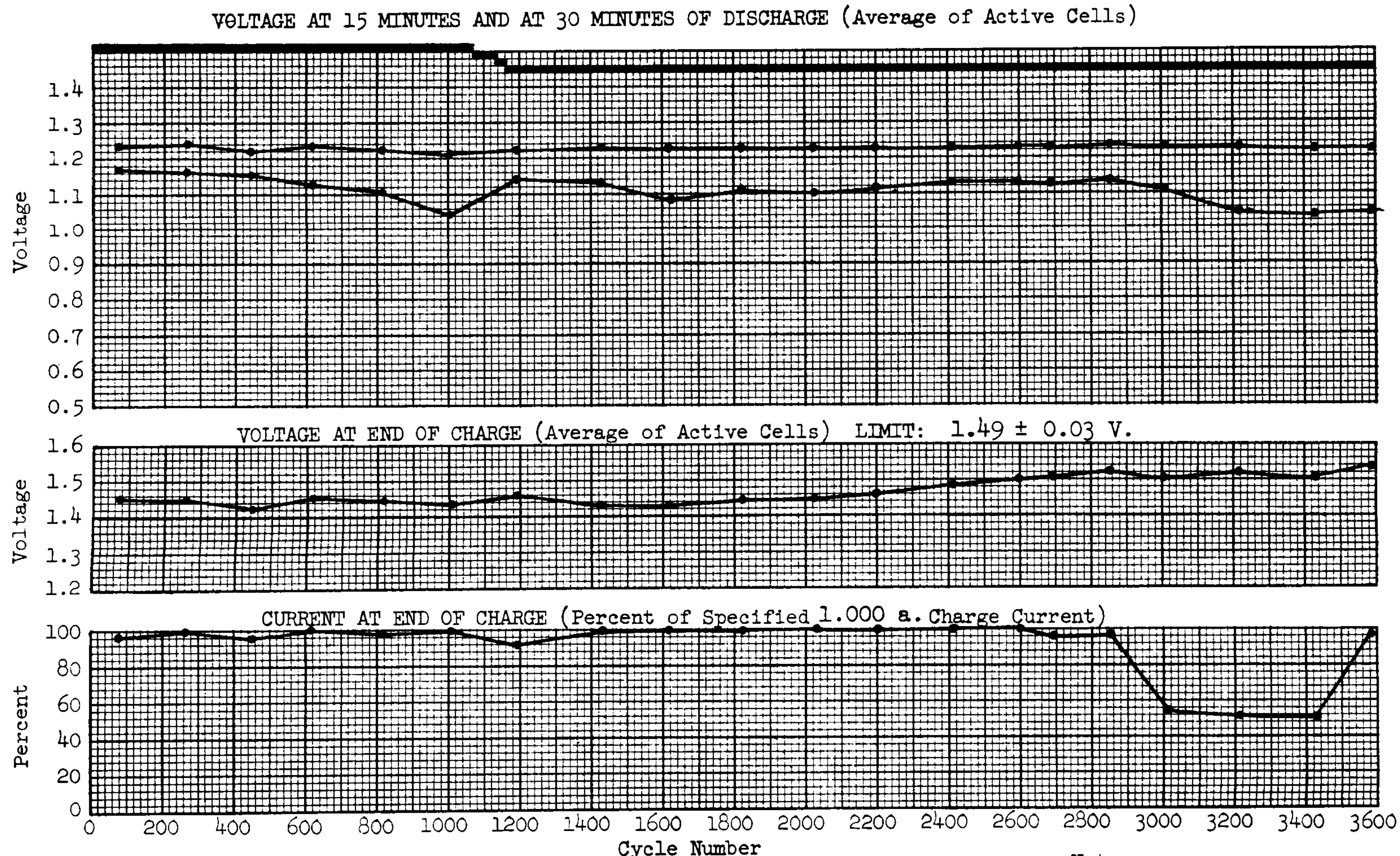
SONOTONE 5.0 a.h. (Pack 5)
Test Temperature: 25° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: 8 cells cycling after 5364 cycles.

Notes

1. Cycles 3134-3625: Cell 4351 failed; returned to pack after it regained normal capacity during failure test; failed again after cycle 3771. The remaining cells had completed 4262 cycles.
2. Cycles 4220, 4794: Capacity Check.

FIGURE 14(g) (Contd)



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%

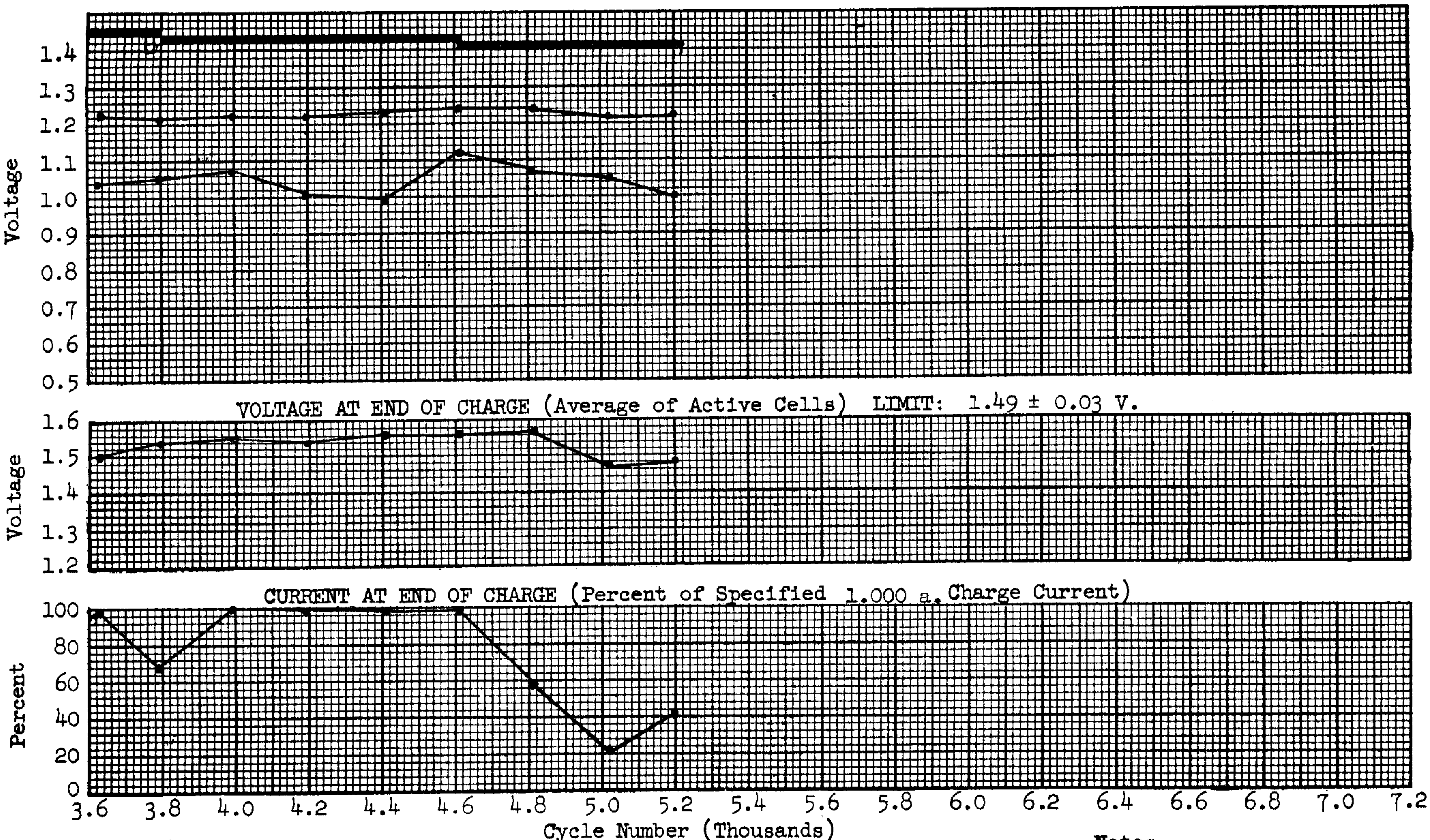
Status: Continued

Notes

1. Cycles 700, 1365, 2100, 2712, 3354: Capacity Check.

FIGURE 14(h)

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



Cell Number	Cycle Failed
6875	3798
6882	4608
6880	5211

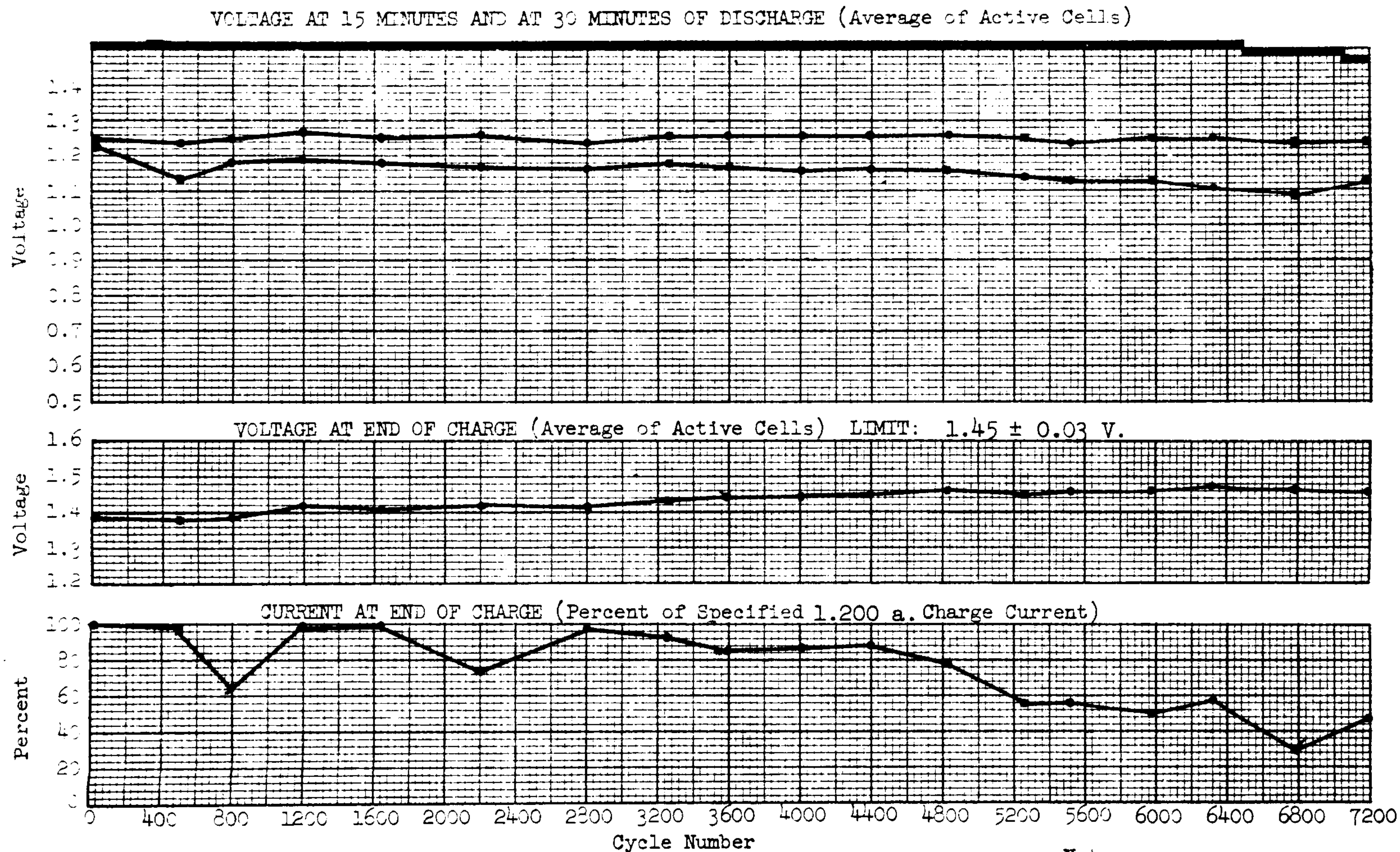
SONOTONE 5.0 a.h. (Pack 6)
Test Temperature: 25° C
Orbit Period: 3 hours
Depth of Discharge: 40%

Status: Pack Failed: Cycle 5211

Notes

1. Cycles 4198, 4563, 5145 Capacity Check.

FIGURE 14(h) (Contd)



Cell Number	Cycle Failed
4852	6487
4364	7052

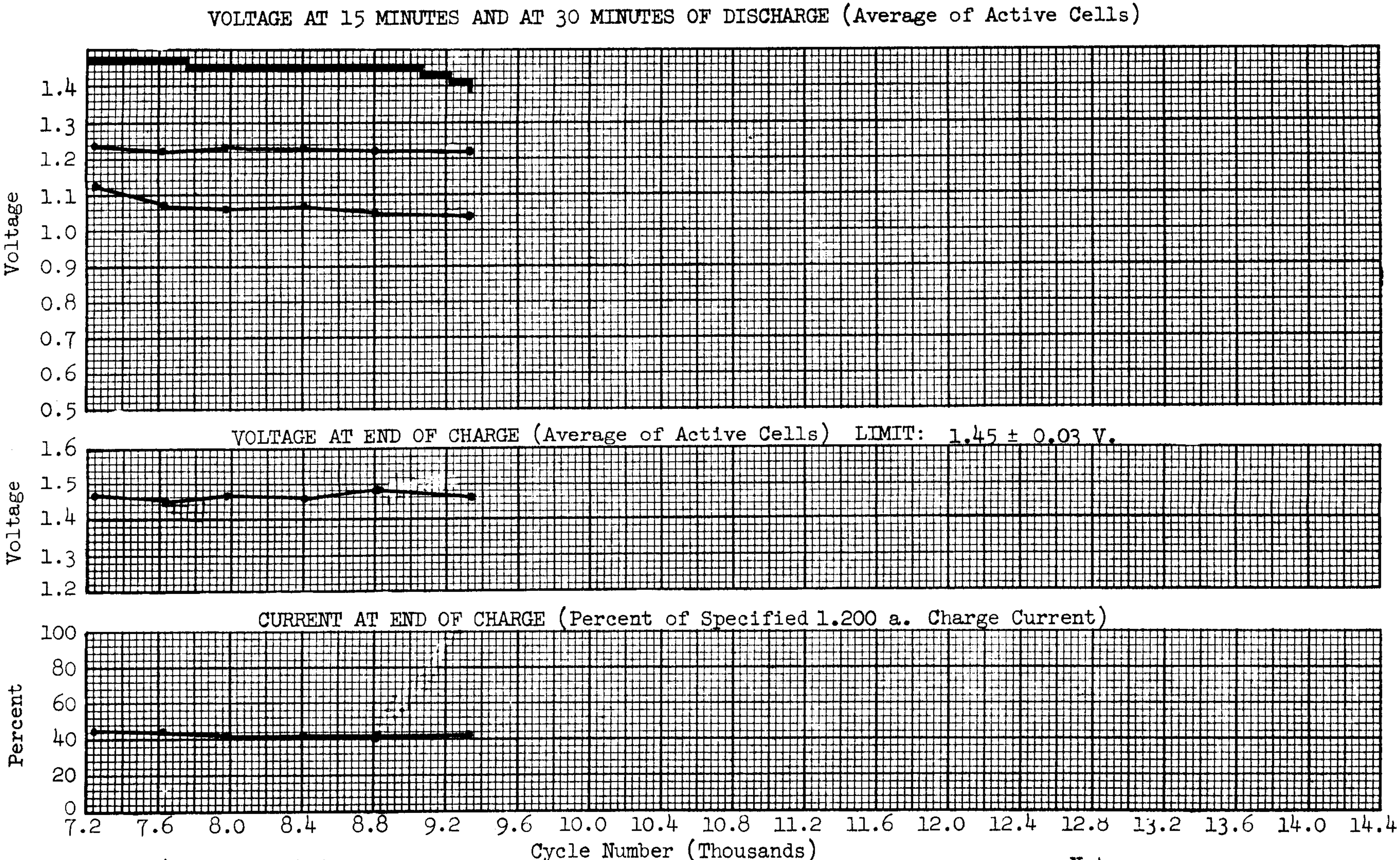
SONOTONE 5.0 a.h. (Pack 25)
Test Temperature: 50° - 40° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

Status: Continued

Notes

1. Cycle 703: Changed to 40° C.
2. Cycle 1004: Voltage limit raised to 1.45 V/cell.
3. Cycles 1417, 2755, 4246, 5859, 6950: Capacity Check.

FIGURE 14(i)



Cell Number	Cycle Failed
4317	7758
4350	9070
6850	9220
4347	9328

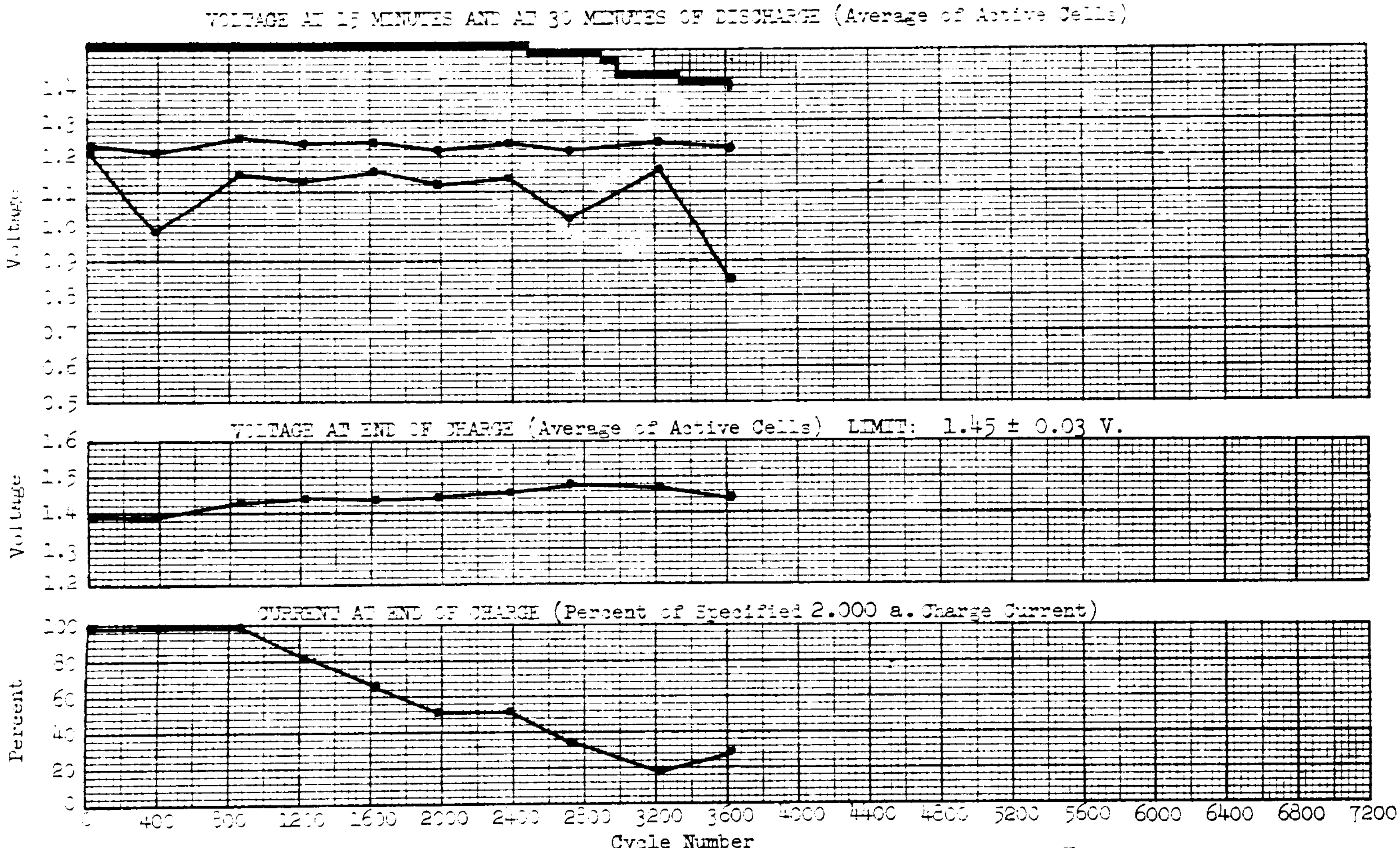
SONOTONE 5.0 a.h. (Pack 25)
Test Temperature: 50°-40° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

Status: Pack Failed: Cycle 9328

Notes

1. Cycles 8317, 9236: Capacity Check.

FIGURE 14(i) (Contd)



Cell Number	Cycle Failed
4323	2487
6773	2992
7224, 7232	2993
4381	3344
4240	3625

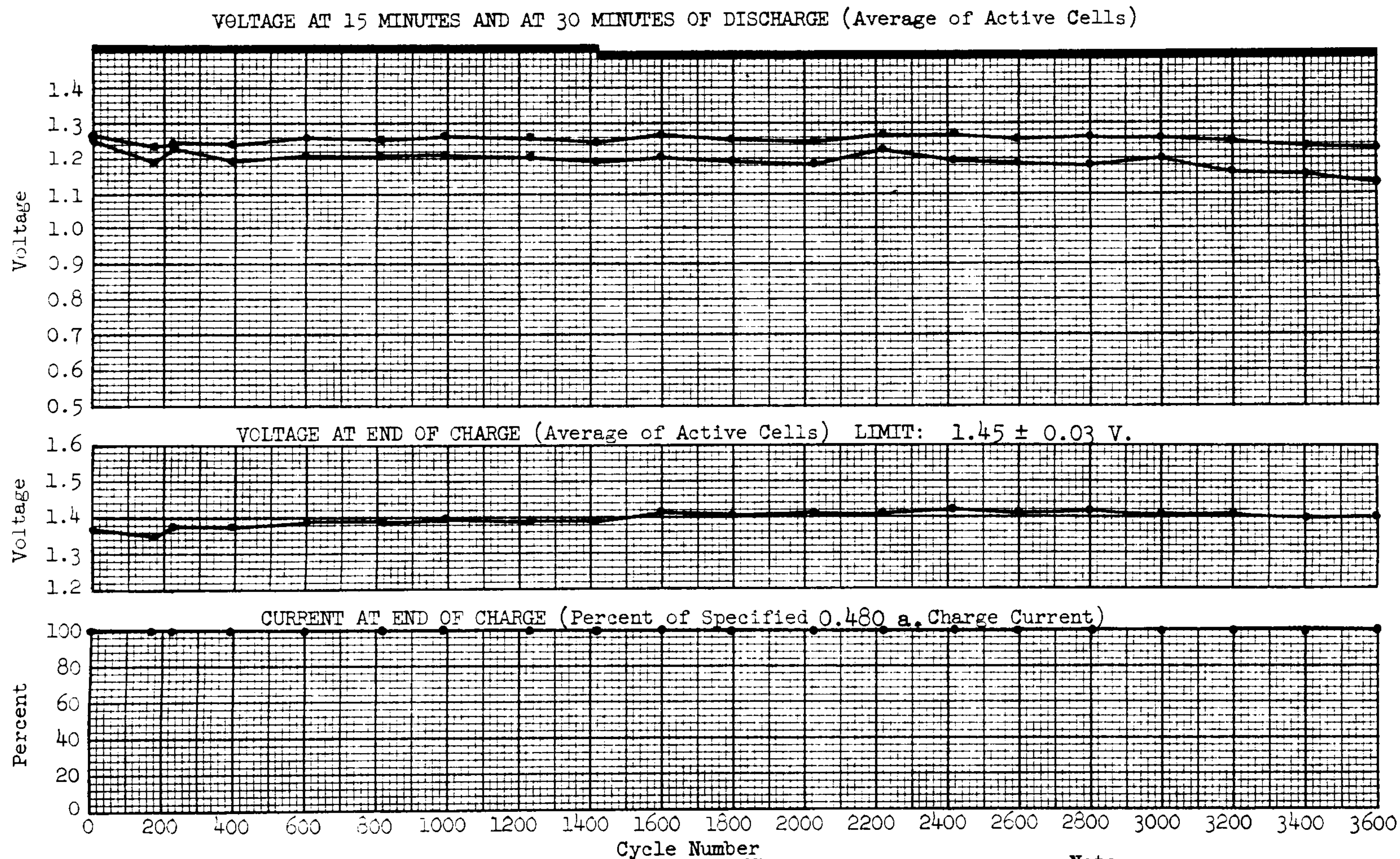
SONOTONE 5.0 a.h. (Pack 26)
Test Temperature: 50° - 40° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

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 14(j)



Cell Number	Cycle Failed
3626	1418

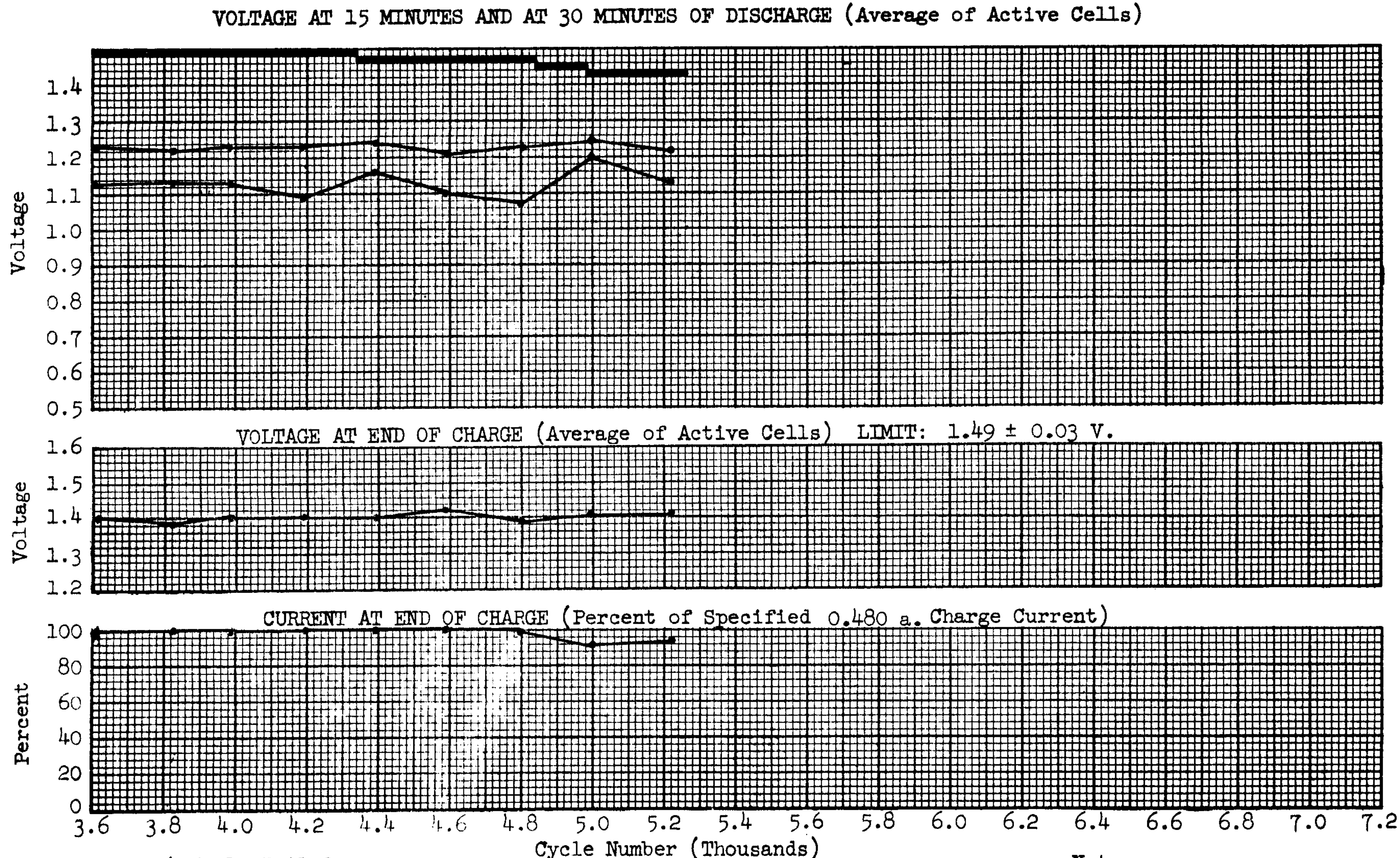
SONOTONE 5.0 a.h. (Pack 29)
Test Temperature: 50° - 40° C
Orbit Period: 3 hours
Depth of Discharge: 15%

Status: Continued

Notes

1. Cycle 223: Changed to 40° C.
2. Cycle 381: Voltage limit raised to 1.45 V/cell.
3. Cycles 726, 1552, 2207, 2958: Capacity Check.

FIGURE 14(k)



Cell Number	Cycle Failed
4327	4340
810	4835
4340	4964

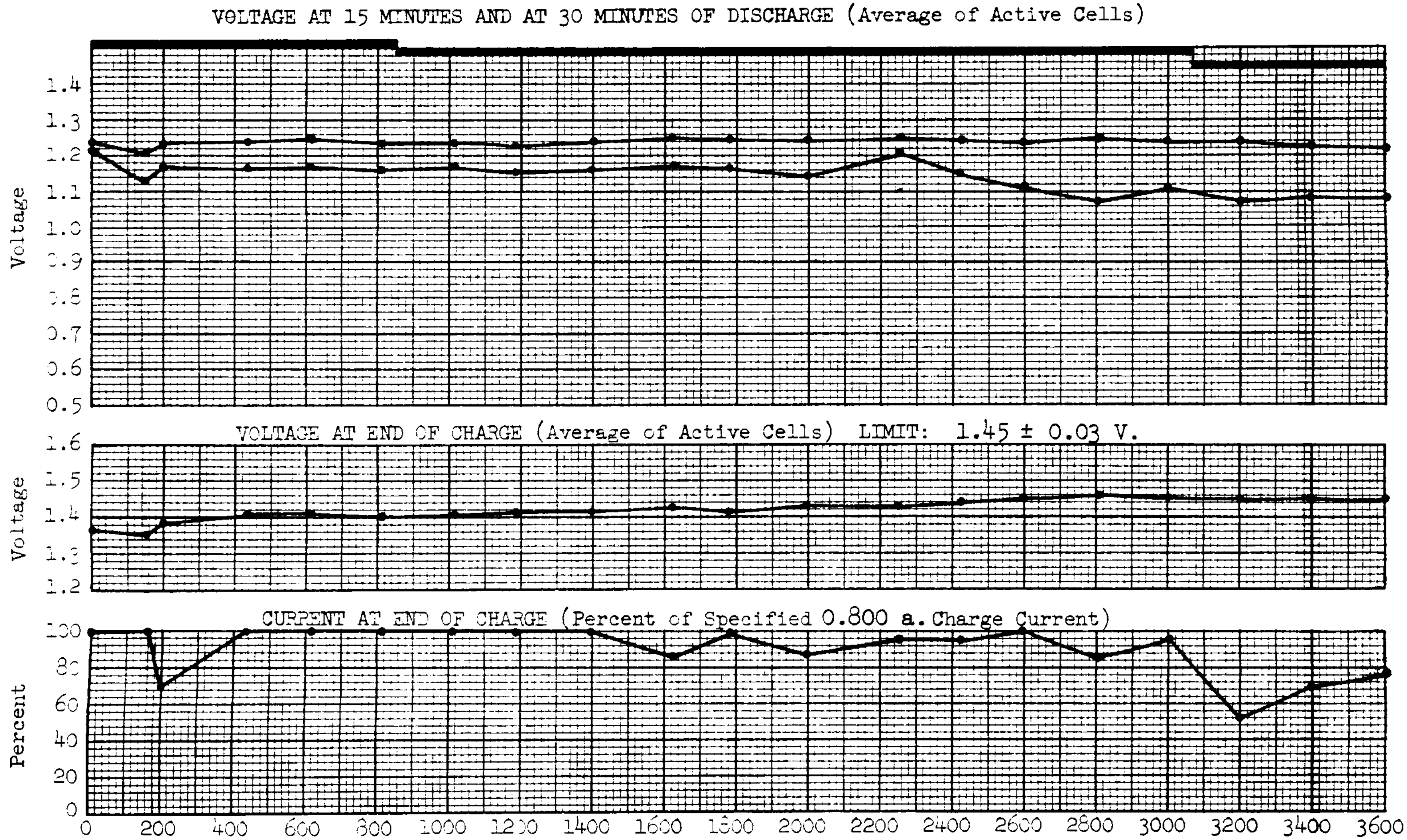
SONOTONE 5.0 a.h. (Pack 29)
Test Temperature: 50°-40° C
Orbit Period: 3 hours
Depth of Discharge: 15%

Status: 6 cells cycling after 5252 cycles.

Notes

1. Cycles 3657, 4363, 4889: Capacity Check.

FIGURE 14(k) (Contd)



Cell Number	Cycle Failed
3657	855
3643	3068
809	3068

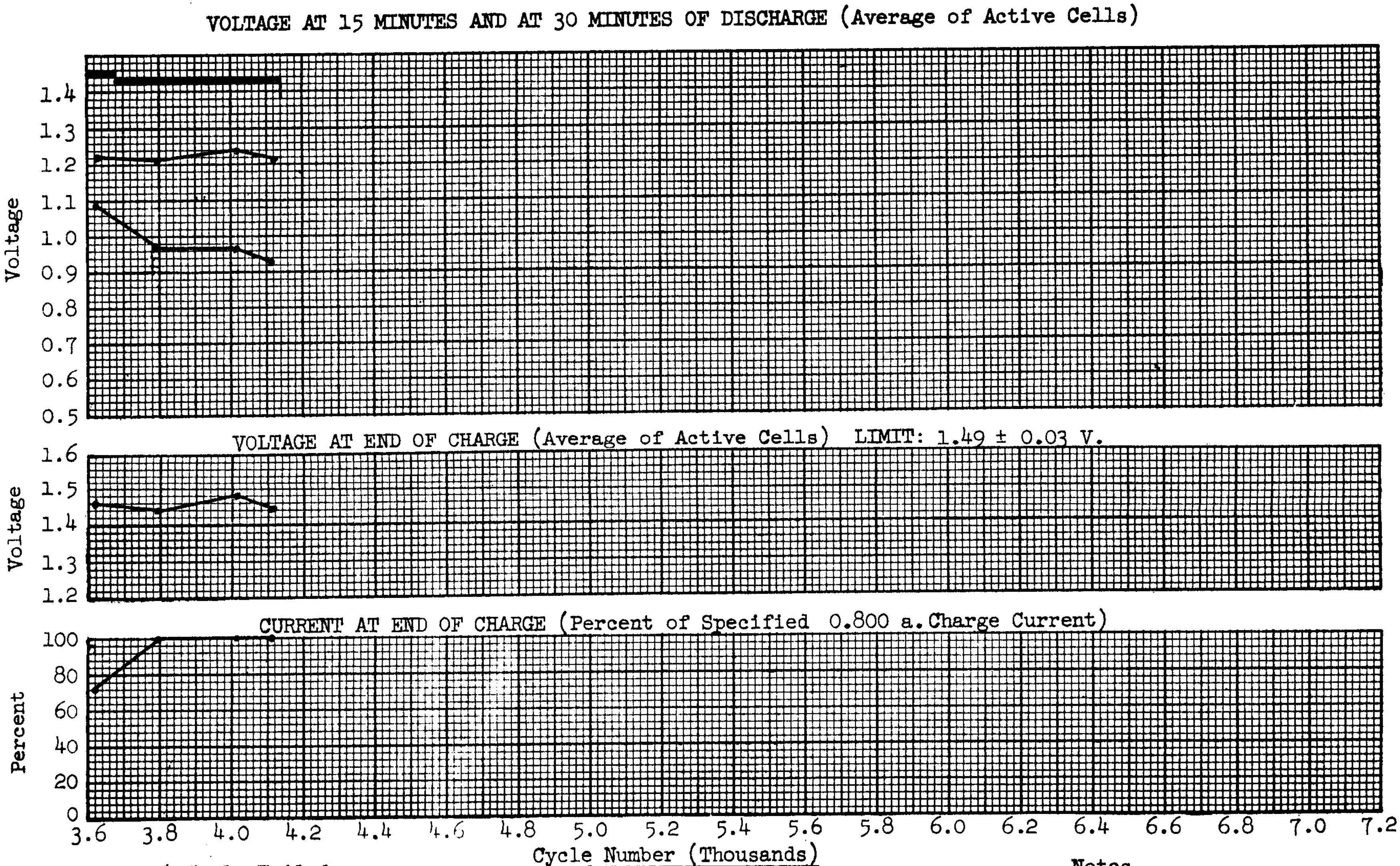
SONOTONE 5.0 a.h. (Pack 30)
Test Temperature: 50° - 40° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: Continued

Notes

1. Cycle 183: Changed to 40° C.
2. Cycle 329: Voltage limit raised to 1.45 V/cell.
3. Cycles 726, 1552, 2207, 2980, 3566: Capacity Check.

FIGURE 14(1)



Cell Number	Cycle Failed
3658	3684
3617	4141
7230	4141

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

Status: Pack Failed: Cycle 4141

Notes

FIGURE 14(1) (Contd)

V. TEST FACILITIES

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

1. -20° C. A 12 cubic foot chamber manufactured by General Thermodynamics, Inc., Model UCH 322 C-B, temperature controls accurate to within ± 1.5° C.

2. 0° C. A 27 cubic foot chamber manufactured by the A. Webber Engineering Corporation, Model WF-27-40, temperature controls accurate to within ± 1.5° C.

3. 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.

4. 40° C. A 27 cubic foot chamber manufactured by Tenney Engineering, Inc., Model UF-40240, temperature controls accurate to within ± 1.5° C.

5. Several small chambers are used as required for additional packs and for any special temperature requirements. They range in size from 1.5 to 2.5 cubic feet and have a temperature range of -75° C to 175° 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 the 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 a stepping relay which receives a pulse for each minute from a digital clock. The stepping relay is wired for both the 1.5-hour and 3-hour orbits. Each unit is connected to the corresponding output for its cycle period. The reference voltage for the voltage limiting circuit in each unit is supplied by using a voltage divider in series with a constant current circuit.

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 15 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 than 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.

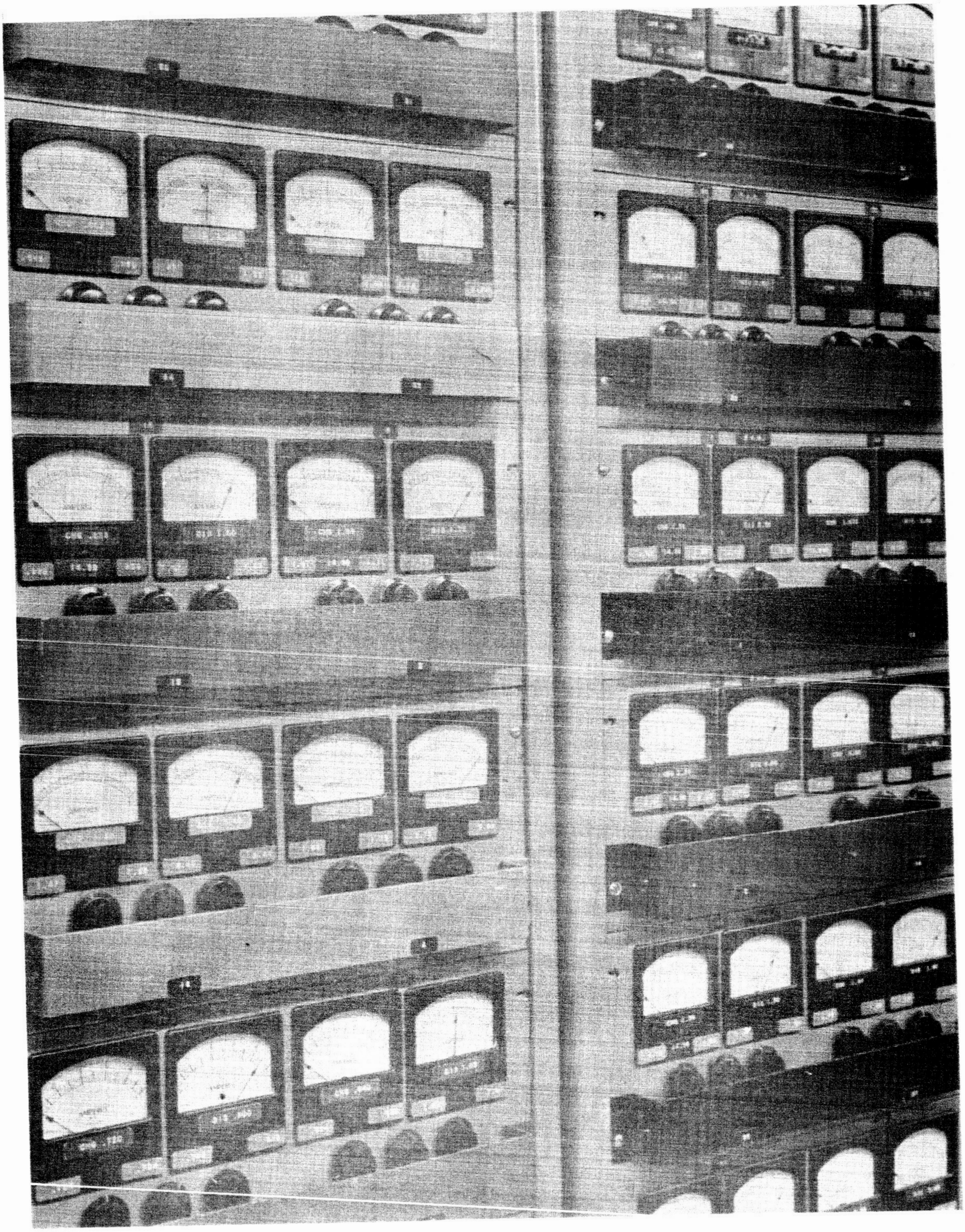
1. Up to six 10-cell packs and 12 5-cell packs may be plugged into a selector system from the central wiring panel. Through reed relays operated by a selector switch, any of these packs can then be connected to the input of the data logging system. This arrangement allows all currents and cell and thermocouple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

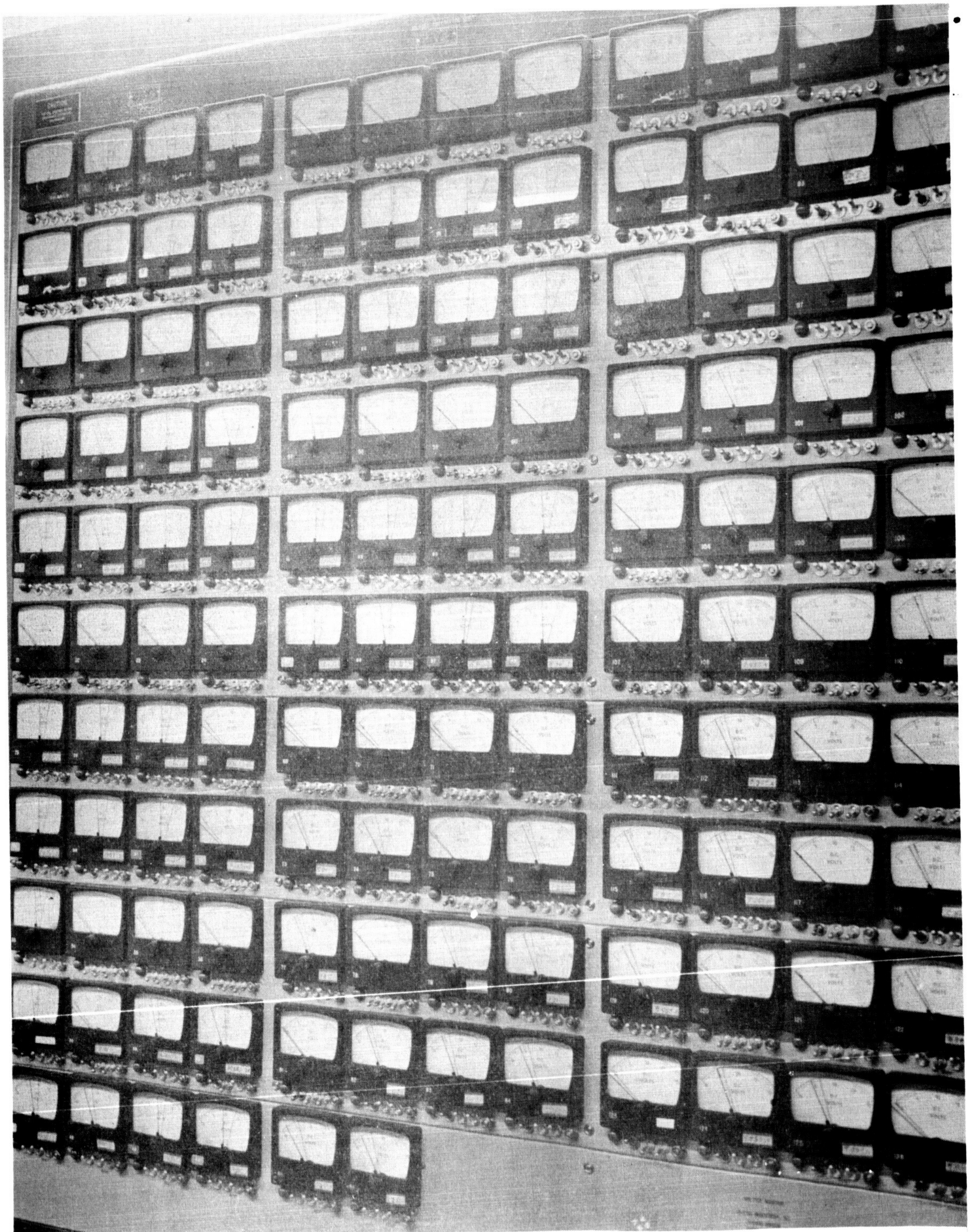
3. Photograph 4 shows the pack selector switch located on top of the data logging system.

G. Block Diagram of Entire Test Setup: Figure 16 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.

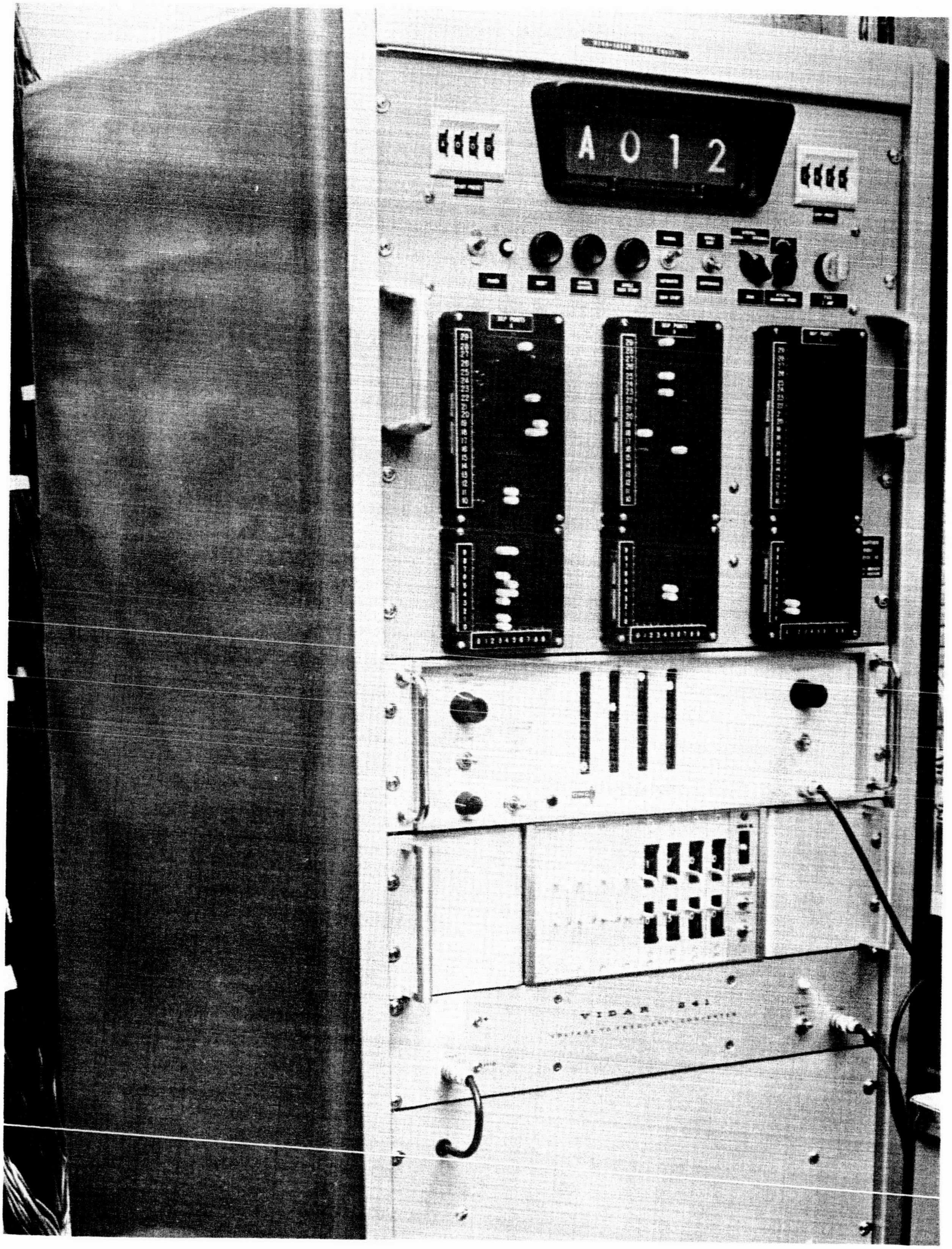
H. Photograph of Test Area: Photograph 7 shows the overall arrangement of the test equipment described in paragraphs V.B. through V.G.



Several Charge and Discharge Control Units
PHOTOGRAPH 2



Pack Voltage Monitoring Panel
PHOTOGRAPH 3

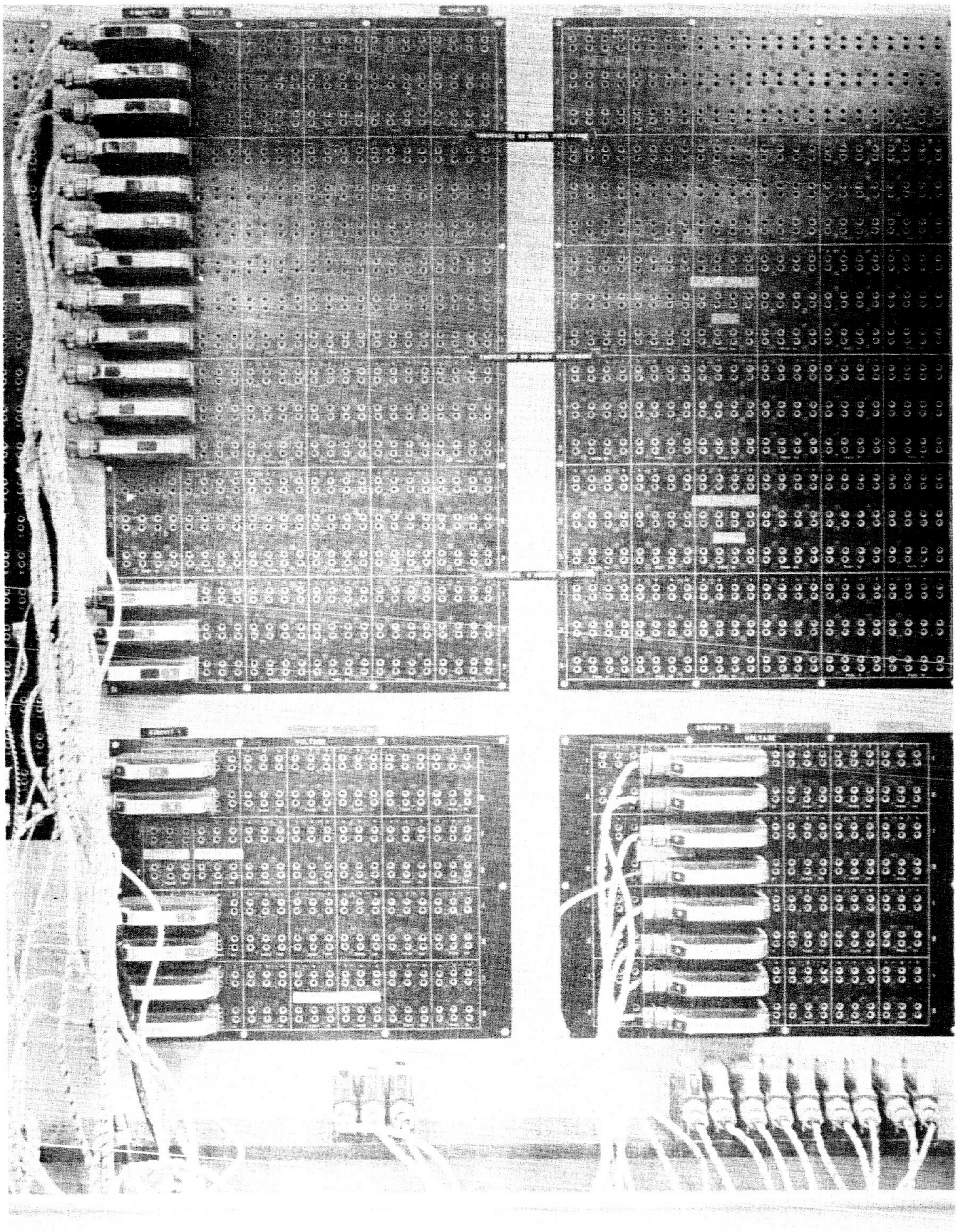


Individual Cell Voltage Scanning System

PHOTOGRAPH 4

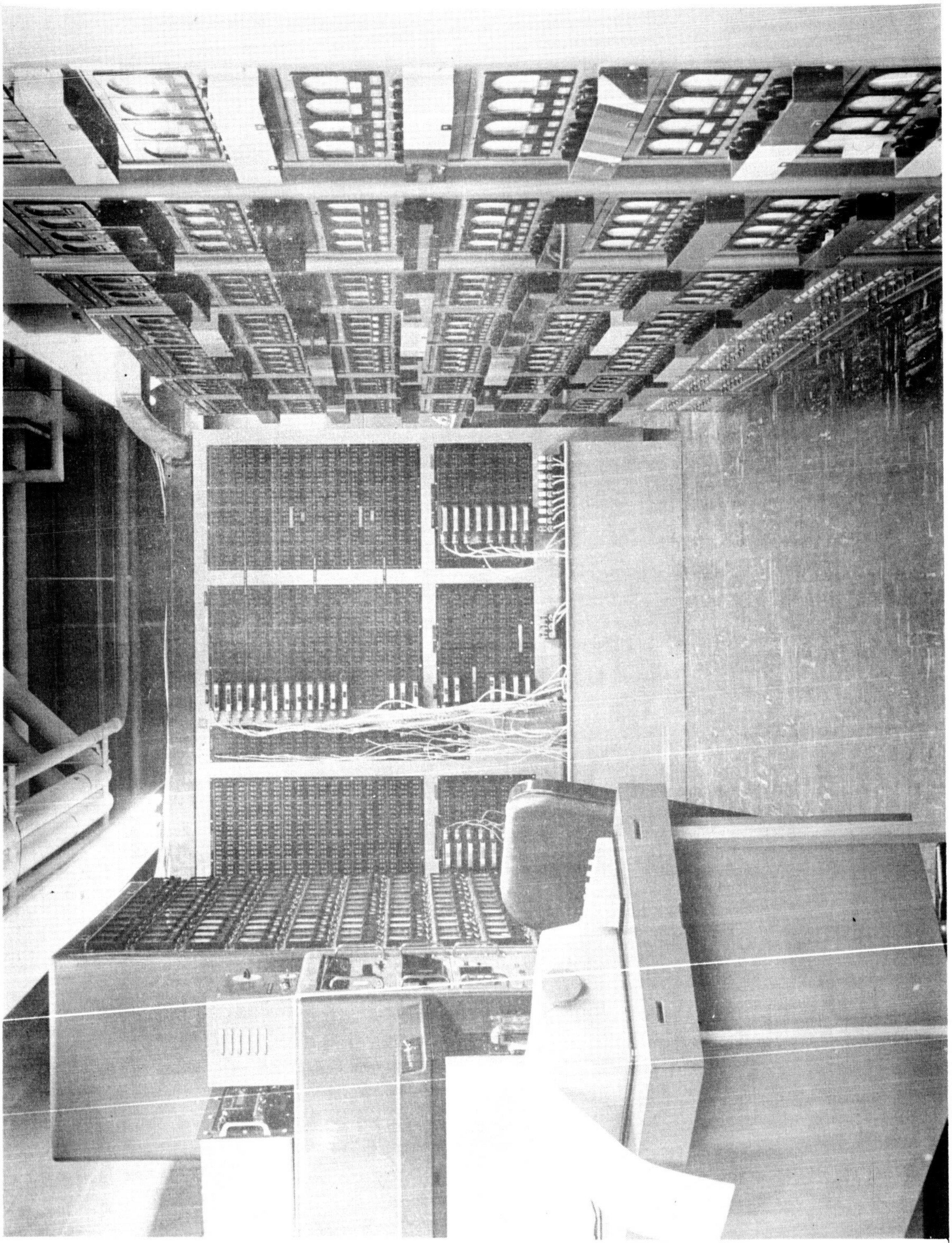
Data Logging System

PHOTOGRAPH 5

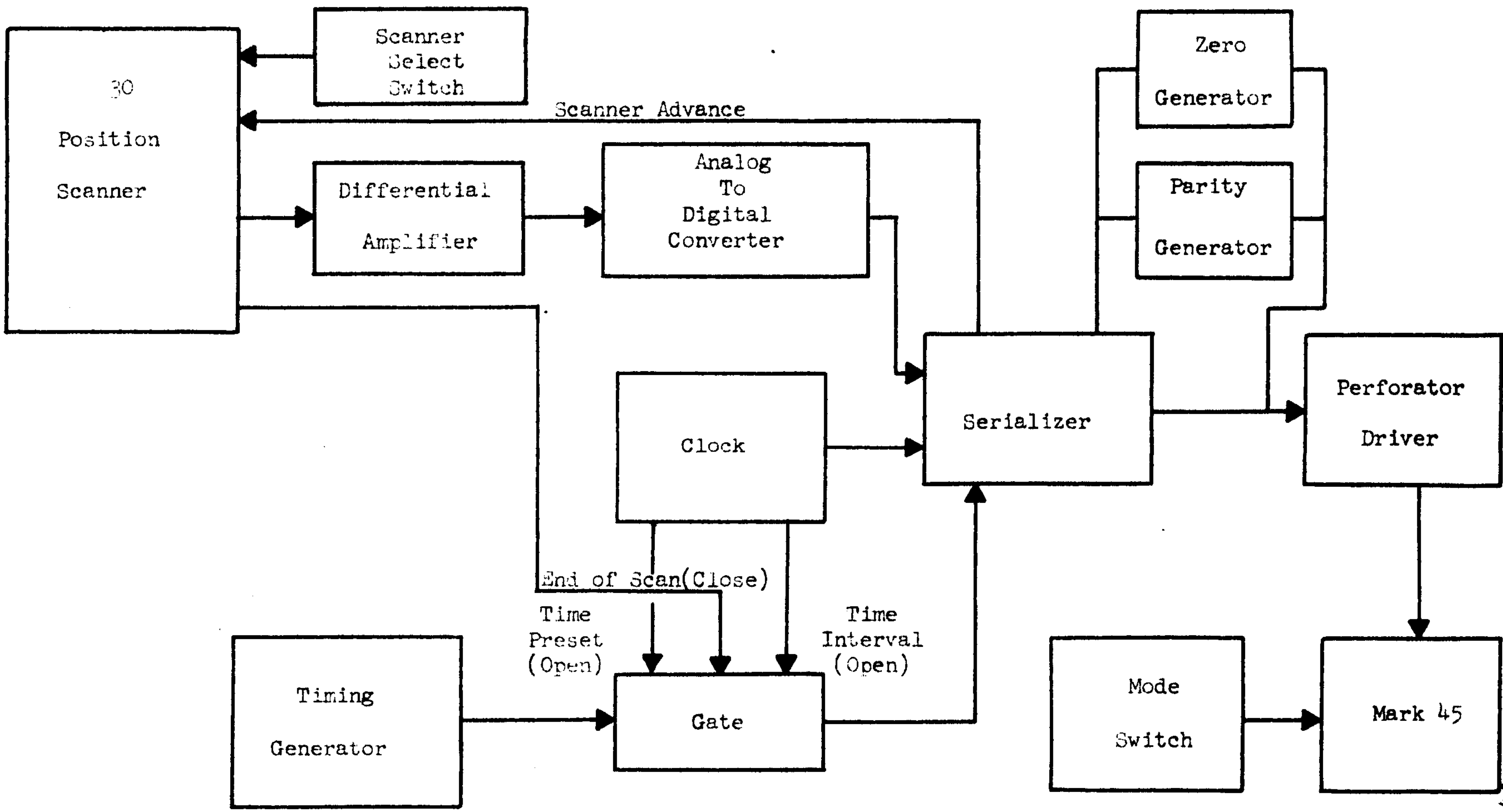


Portion of Central Wiring Panel

PHOTOGRAPH 6

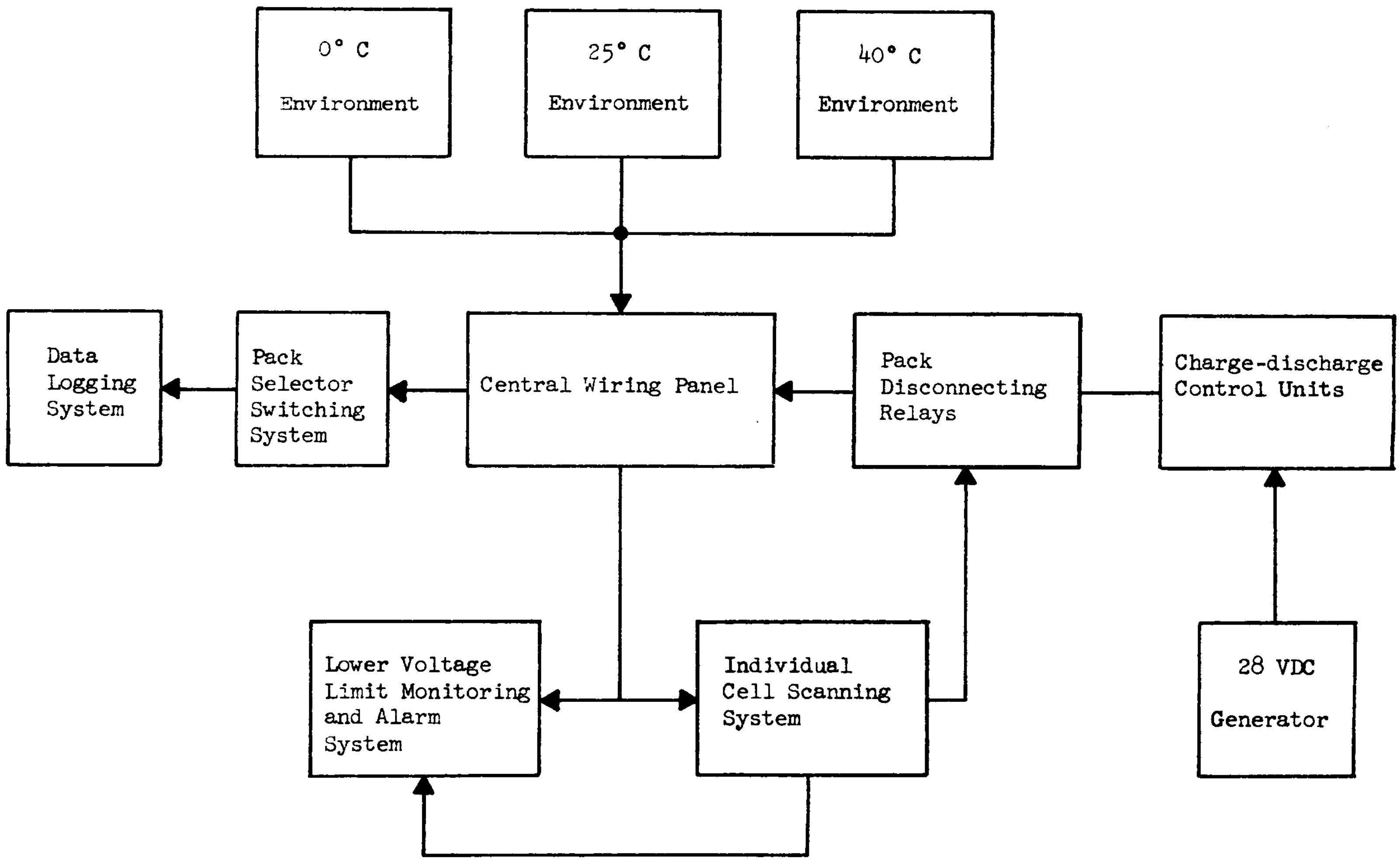


Test Area
PHOTOGRAPH 7



Block Diagram of Data Logging System

FIGURE 15



Block Diagram of Test Setup
FIGURE 16

SECTION II

CELLS ADDED TO THE CYCLE LIFE TEST PROGRAM

I. CELLS USING CONVENTIONAL CHARGE CONTROL METHODS

A. Nickel-Cadmium Types:

1. Gulton 4.0 a.h. (commercial), Six 5-cell Packs, 1.5-hour Orbit Period:

a. Cell Description: These are rectangular sealed cells of commercial grade, but were not hermetically sealed as supplied. They were epoxy potted into 5-cell packs at the Goddard Space Flight Center in order to hermetically seal the cells before test.

b. Test Parameters:

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

c. Test Results:

(1) Performance on cycling: (Figures 17(a) through 17(f).) These packs have completed from 7638 to 8136 cycles, with two cell failures. In all cases there appears to have been a slight tendency toward increasing end-of-charge voltage or decreasing end-of-charge current. Some leakage occurred as follows:

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

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

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

(d) Pack 214: Leakage under the epoxy. A crack developed at the bottom of the epoxy case after 1785 cycles, allowing some electrolyte to escape. One cell, which failed after 7564 cycles, is awaiting the failure of the pack before it can be analyzed.

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

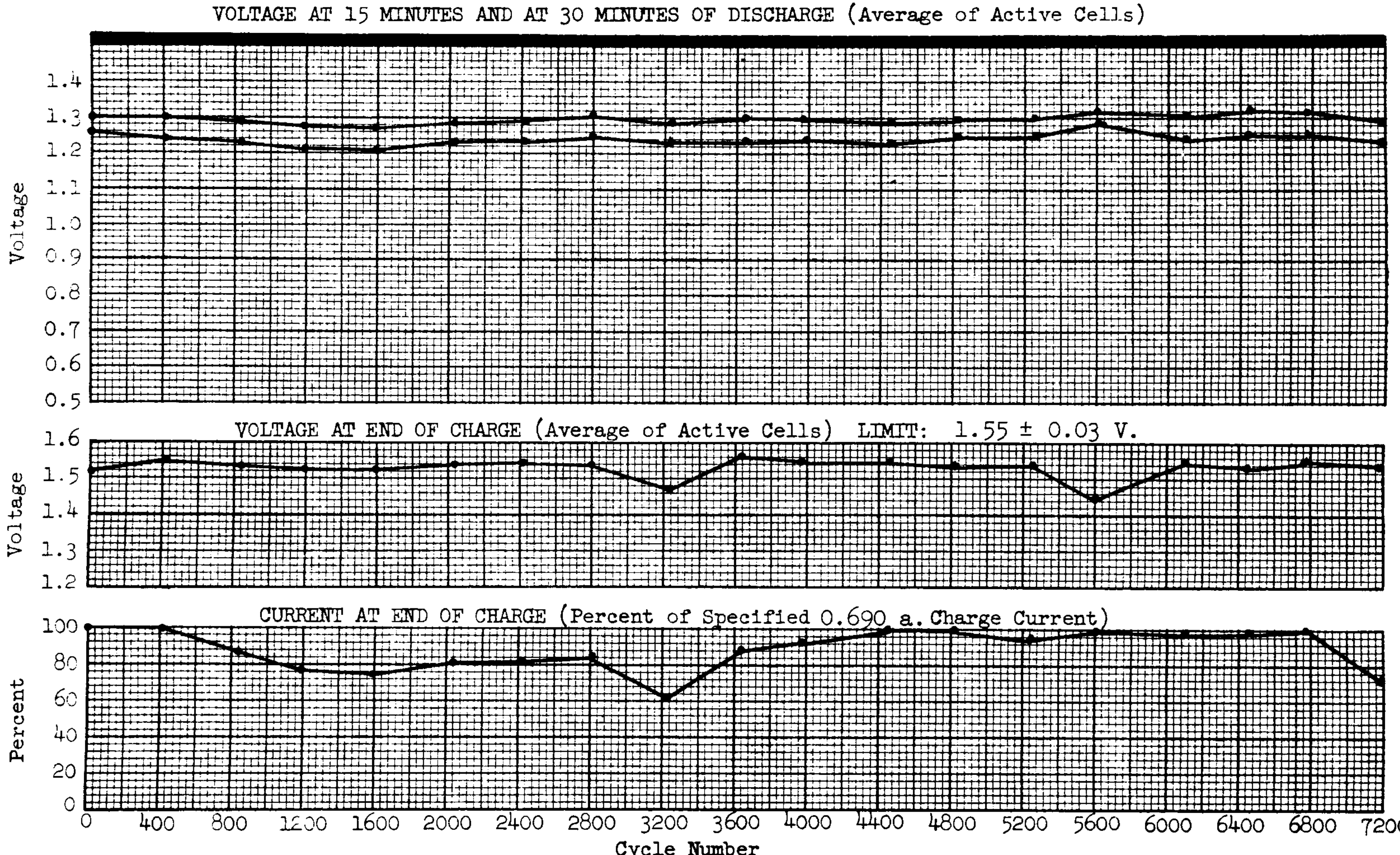
(f) Pack 240: Possible leakage under the epoxy. One cell, which failed after 7900 cycles, is awaiting the failure of the pack before it can be analyzed.

(2) Capacity Checks: The ampere-hour capacities of the cells on the preconditioning and capacity check cycles are shown in Table IX.

TABLE IX

AMPERE-HOUR CAPACITY ON PRECONDITIONING CYCLES AND CAPACITY CHECKS
GULTON 4.0 a.h.

PACK NUMBER	PRECONDITIONING	88 DAYS DISCHARGE		176 DAYS DISCHARGE		264 DAYS DISCHARGE		352 DAYS DISCHARGE		440 DAYS DISCHARGE	
		#1	#2	#1	#2	#1	#2	#1	#2	#1	#2
315	5.04	3.28	3.57	3.60	4.03	3.67	4.00	3.80	3.50	3.80	4.07
326	4.87	3.23	4.00	3.43	3.87	3.33	3.73	3.17	3.60	3.17	3.60
204	4.63	2.30	2.47	1.90	2.07	1.70	1.83	1.63	1.80	3.30	3.67
214	5.00	1.93	2.00	1.87	2.07	1.67	1.87	1.80	1.93	1.63	1.93
228	4.20	1.77	1.70	1.50	1.67	1.47	1.43	1.43	1.53	1.93	1.53
240	3.37	1.13	1.17	1.10	1.13	1.17	1.30	1.03	0.96	1.30	1.17



Cell Number	Cycle Failed

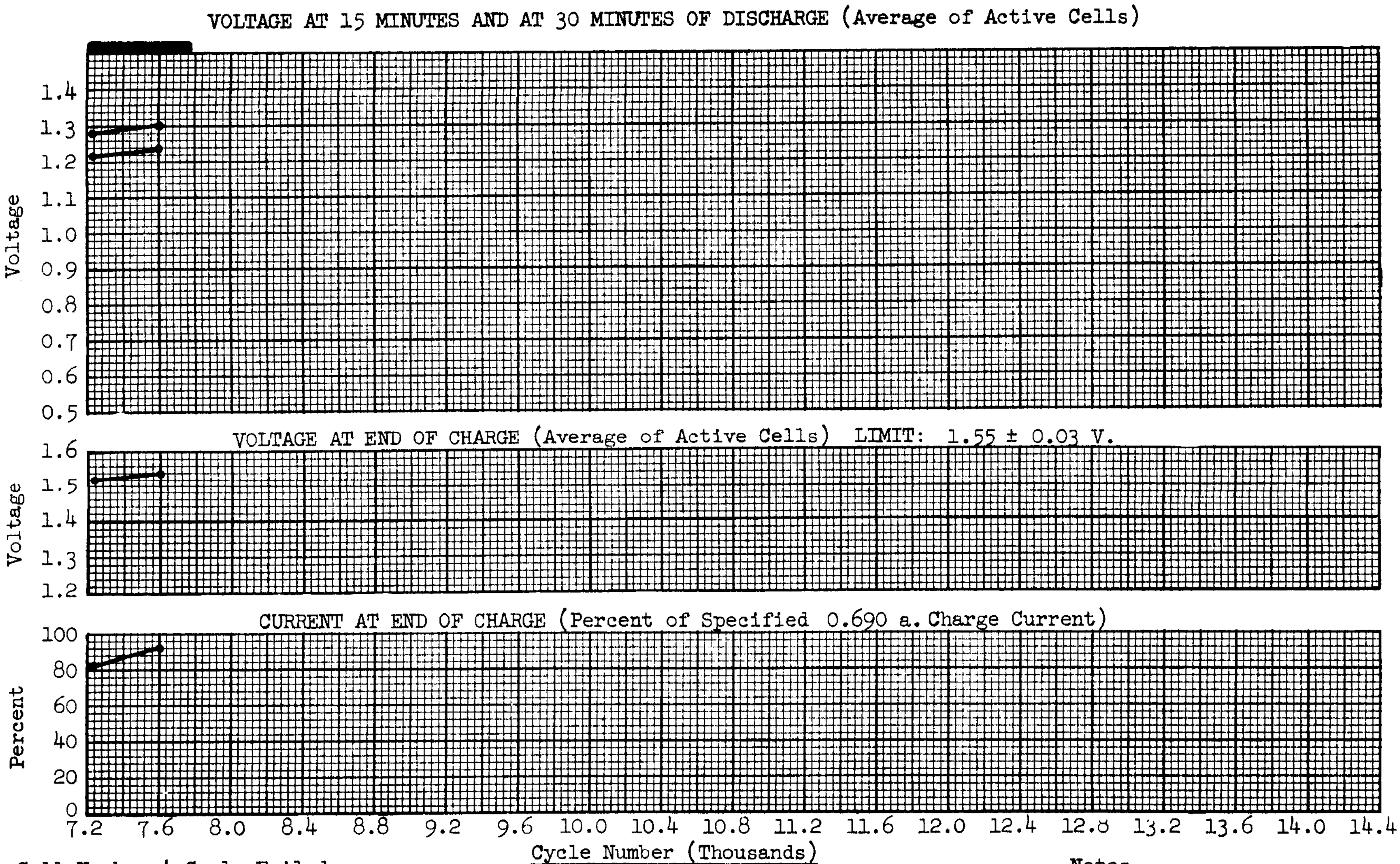
GULTON 4.0 a.h. (Pack 315)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

Status: Continued

Notes

1. Cycle 1669, 3149, 4346, 5553, 6783: Capacity Check.

FIGURE 17(a)



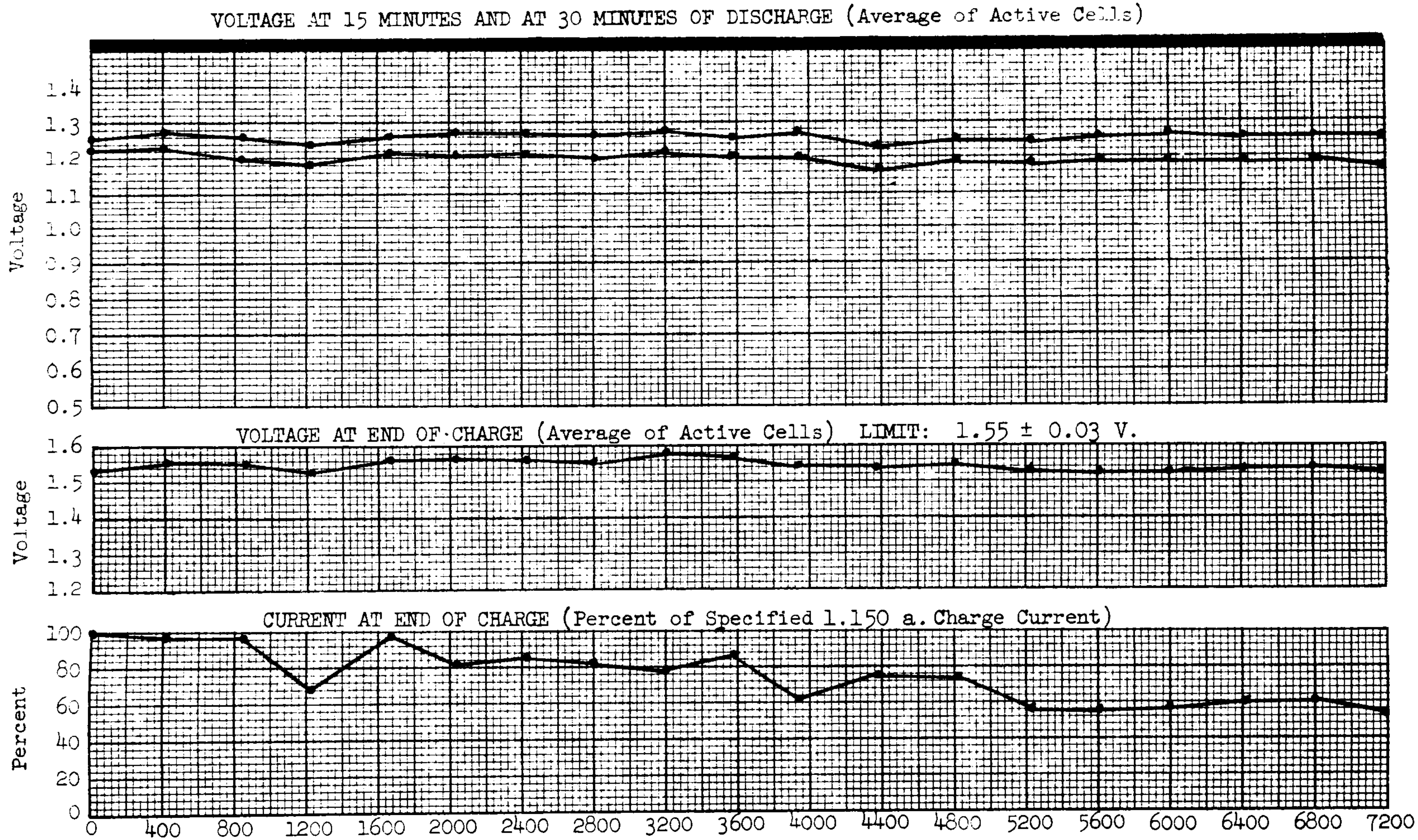
Cell Number	Cycle Failed

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 7781 cycles.

Notes

FIGURE 17(a) (Contd)



Cell Number	Cycle Failed

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

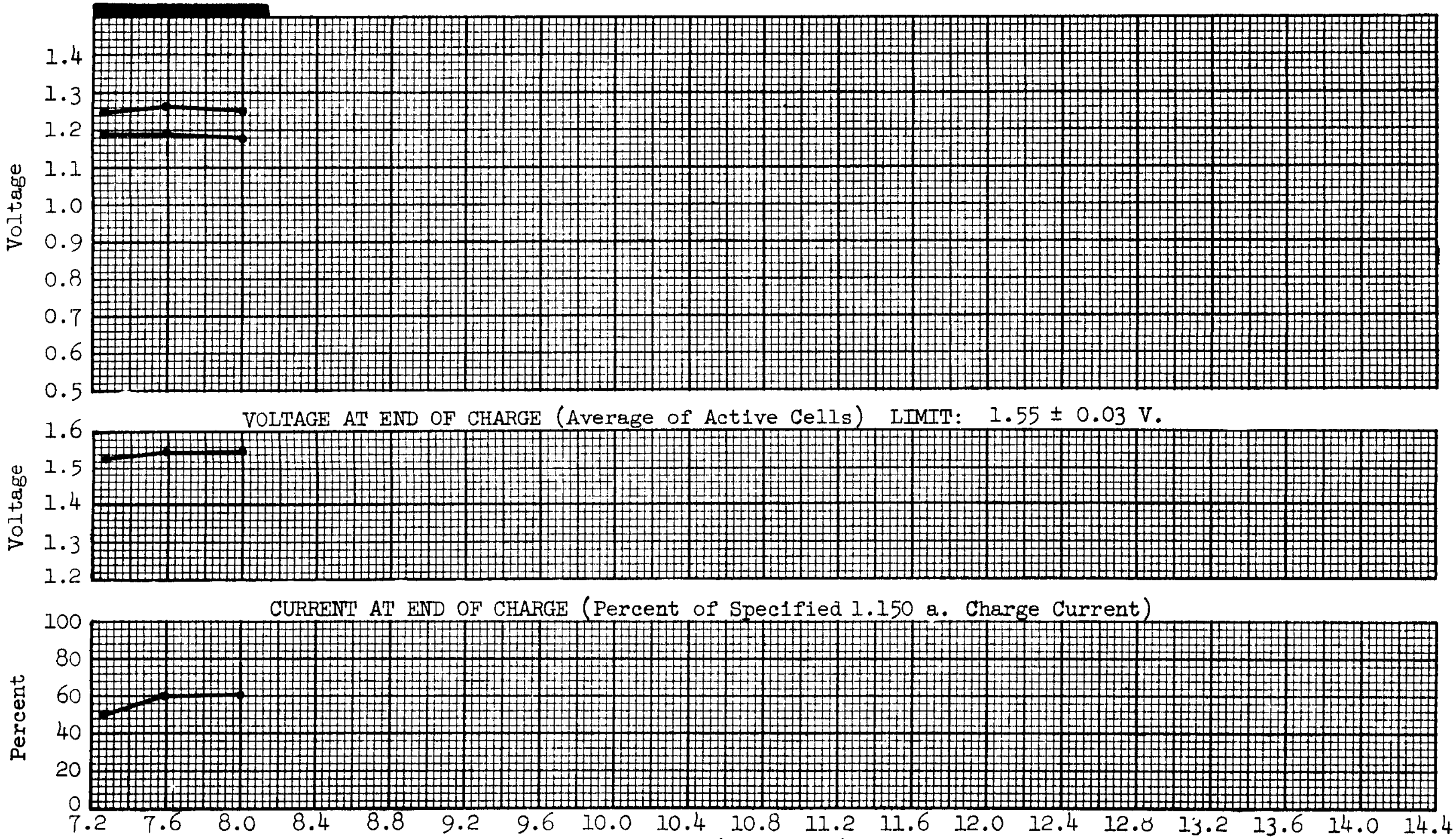
Status: Continued

Notes

1. Cycles 1669, 3149, 4545, 6625: Capacity Check.

FIGURE 17(b)

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



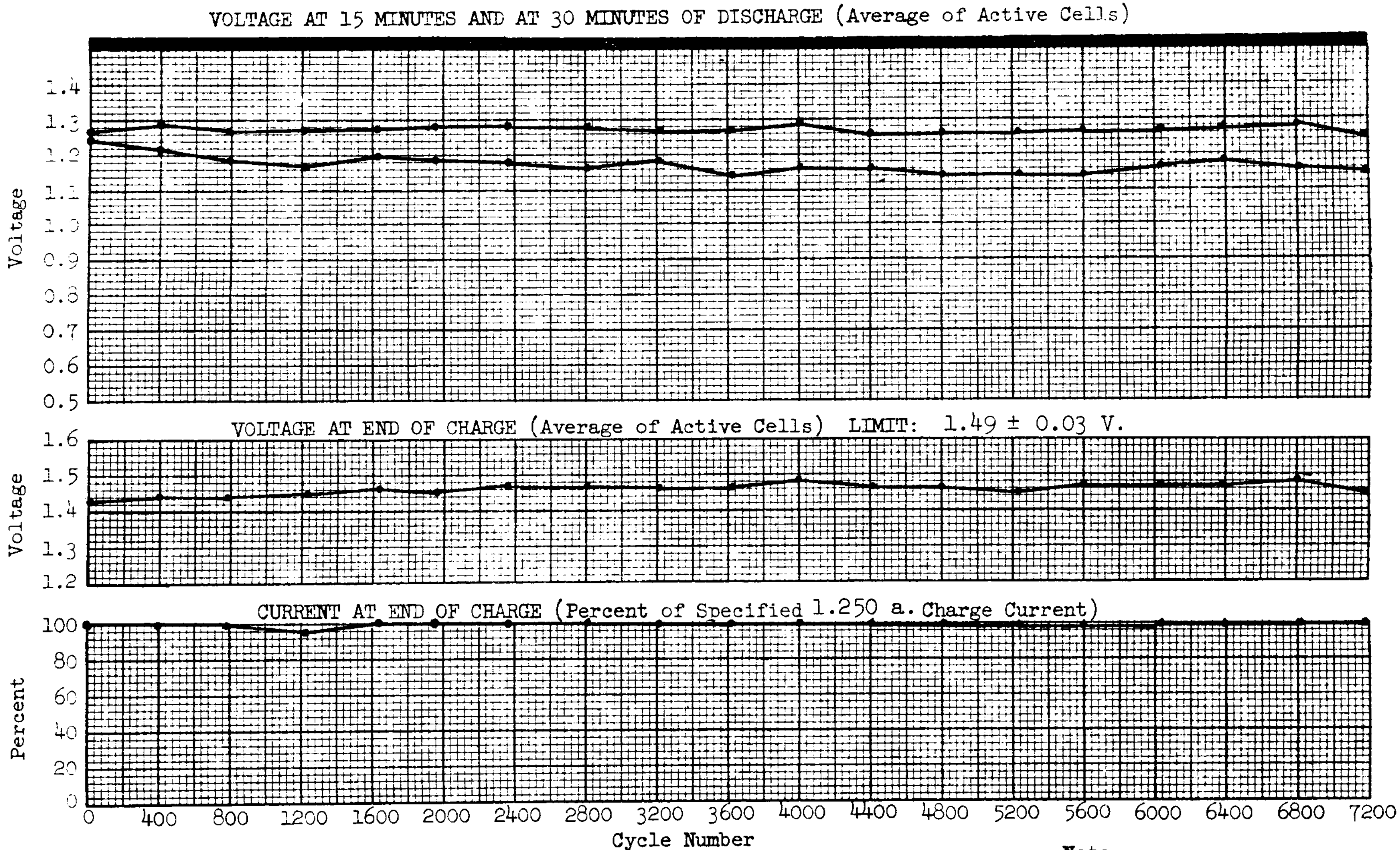
Cell Number	Cycle Failed

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 8136 cycles.

Notes

FIGURE 17(b) (Contd)



Cell Number	Cycle Failed

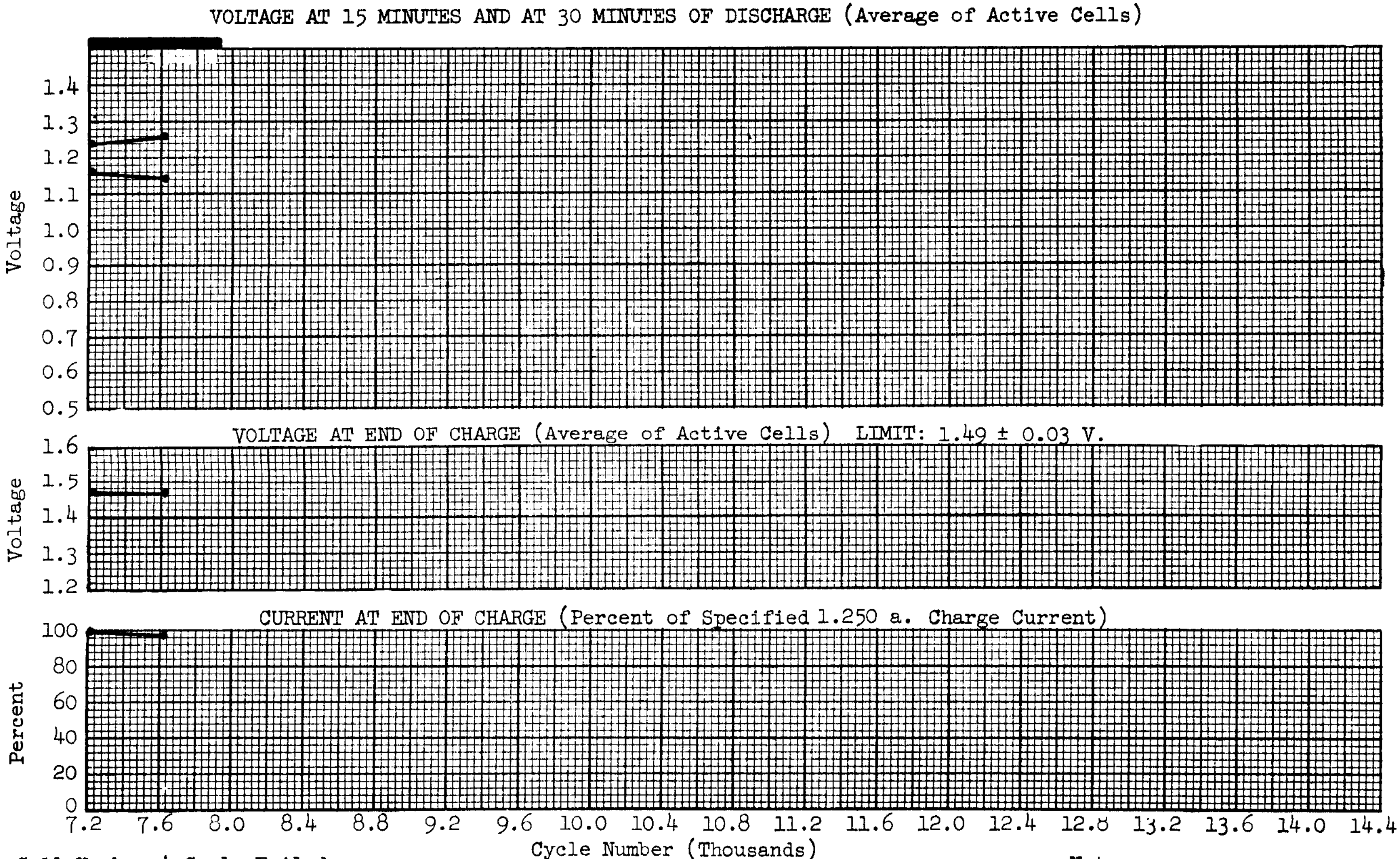
GULTON 4.0 a.h. (Pack 204)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: Continued

Notes

1. Cycle 1484, 2880, 4271, 5514, 5933: Capacity Check.

FIGURE 17(c)



Cell Number	Cycle Failed

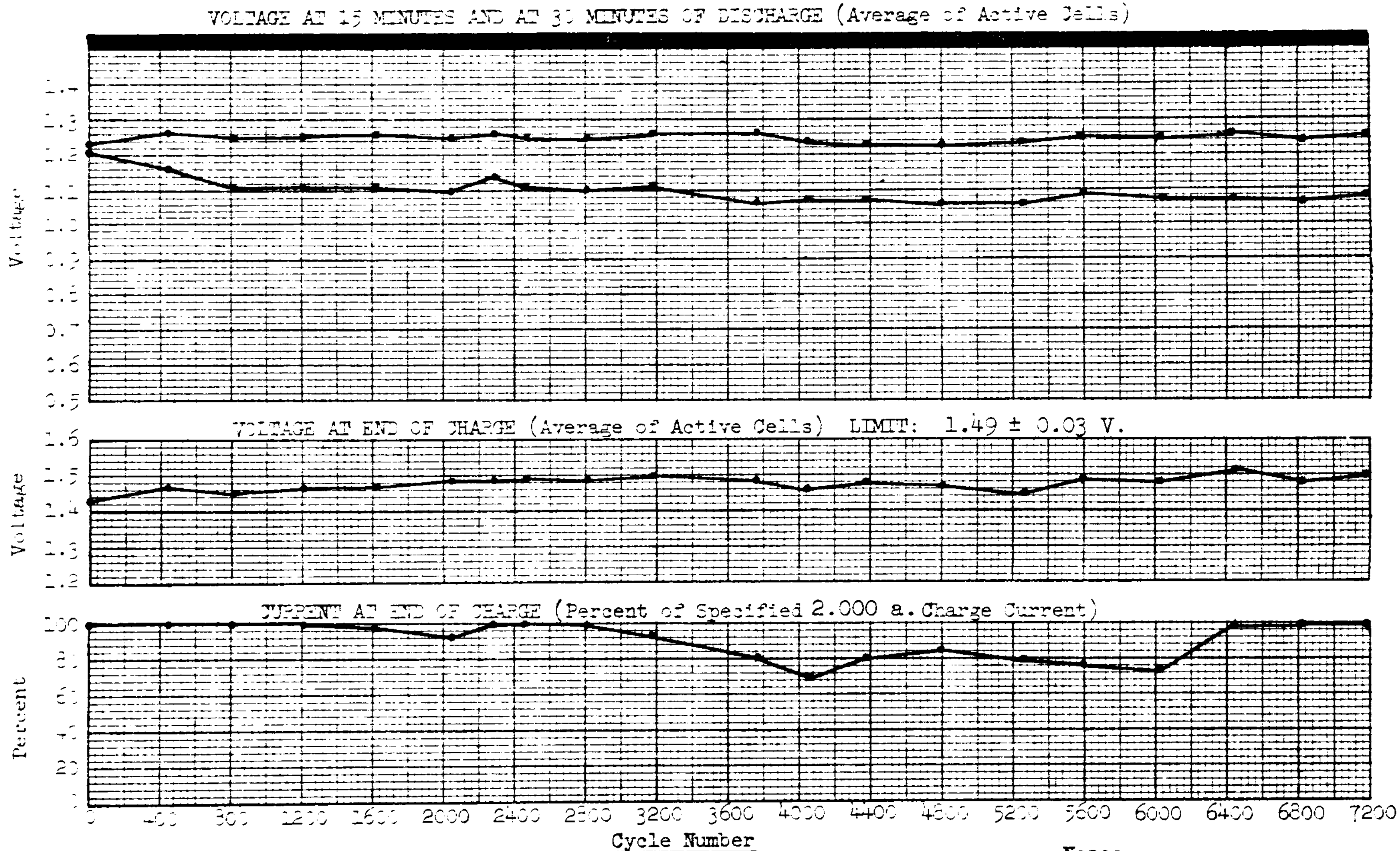
GULTON 4.0 a.h. (Pack 204)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: 5 cells cycling after 7933 cycles.

Notes

1. Cycles 7142: Capacity Check.

FIGURE 17(c) (Contd)



Cell Number	Cycle Failed

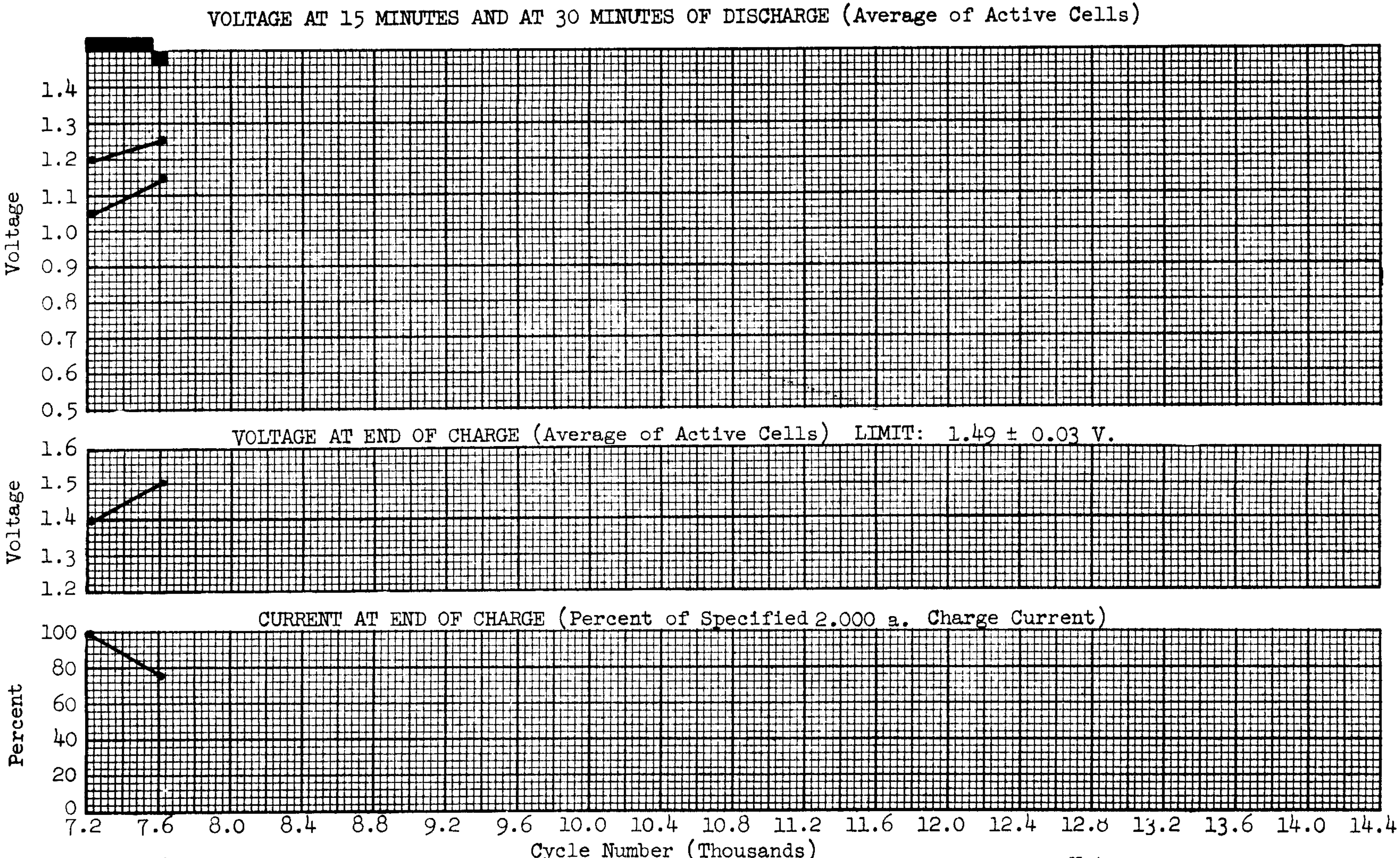
GULTON 4.0 a.h. (Pack 214)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 40%

Status: Continued

Notes

1. Cycle 1515, 2608, 3969, 6199: Capacity Check.

FIGURE 17(d)



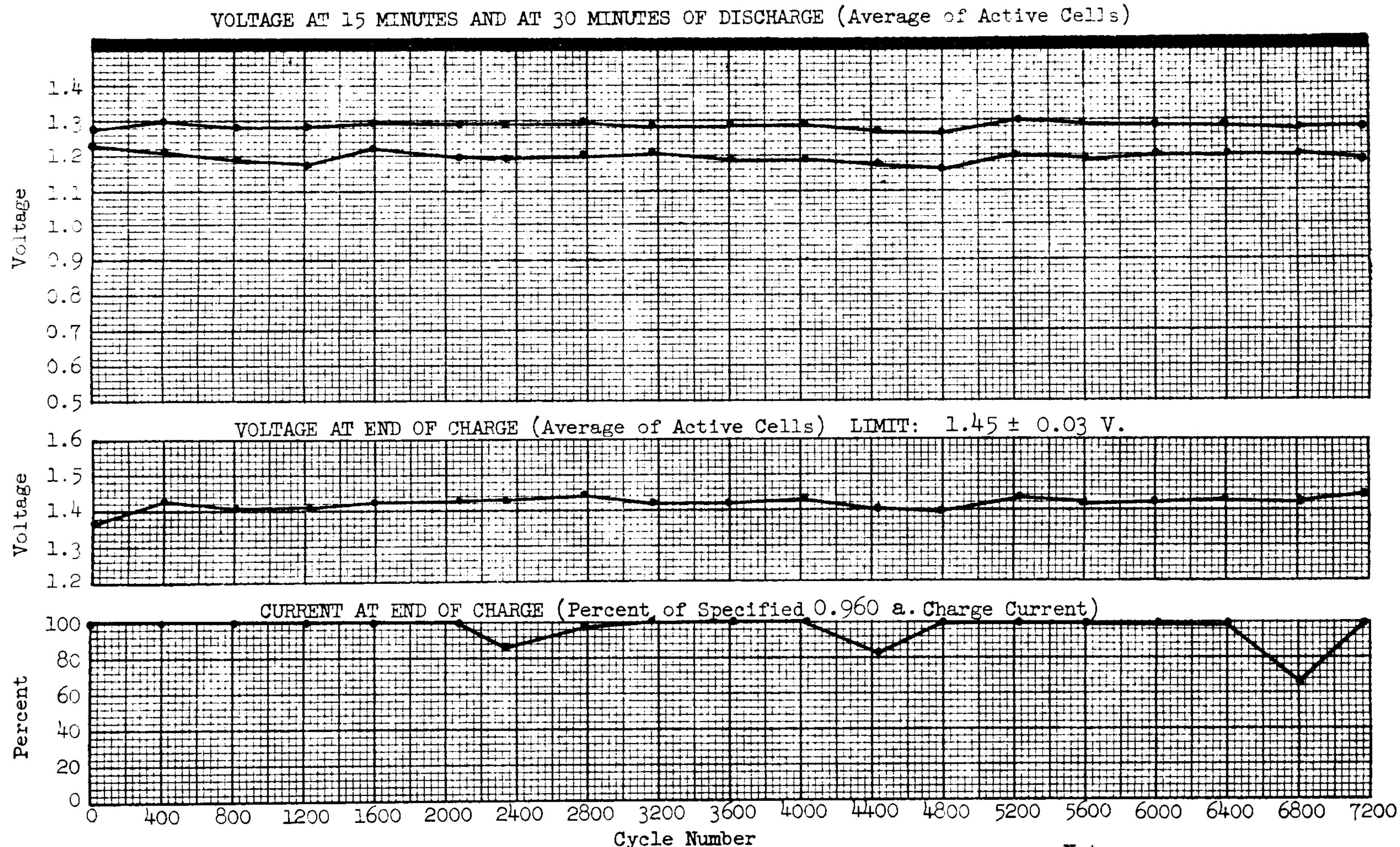
Cell Number	Cycle Failed
Position 3	7564

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

Status: 4 cells cycling after 7638 cycles.

Notes

FIGURE 17(d) (Contd)



Cell Number	Cycle Failed

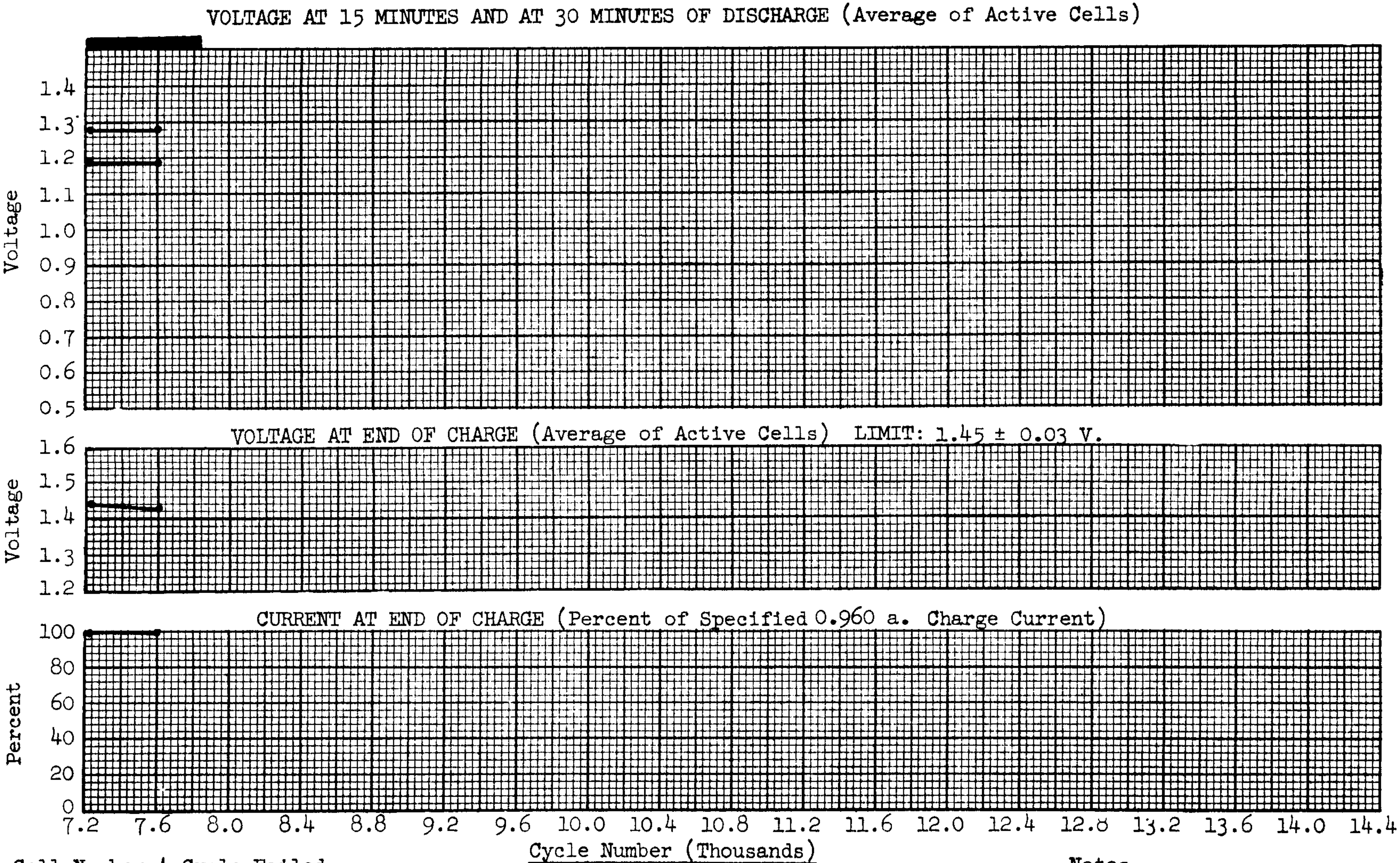
GULTON 4.0 a.h. (Pack 228)
Test Temperature: 40° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

Status: Continued

Notes

1. Cycle 1483, 2881, 4254, 5610, 6724: Capacity Check.

FIGURE 17(e)



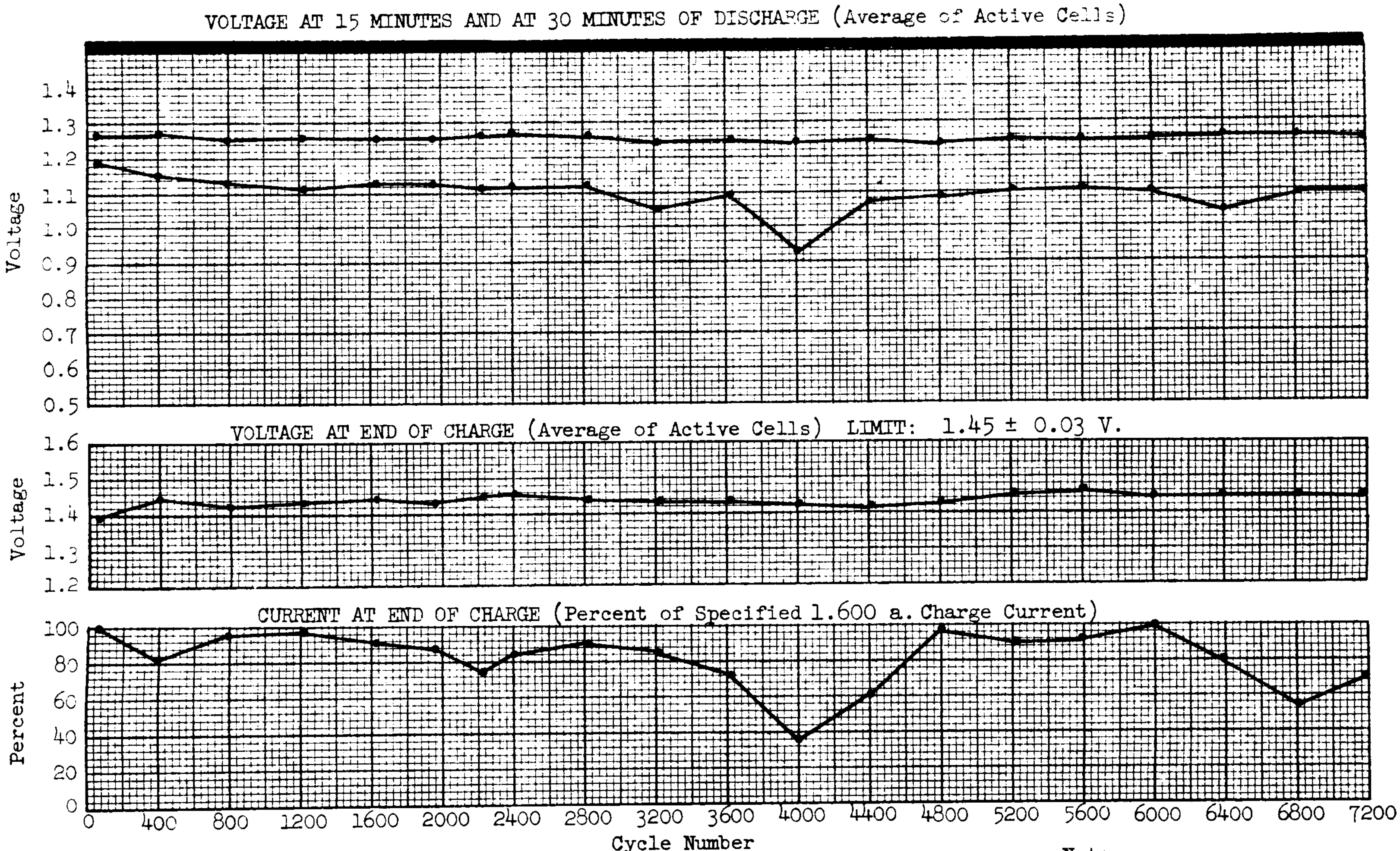
Cell Number	Cycle Failed

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 7826 cycles.

Notes

FIGURE 17(e) (Contd)



Cell Number	Cycle Failed
	.

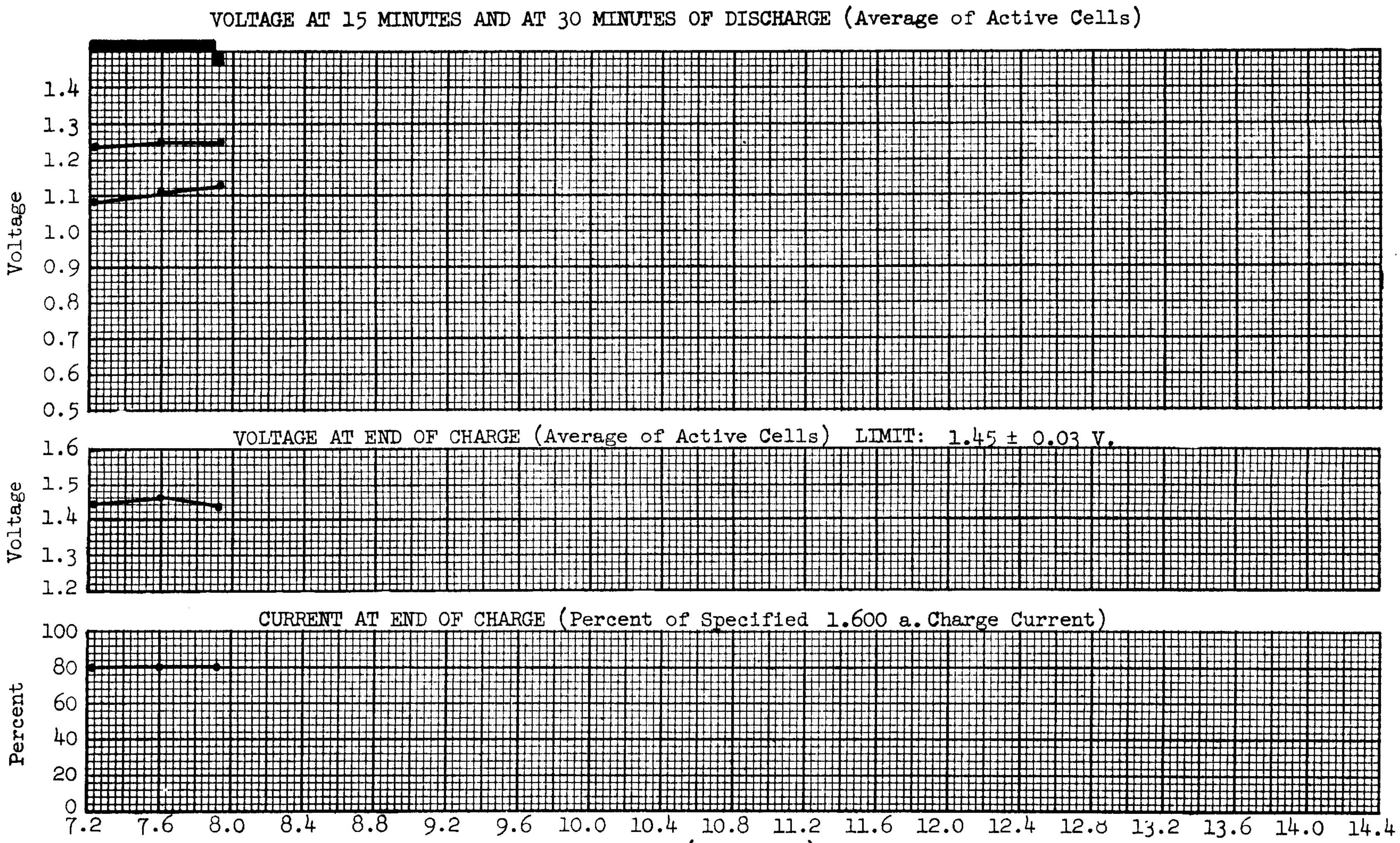
GULTON 4.0 a.h. (Pack 240)
Test Temperature: 40° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: Continued

Notes

1. Cycle 1517, 2915, 4277, 5710, 6839: Capacity Check.

FIGURE 17(f)



Cell Number	Cycle Failed
Position 4	7900

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

Status: 4 cells cycling after 7942 cycles.

Notes

FIGURE 17(f) (Contd)

2. Gulton 5.0 a.h. (NIMBUS), Six 5-cell Packs, 1.5-hour Orbit Period:

a. Cell Description: These cells are cylindrical in shape with a convex base. A threaded stud is fastened to the base to facilitate heat sink mounting. The cell container and the cell cover are made of stainless steel. Two stainless steel tabs, welded to the cover, serve as the contacts for the negative terminal. The positive terminal is insulated from the cell cover by a ceramic seal and protrudes through the cover as a solder type terminal. Two solder tabs are welded to the terminal. Three cells have pressure transducers mounted on the cell to read internal pressure in pounds per square inch absolute. These cells were designed for use in the NIMBUS satellite.

b. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge	Percent of Recharge	Charge Voltage Limit, Per Cell
117	0° C	15	110	1.49 ± 0.03
121*	0° C	25	110	1.49 ± 0.03
120	25° C	25	120	1.49 ± 0.03
318*	25° C	40	120	1.49 ± 0.03
127	40° C	15	130	1.49 ± 0.03
128*	40° C	25	130	1.49 ± 0.03

* One cell in each of these packs is equipped with a pressure transducer.

c. Test Results:

(1) Performance on cycling: (Figures 18(a) through 18(f).)

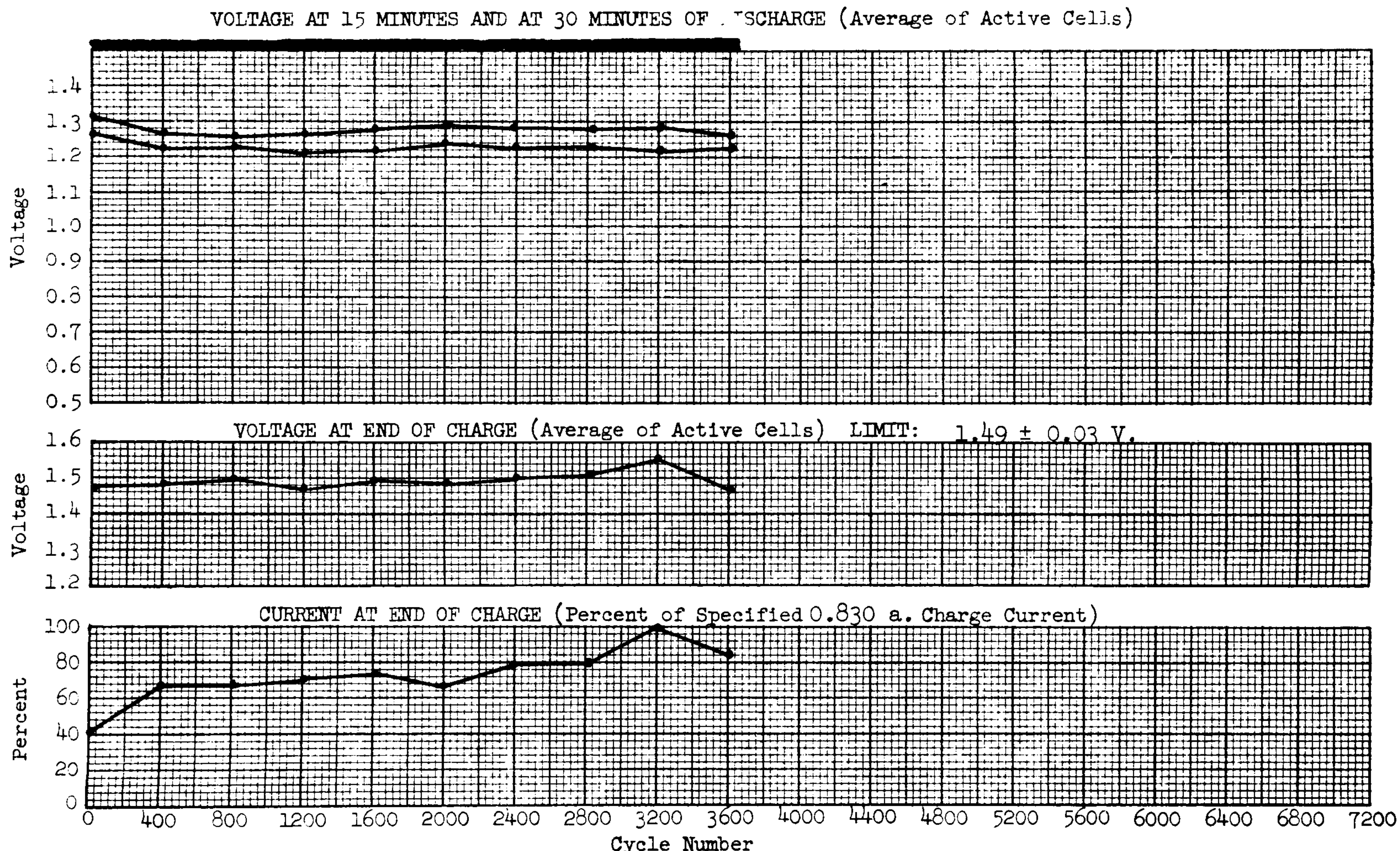
(a) These packs have completed from 3087 to 3795 cycles, with one cell failure, which occurred in Pack 128 after 2422 cycles at 40° C. The cell showed migration of the negative plate material and had a ceramic short.

(b) The end-of-charge voltage showed an increase with cycling but the end-of-discharge voltage remained constant.

(c) The internal pressure of the three cells with the pressure transducers showed an increase in pressure with an increase in temperature. The pressure was 11.0 psia at 0° C, 22.7 psia at 25° C, and 27.0 psia at 40° C.

(2) Capacity Checks: The ampere-hour capacities of the cells on the preconditioning and capacity check cycles are as follows:

Pack Number	Preconditioning	88 Days Discharge #1	88 Days Discharge #2	176 Days Discharge #1	176 Days Discharge #2
117	5.00	4.96	5.17	5.00	5.46
121	5.38	4.92	5.38	4.88	5.33
120	5.25	5.33	5.40	2.96	4.17
318	5.46	1.79	2.55	1.42	1.67
127	3.29	1.29	1.67	1.25	1.50
128	3.04	1.17	1.42	1.38	1.54



Cell Number	Cycle Failed

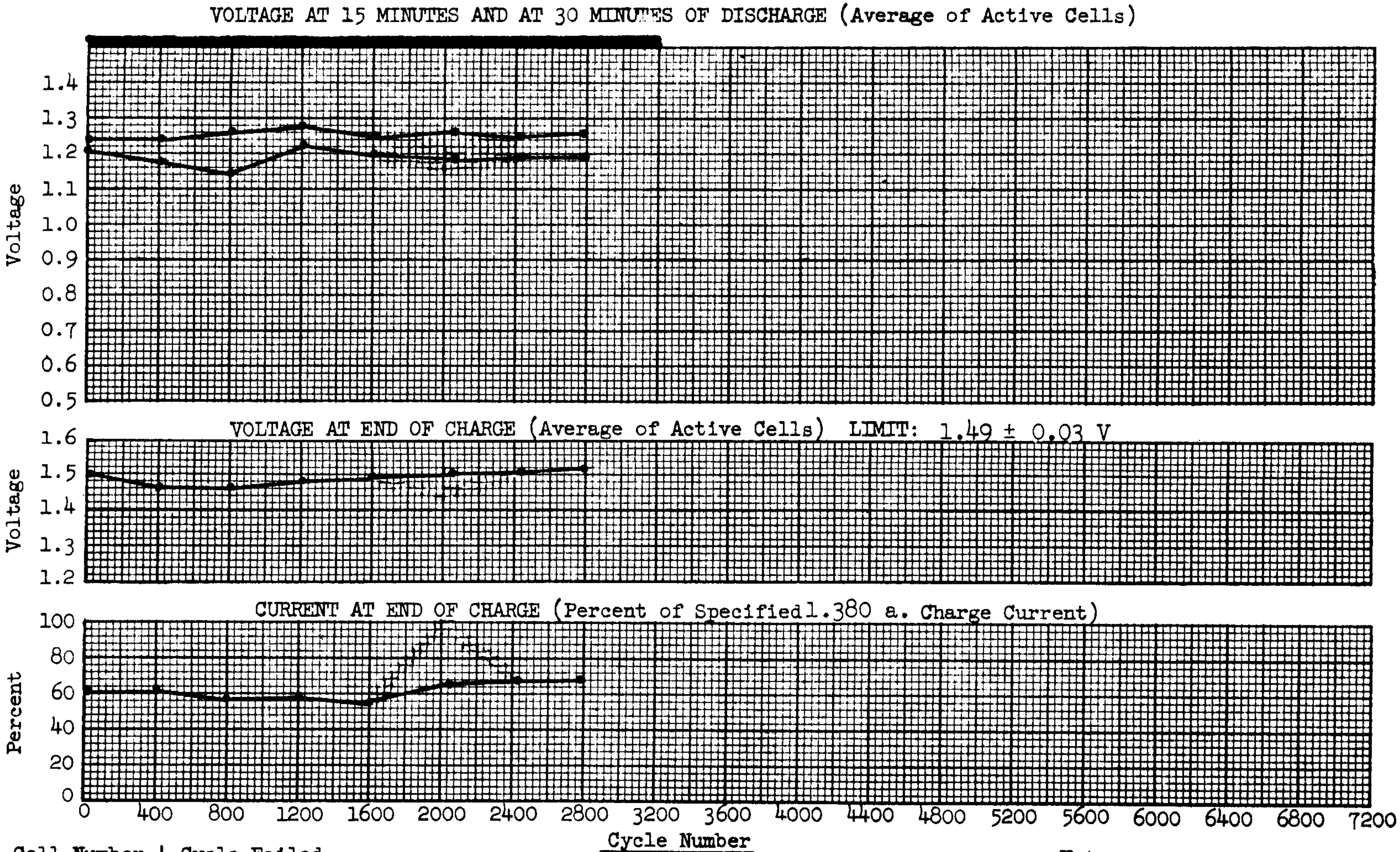
GULTON 5.0 a.h. (Pack 117)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

Status: 5 cells cycling after 3649 cycles.

Notes

1. Cycles 1721, 2967: Capacity Check.

FIGURE 18(a)



Cell Number	Cycle Failed

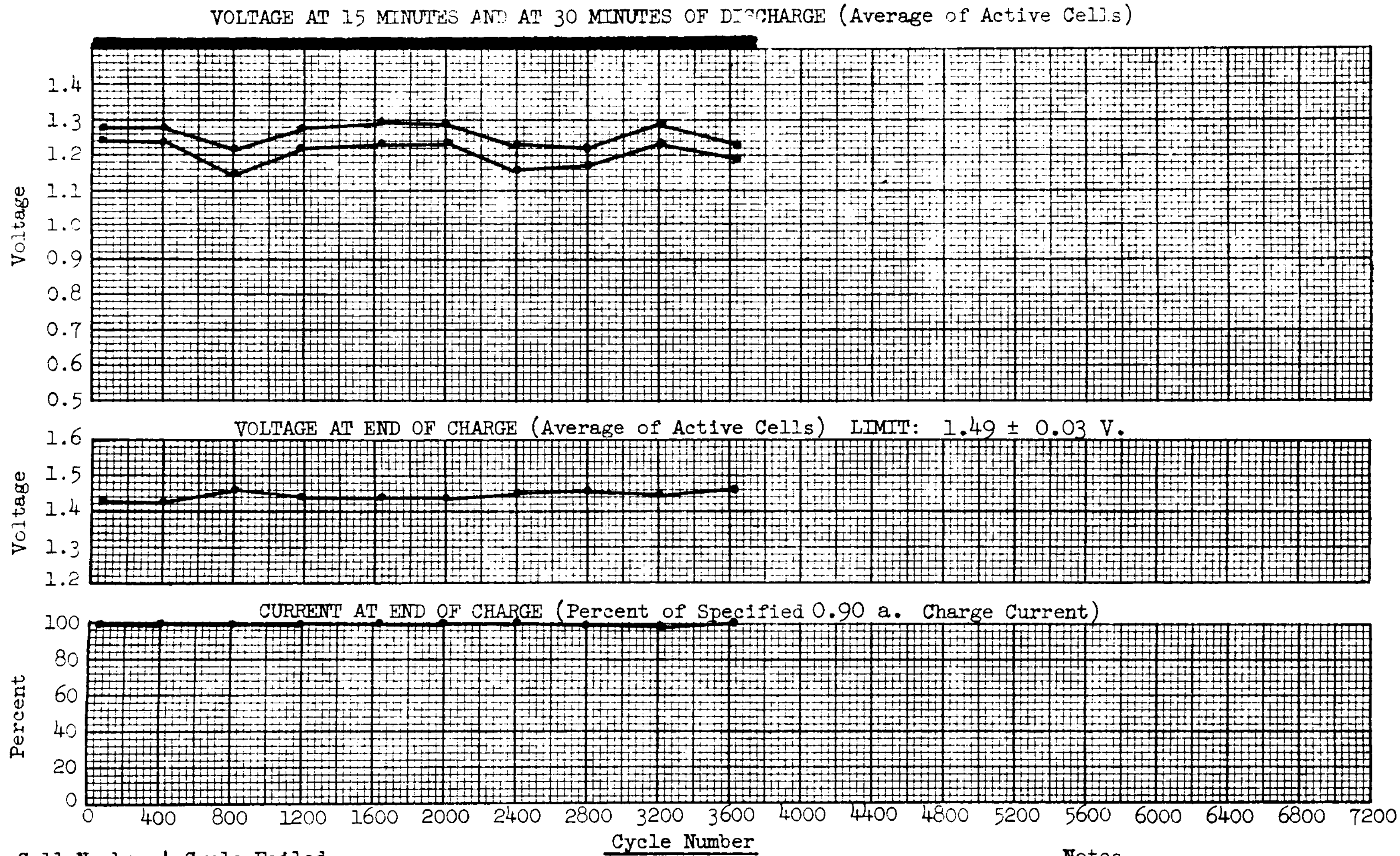
GULTON 5.0 a.h. (Pack 121)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: 5 cells cycling after 3205 cycles.

Notes

1. Cycles 1278, 2524: Capacity Check.

FIGURE 18(b)



Cell Number	Cycle Failed

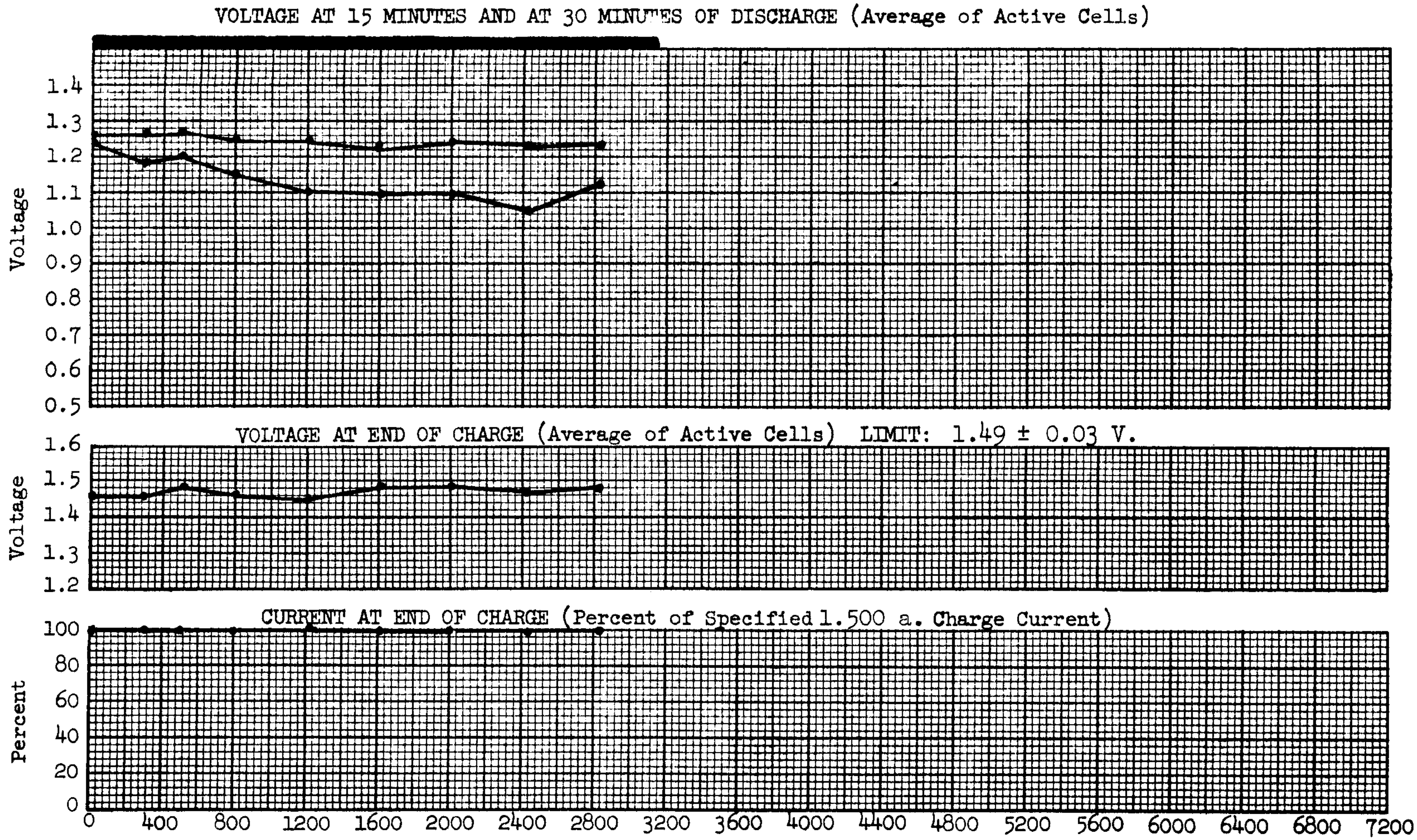
GULTON 5.0 a.h. (Pack 120)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

Status: 5 cells cycling after 3748 cycles.

Notes

1. Cycles 1854, 3101: Capacity Check.

FIGURE 18(c)



Cell Number	Cycle Failed

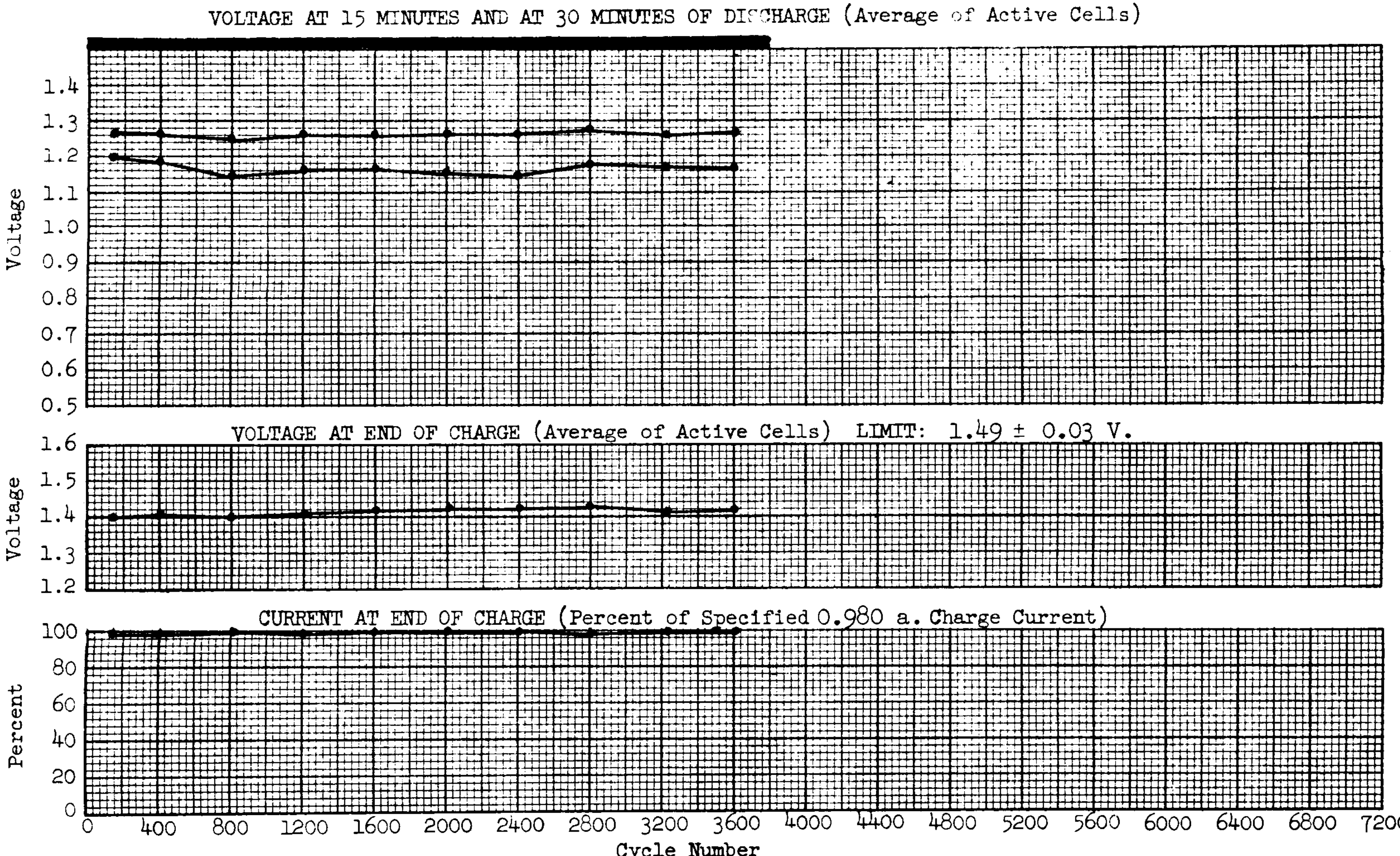
GULTON 5.0 a.h. (Pack 318)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: 5 cells cycling after 3135 cycles.

Notes

1. Cycles 1230, 2477: Capacity Check.

FIGURE 18(d)



Cell Number	Cycle Failed

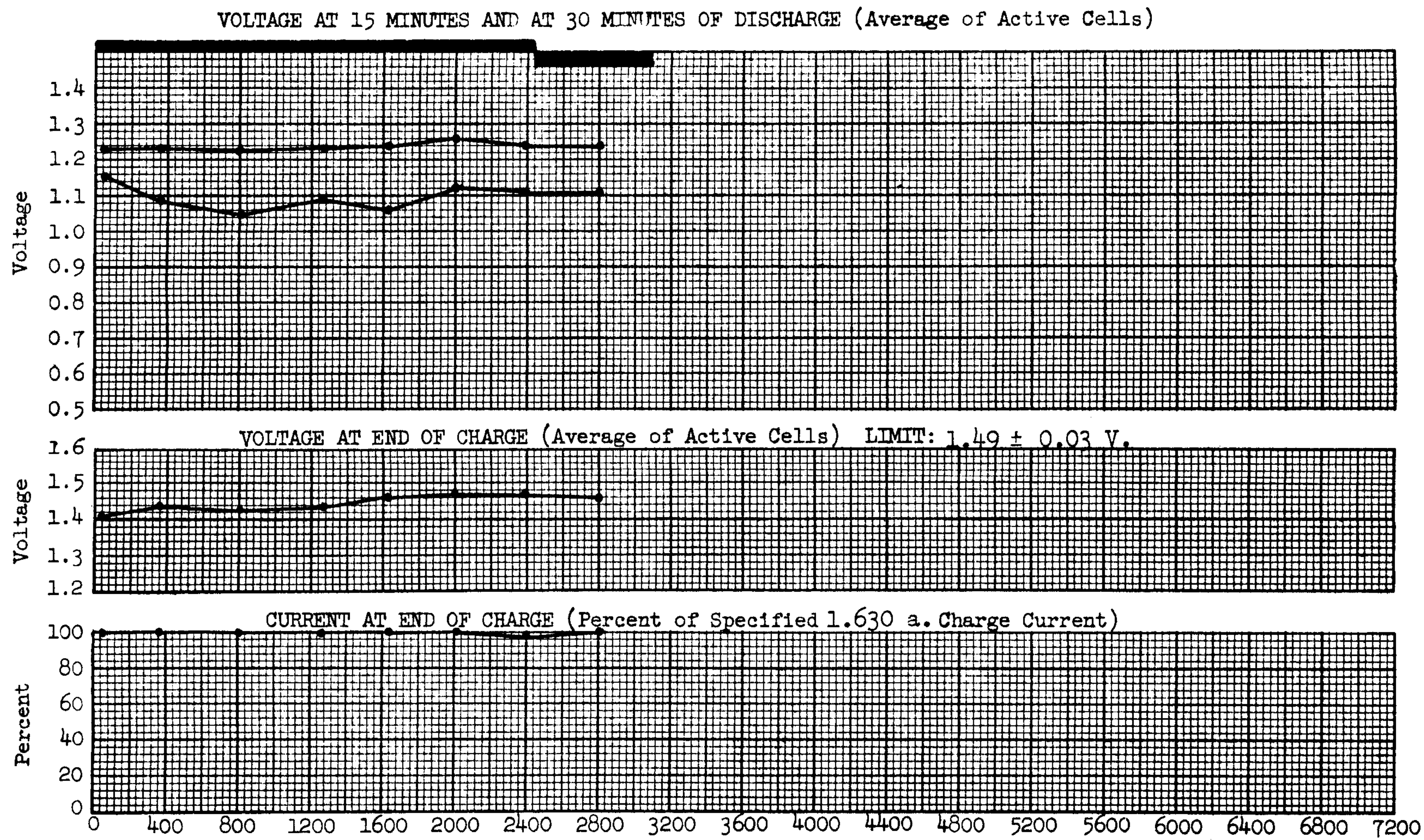
GULTON 5.0 a.h. (Pack 127)
Test Temperature: 40° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

Status: 5 cells cycling after 3795 cycles.

Notes

1. Cycles 1897, 3115: Capacity Check.

FIGURE 18(e)



Cell Number	Cycle Failed
291	2422

GULTON 5.0 a.h. (Pack 128)
Test Temperature: 40° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: 4 cells cycling after 3087 cycles.

Notes

1. Cycles 1193, 2407: Capacity Check.

FIGURE 18(f)

3. Gulton 5.6 a.h. (Neoprene Seal), Six 5-cell Packs, 1.5-hour Orbit Period:

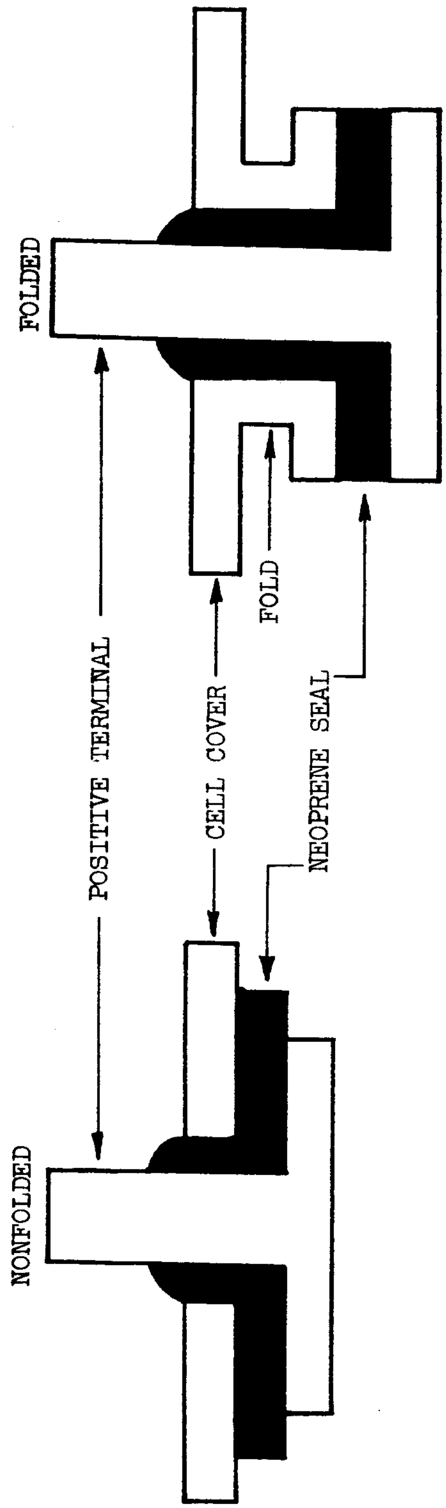
a. Cell Description: These cells are cylindrical in shape. The cell containers and the cell covers are made of cold rolled steel. The positive terminal is insulated from the cell cover by a vulcanized neoprene bushing and protrudes through the bushing as a 1/8 inch projection. The vulcanized neoprene bushing used in the folded cover to terminal seals are longer than those used in the nonfolded cover to terminal seals to protrude through the sleeve formed by the inward fold at the center of the cover (see Figure 19). This design results in a greater length of seal and affords greater protection to the seal from heat during welding of the cover to the can. The possible damage to the neoprene seal of either type cover to terminal seal, by attempting to solder electrical connections to the 1/8 inch positive terminals made it necessary to spot weld metal tabs to these terminals. Metal tabs were also spot welded to the bottom of the cans to serve as the negative terminals.

b. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge	Percent of Recharge	Charge Voltage Limit, Per Cell	Seal
200	0° C	25	115	1.55 ± 0.03	Folded
390	0° C	25	115	1.55 ± 0.03	Nonfolded
276	25° C	25	125	1.49 ± 0.03	Folded
396	25° C	25	125	1.49 ± 0.03	Nonfolded
242	40° C	25	160	1.45 ± 0.03	Folded
230	40° C	25	160	1.45 ± 0.03	Nonfolded

c. Test Results:

(1) Performance on cycling: These packs have completed from 208 to 453 cycles with no failures to date. Several cells cycling at 40° C and 25° C have shown signs of leakage around the top edge of the weld between the cover and the container.



CROSS SECTION OF NEOPRENE SEAL

FIGURE 19

4. Gulton 6.0 a.h., One 5-cell Pack, 24-hour Orbit Period (Pack 79):

a. Cell Description: The cells are rectangular in shape. 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. These are the same as those described in section I, paragraph II.A.3.a.

b. Test Parameters:

(1) Initial Test Parameters:

(a) Test Temperature: 25° C.

(b) Depth of Discharge: 50%.

(c) Percent of Recharge: 150%.

(d) Charge Voltage Limit: 1.49 ± 0.03 volts per cell, average.

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

(2) Due to low end-of-discharge voltage, recharging was increased, after 57 cycles, to 200 percent. This change improved the operation of the pack.

c. Test Results:

(1) Performance on cycling: (Figure 20.)

(a) All cell voltages became quite low at the end-of-discharge with the original 150 percent of recharging. 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 cells climbed to an average of 1.08 volts per cell. After 545 cycles two additional cells failed.

(b) 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.

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

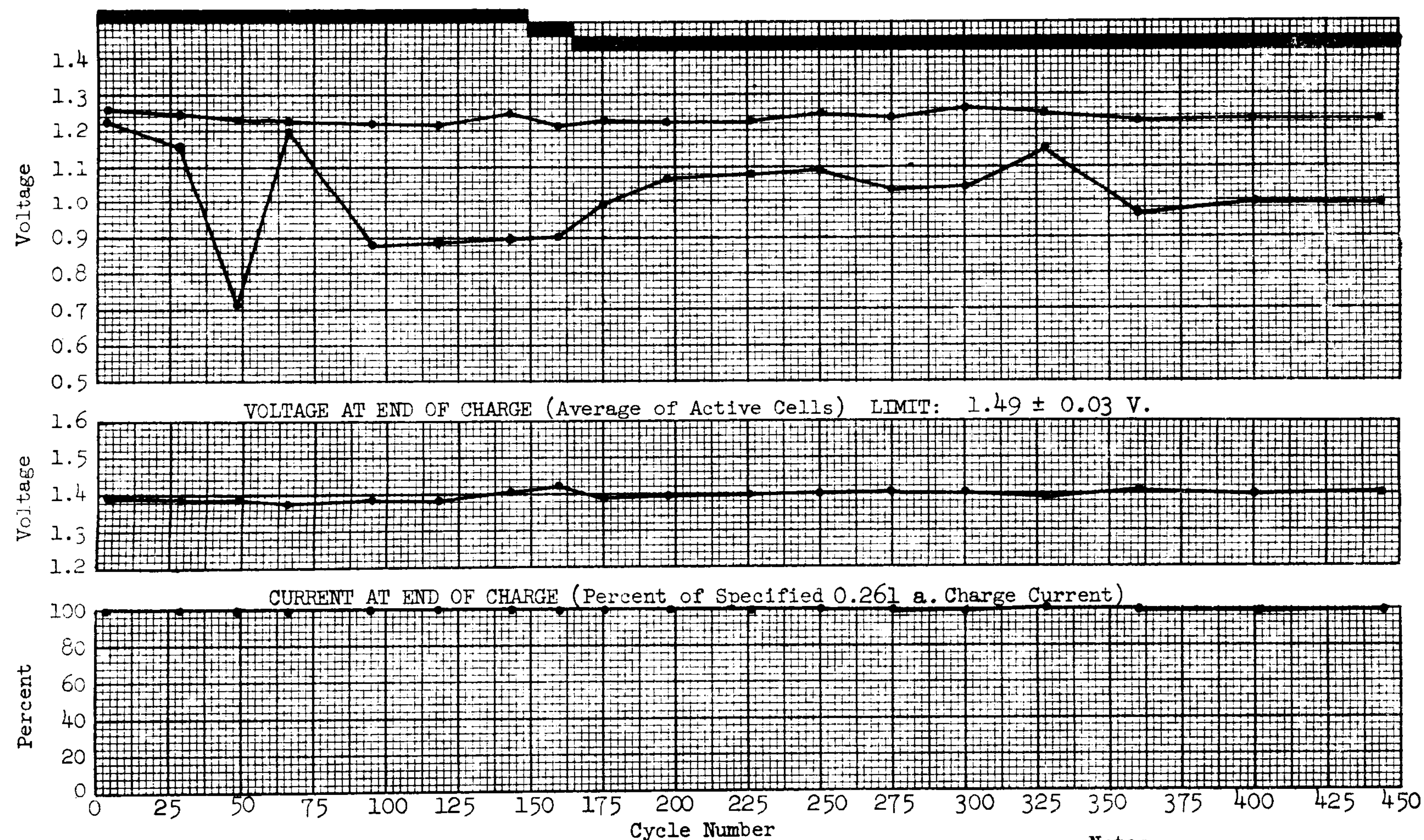
(d) Cell Failures: An analysis of the four cell failures showed that all had separator deterioration and blistering on the positive plates. The two earlier failures were still under high pressure when opened. The last two failures had pinpoint migration which caused shorts through the separator.

(2) Capacity check results are as follows:

Preconditioning	88 Days Discharge #1	88 Days Discharge #2	176 Days Discharge #1	176 Days Discharge #2
6.60	2.88	3.55	3.15	4.00

264 Days Discharge #1	264 Days Discharge #2	352 Days Discharge #1	352 Days Discharge #2	440 Days Discharge #1	440 Days Discharge #2
2.90	4.25	2.95	4.05	2.85	3.50

VOLTAGE AT 30 MINUTES AND AT 60 MINUTES OF DISCHARGE (Average of Active Cells)



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

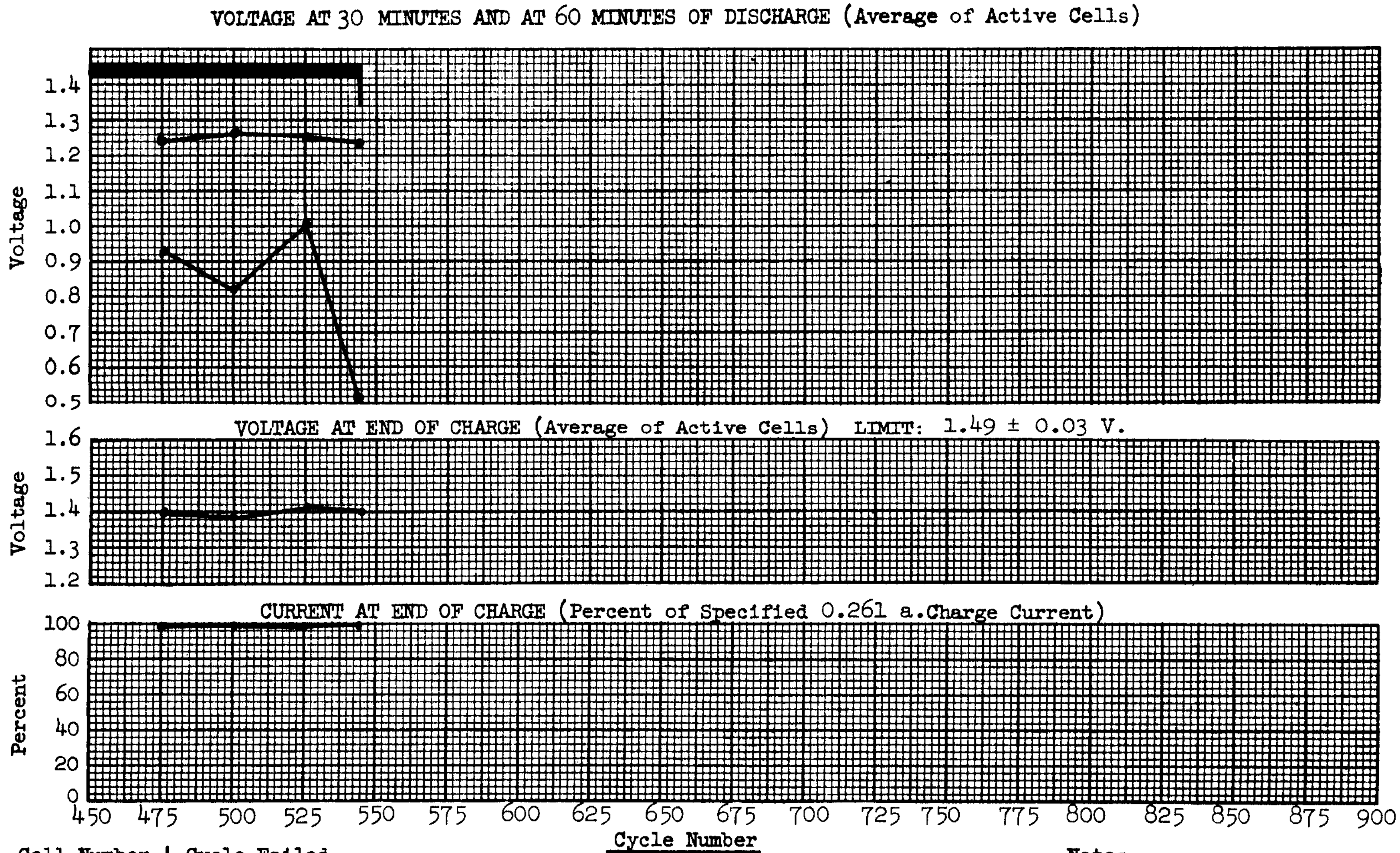
GULTON 6.0 a.h. (Pack 79)
Test Temperature: 25° C
Orbit Period: 24 hours
Depth of Discharge: 50%

Status: Continued

Notes

1. Cycle 57: Raised charge current from 0.196 a. (150% recharge) to 0.261 a. (200% recharge).
2. Cycles 100, 232, 327, 414: Capacity Check.

FIGURE 20



Cell Number	Cycle Failed
2983 (Position 2)	545
2985 (Position 4)	545

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

Status: Pack Failed: Cycle 545

Notes

1. Cycle 516: Capacity Check.

FIGURE 20 (Contd)

5. Gulton 6.0 a.h. (Improved), Three 5-cell Packs, 1.5-hour Orbit Period:

a. Cell Description: The cells are rectangular in shape. 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. These are the same as those described in section I, paragraph II.A.3.a., but of more recent manufacture with improved techniques.

b. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge	Percent of Recharge	Charge Voltage Limit, Per Cell
213	0° C	25	115	1.55 ± 0.03
218	25° C	40	125	1.49 ± 0.03
238	40° C	25	160	1.45 ± 0.03

c. Test Results:

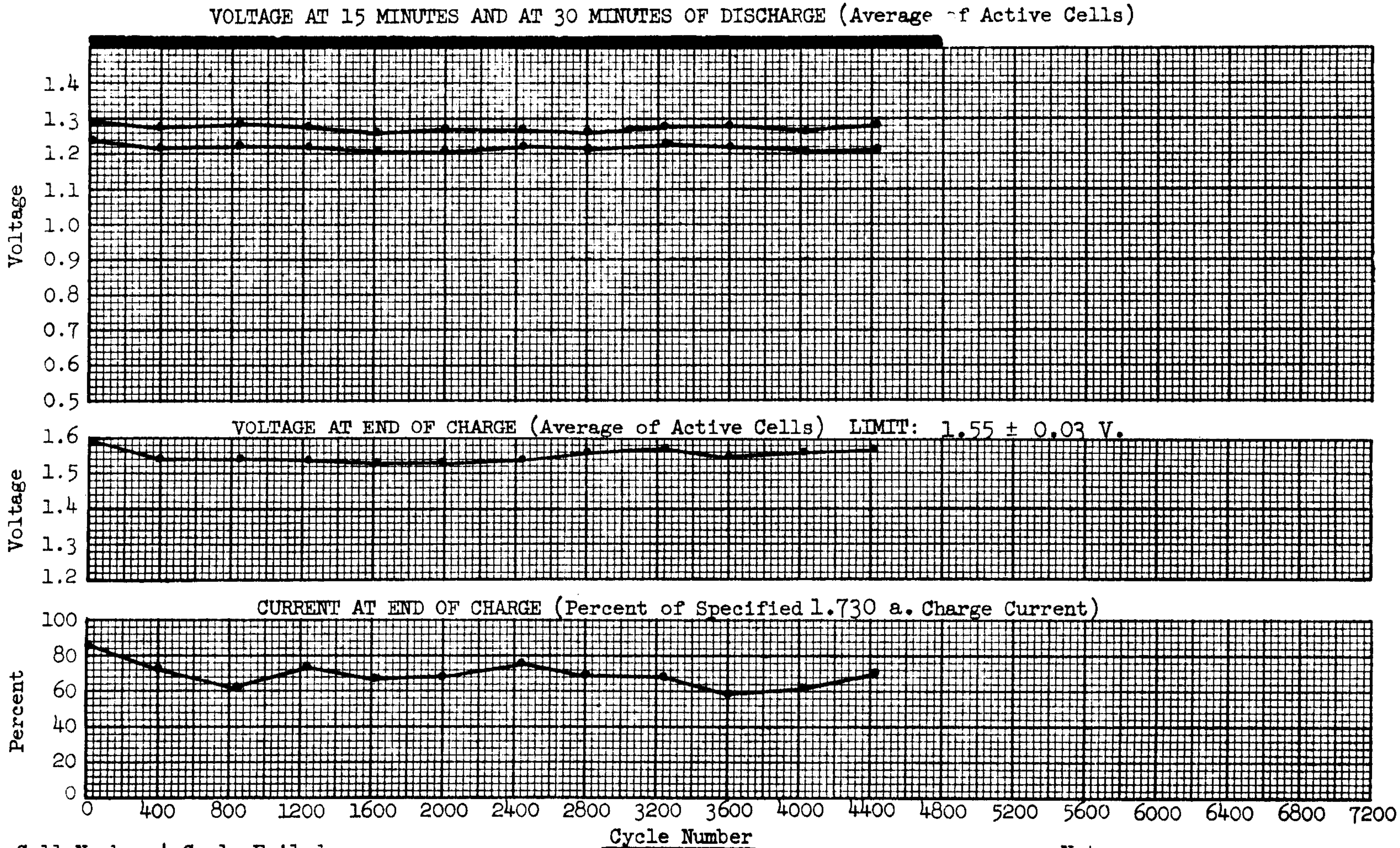
(1) Performance on cycling: (Figures 21(a) through 21(c).)

(a) These packs have completed from 4697 to 4793 cycles, with one cell failure. In all cases there appears to have been a slight tendency towards increasing end-of-charge voltage or decreasing end-of-charge current. There have been no visible leaks to date.

(b) The one cell failure occurred after 4350 cycles. This failure showed severe separator deterioration which allowed the positive and negative plates to short together.

(2) Capacity Checks: The ampere-hour capacities of the cells on the preconditioning and capacity check cycles are as follows:

Pack Number	Preconditioning	88 Days Discharge #1	88 Days Discharge #2	176 Days Discharge #1	176 Days Discharge #2	264 Days Discharge #1	264 Days Discharge #2
213	7.30	7.30	6.95	7.10	7.25	7.05	7.20
218	6.90	2.40	3.00	3.10	3.60	3.20	3.80
238	5.00	1.60	1.75	1.90	2.00	1.85	1.50



Cell Number	Cycle Failed

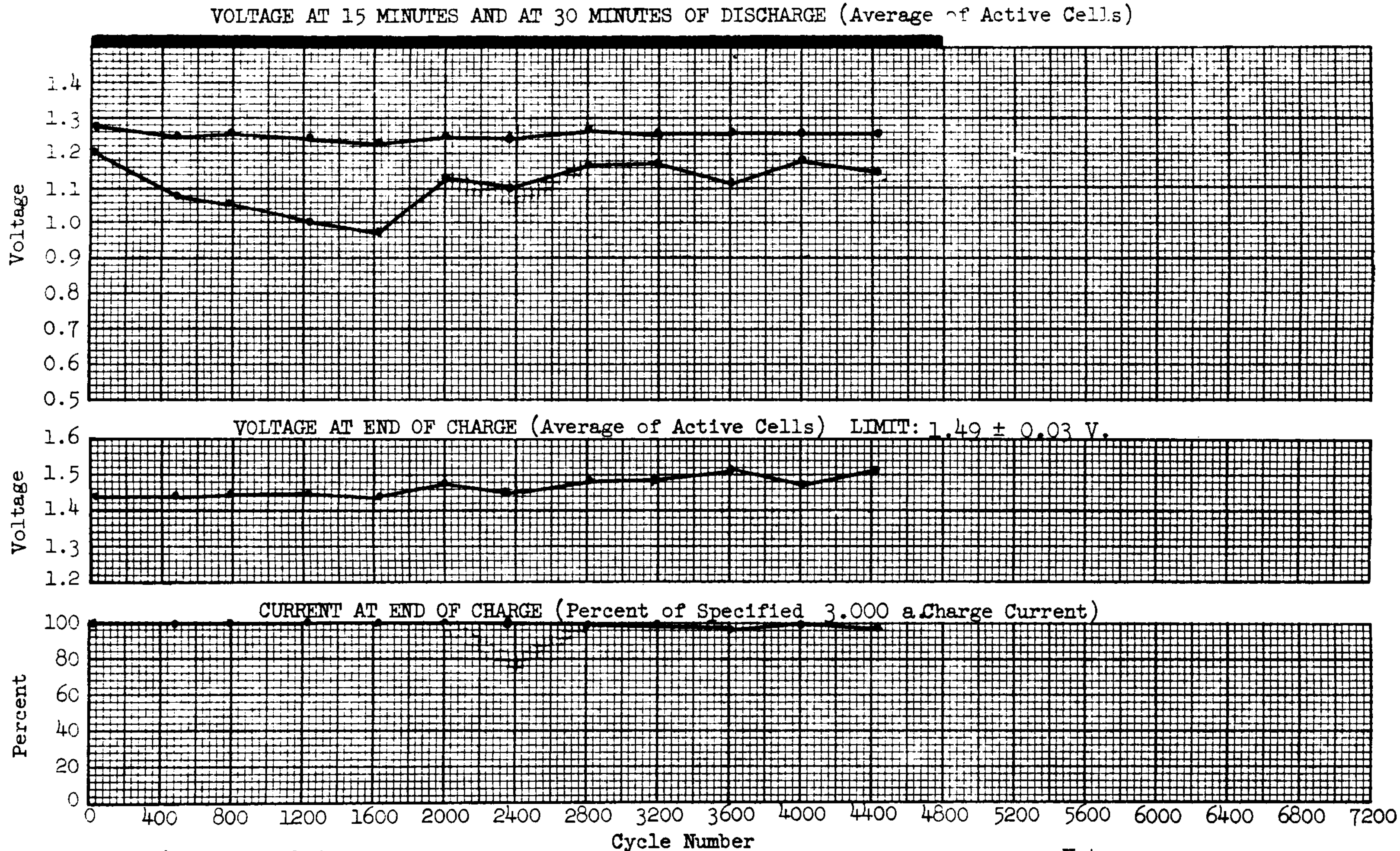
GULTON 6.0 a.h. (Pack 213)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: 5 cells cycling after 4793 cycles.

Notes

1. Cycles 1381, 3080, 4367: Capacity Check.

FIGURE 21(a)



Cell Number	Cycle Failed

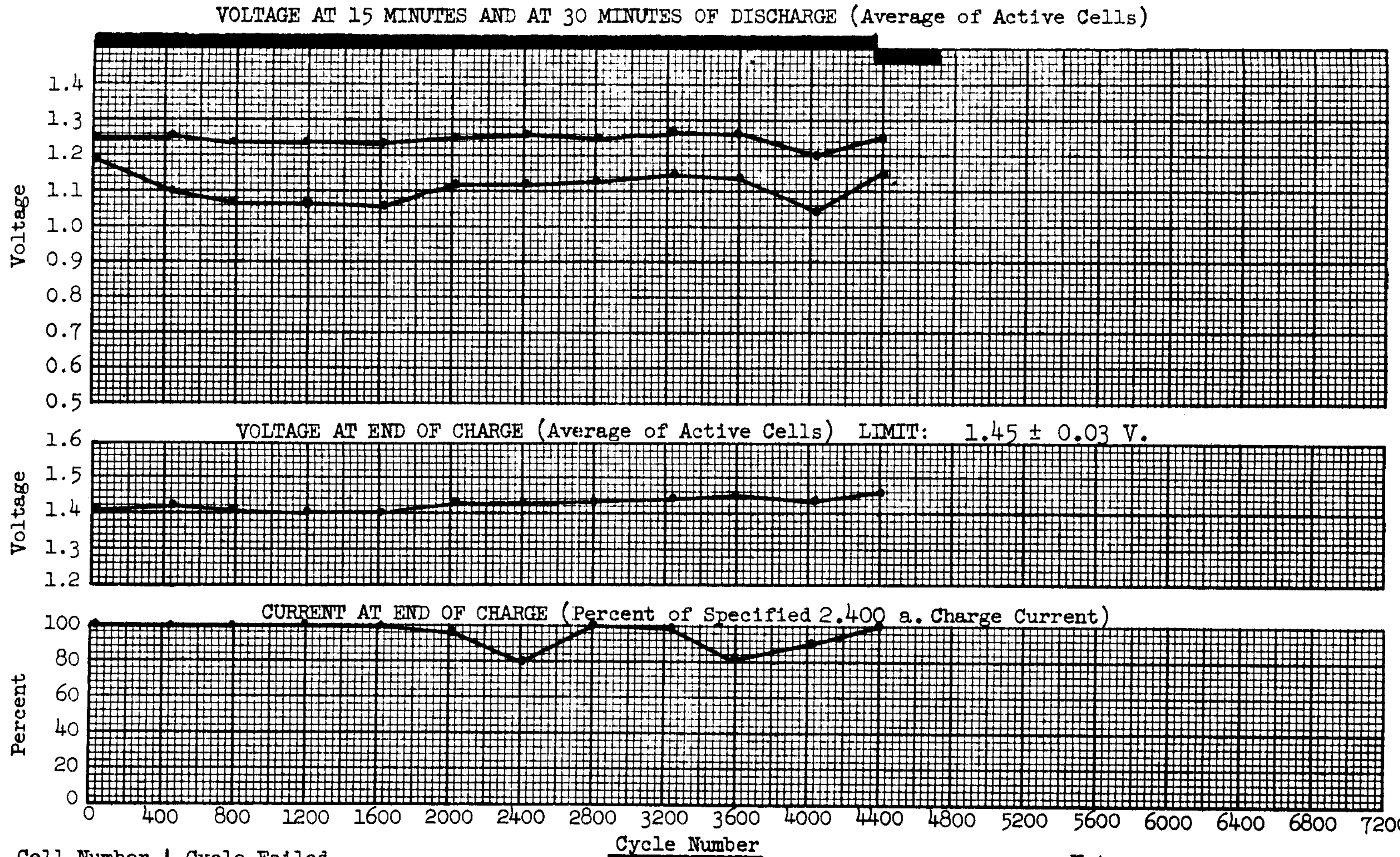
GULTON 6.0 a.h. (Pack 218)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 40%

Status: 5 cells cycling after 4769 cycles.

Notes

1. Cycles 1384, 3086, 4345: Capacity Check.

FIGURE 21(b)



Cell Number	Cycle Failed
5321	4350

GULTON 6.0 a.h. (Pack 238)
Test Temperature: 40° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: 4 cells cycling after 4697 cycles.

Notes

1. Cycles 1384, 2897, 4142: Capacity Check.

FIGURE 21(c)

6. Gulton 12 a.h. (OGO), Six 5-cell Packs, 1.5-hour Orbit Period:

a. Cell Description: These cells are rectangular in shape. The cell container and 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. These cells were designed for use in the OGO satellite.

b. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge	Percent of Recharge	Charge Voltage Limit, Per Cell
216	0° C	15	115	1.55 ± 0.03
301	0° C	25	115	1.55 ± 0.03
227	25° C	25	125	1.49 ± 0.03
296	25° C	40	125	1.49 ± 0.03
78	40° C	15	160	1.45 ± 0.03
290	40° C	25	160	1.45 ± 0.03

c. Test Results:

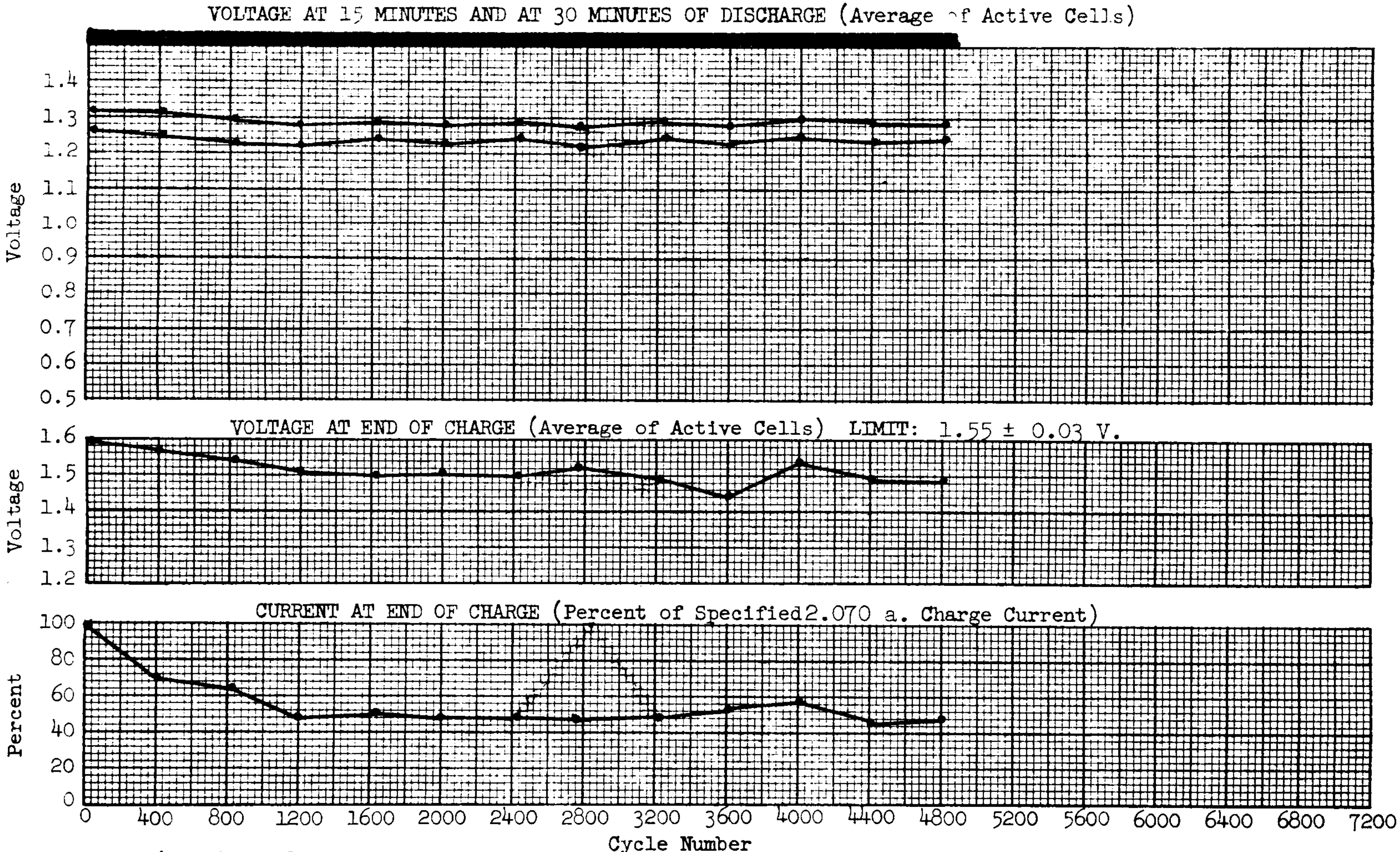
(1) Performance on cycling: (Figures 22(a) through 22(f).)

(a) These packs have completed from 4869 to 5793 cycles, with eight cell failures. The end-of-charge voltages show very little change throughout cycling.

(b) All of the cell failures showed signs of migration of the negative plate material and all had severe separator deterioration. Four cells had the plates shorted together.

(2) Capacity Checks: The ampere-hour capacities of the cells on the preconditioning and capacity check cycles are as follows:

Pack Number	Preconditioning	88 Days Discharge #1	88 Days Discharge #2	176 Days Discharge #1	176 Days Discharge #2	264 Days Discharge #1	264 Days Discharge #2
216	14.0	14.0	13.5	13.6	14.1	13.9	14.2
301	14.2	14.0	14.5	13.9	14.4	14.2	12.9
227	14.1	5.2	5.9	3.4	3.5	4.0	4.1
296	13.3	4.7	3.2	4.6	5.4	4.9	5.0
78	6.8	4.1	4.3	2.4	3.1	2.9	3.3
290	11.4	2.9	5.4	3.5	3.6	3.3	3.7



Cell Number	Cycle Failed

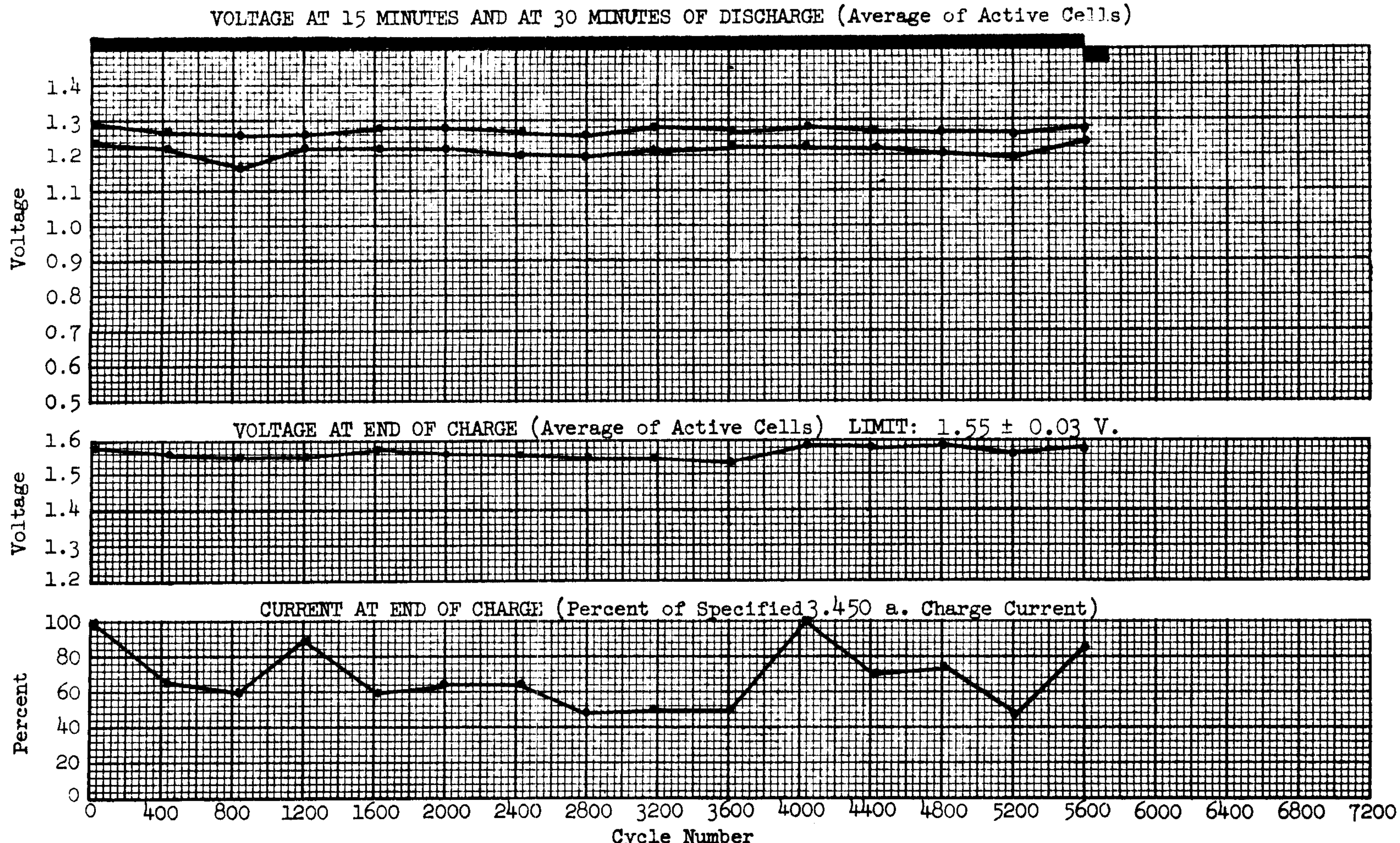
GULTON 12.0 a.h. (Pack 216)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

Status: 5 cells cycling after 4869 cycles.

Notes

1. Cycles 1407, 2867, 4078: Capacity Check.

FIGURE 22(a)



Cell Number	Cycle Failed
1455	5586

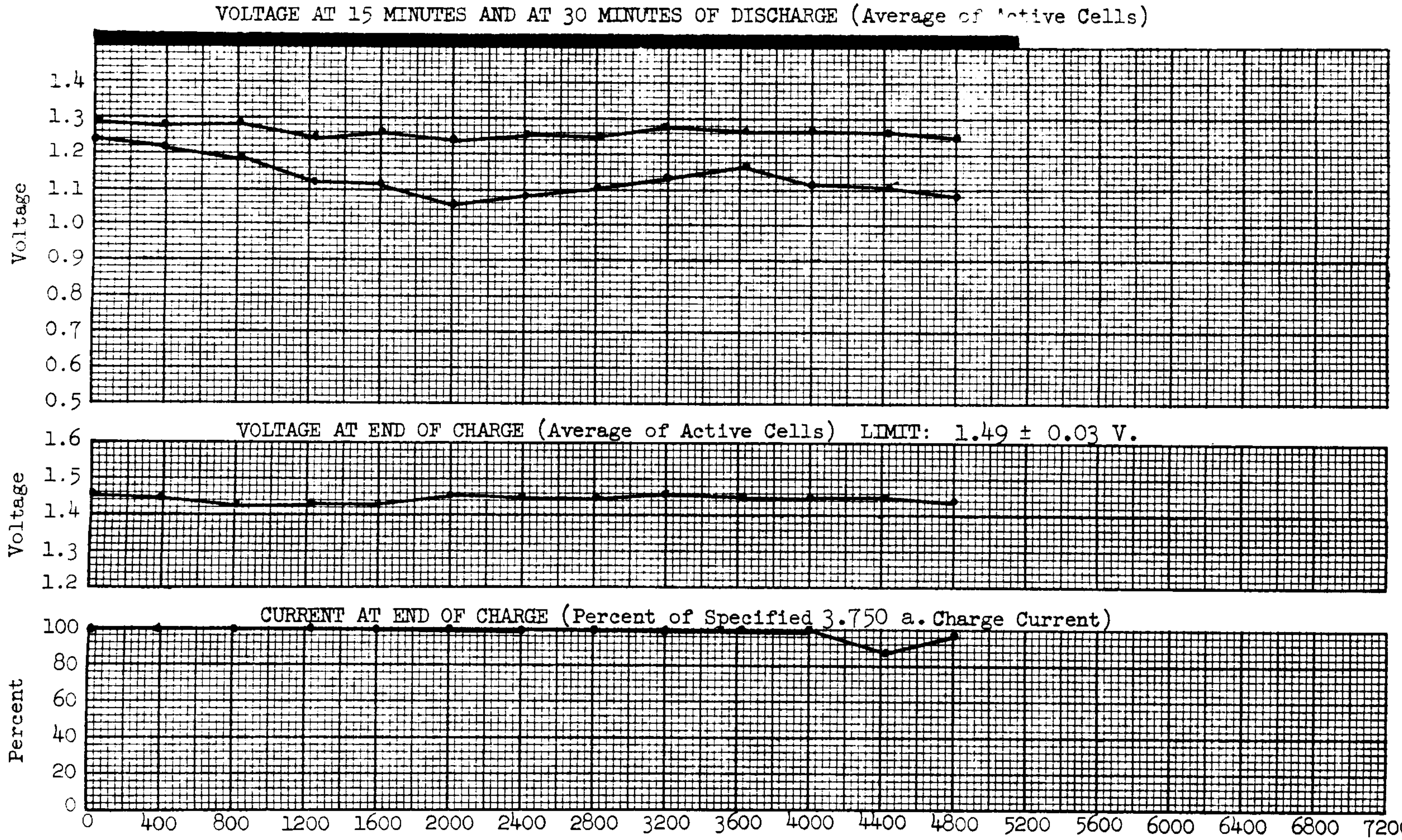
GULTON 12.0 a.h. (Pack 301)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: 4 cells cycling after 5739 cycles.

Notes

1. Cycles 1416, 3371, 4526: Capacity Check.

FIGURE 22(b)



Cell Number	Cycle Failed

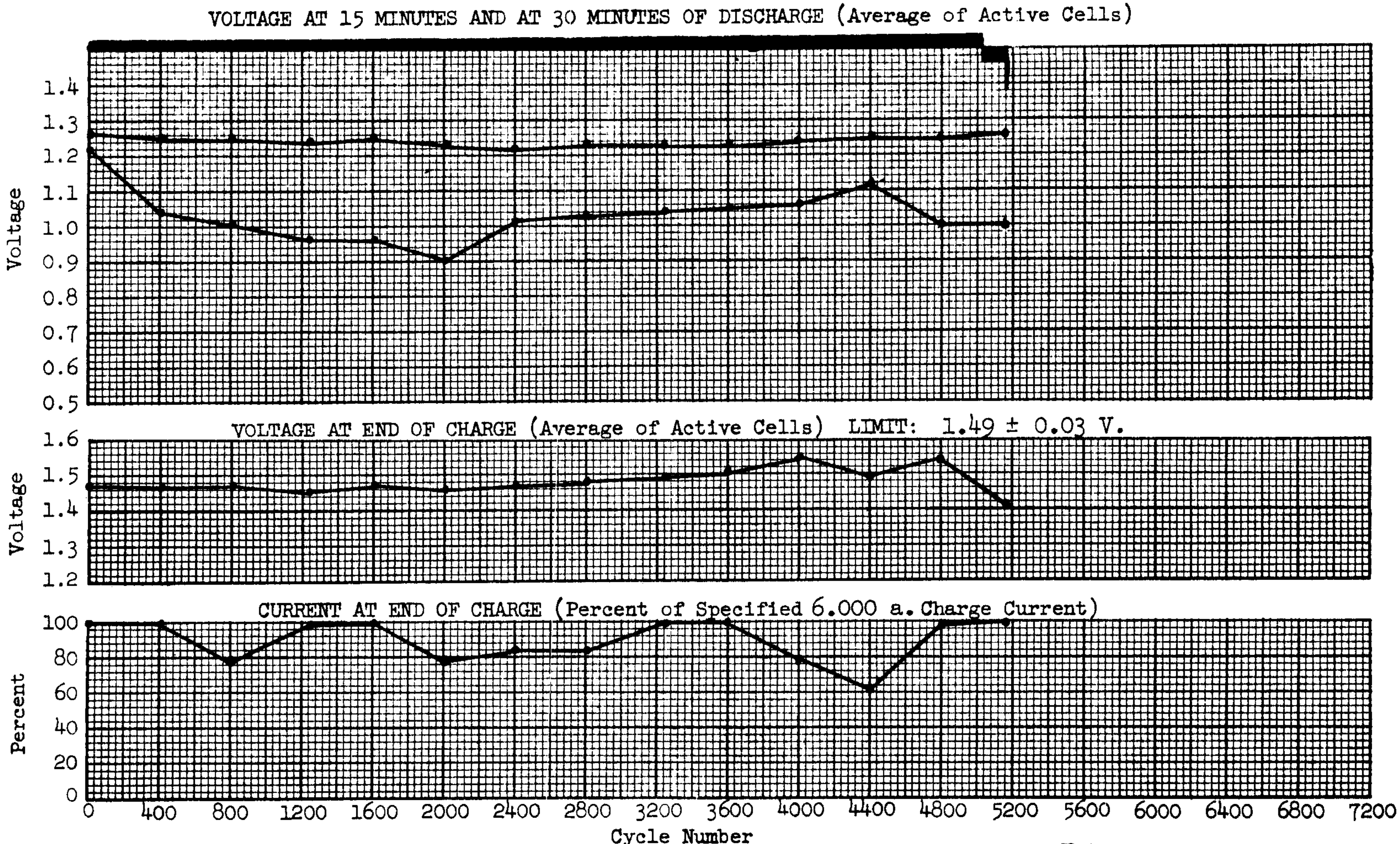
GULTON 12.0 a.h. (Pack 227)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: 5 cells cycling after 5136 cycles.

Notes

1. Cycles 1438, 2921, 4080: Capacity Check.

FIGURE 22(c)



Cell Number	Cycle Failed
1447	5036
1443	5152
1445	5152

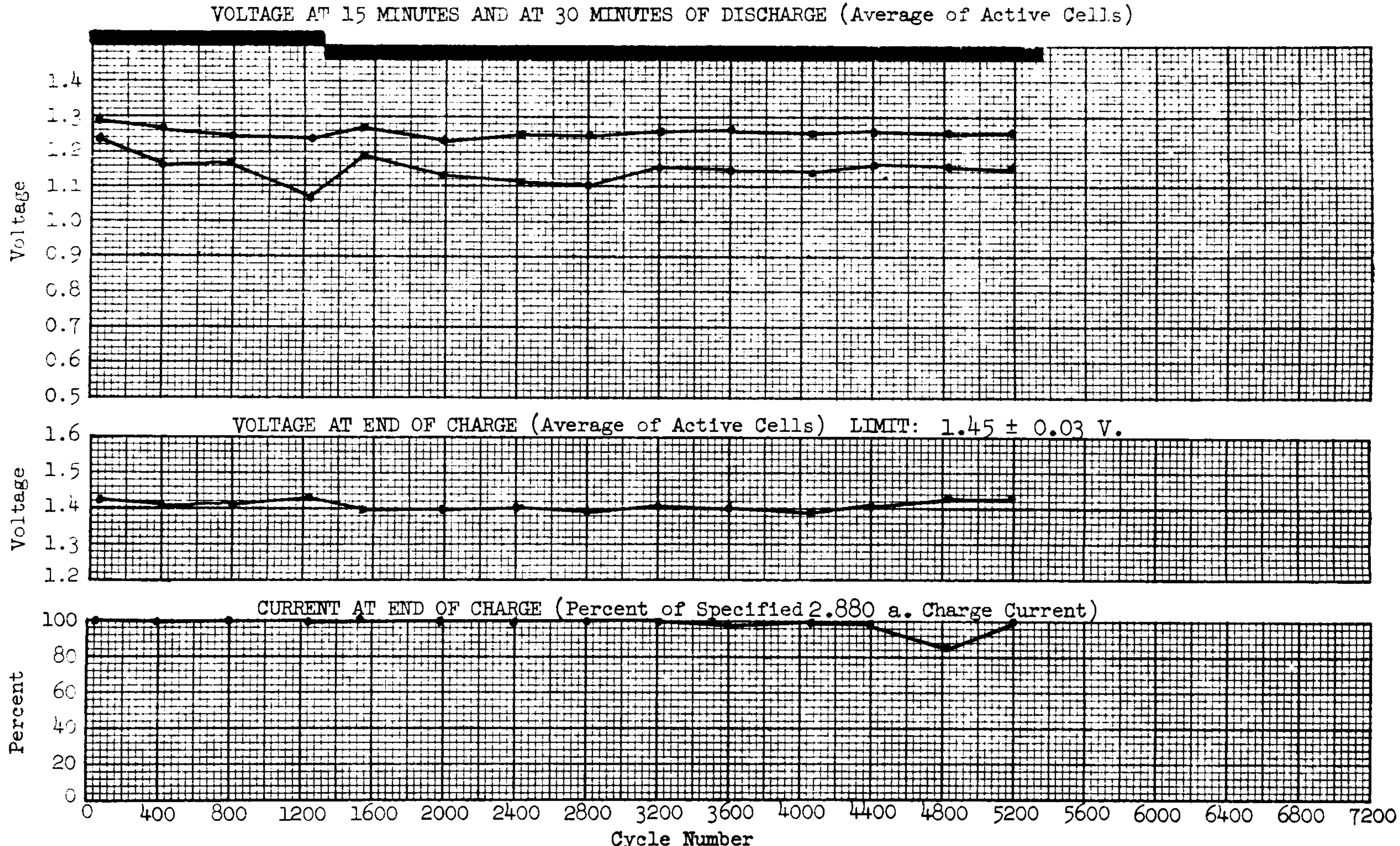
GULTON 12.0 a.h. (Pack 296)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 40%

Status: Pack Failed: Cycle 5124

Notes

1. Cycles 1494, 3331, 4631: Capacity Check.

FIGURE 22(d)



Cell Number	Cycle Failed
1471	1307

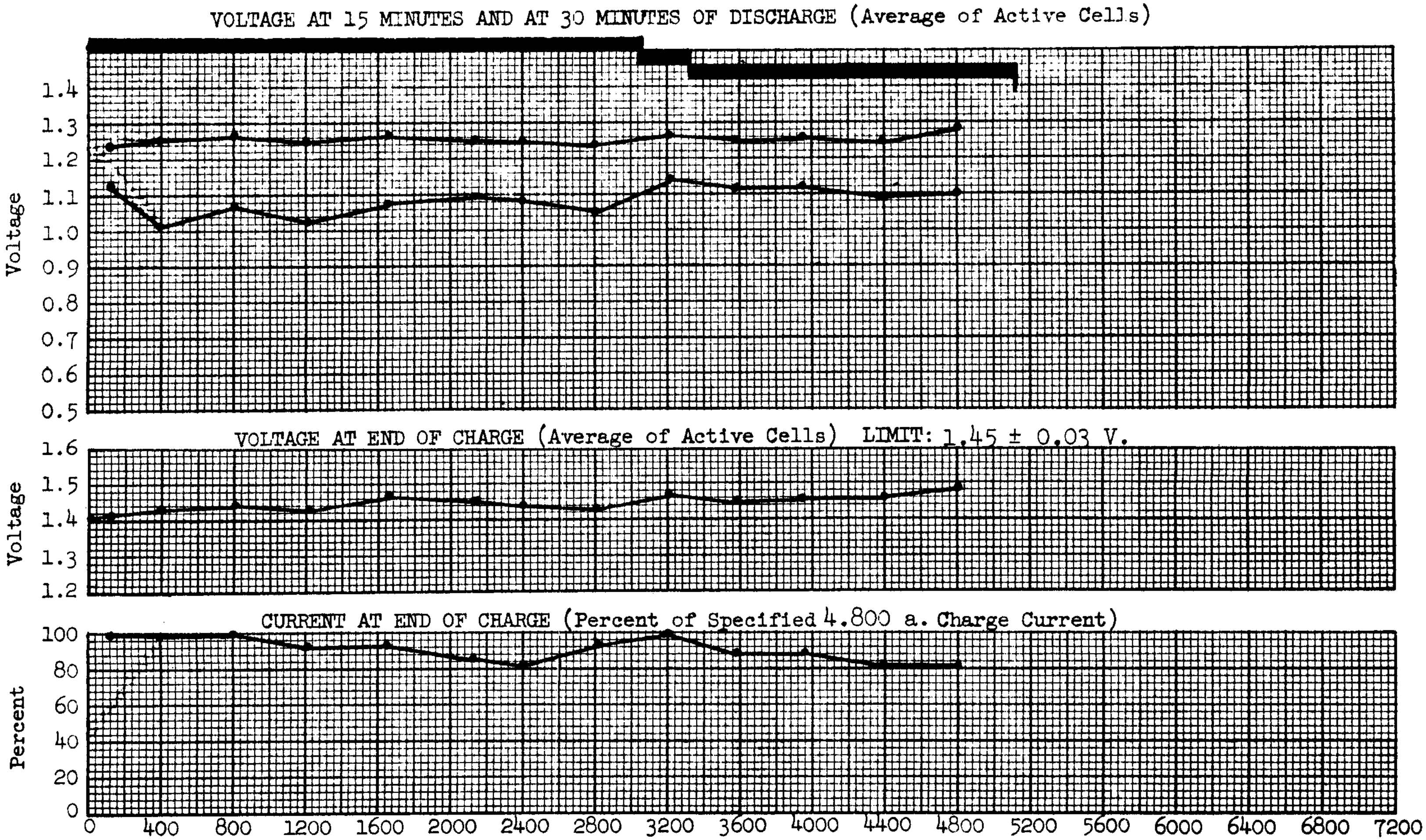
GULTON 12.0 a.h. (Pack 78)
Test Temperature: 40° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

Status: 4 cells cycling after 5337 cycles.

Notes

1. Cycles 1528, 3182, 4423: Capacity Check.

FIGURE 22(e)



Cell Number	Cycle Failed
1460	3060
1459	3318
1461	5124

GULTON 12.0 a.h. (Pack 290)
Test Temperature: 40° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: Pack Failed: Cycle 5124

Notes

1. Cycles 1493, 3174, 4433: Capacity Check.

FIGURE 22(f)

7. Gulton 50 a.h., Two 5-cell Packs, 1.5-hour Orbit Period:

a. Cell Description: These are rectangular, hermetically sealed nickel-cadmium cells.

b. Test Parameters:

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

c. Test Results:

(1) Performance on cycling: (Figures 23(a) and 23(b).)

(a) Pack 95 completed 3227 cycles. The end-of-charge voltage increased or the end-of-charge current decreased steadily until the first cell failed after cycle 2643. The end-of-charge voltage, then, decreased and the end-of-charge current increased. The second cell failure occurred after 2938 cycles but this did not affect the operation of the pack. The third cell failed after 3227 cycles. The separator in each of the first two failed cells was very dry and short circuits had occurred between the plates. Large blisters were present on the positive plates of the first and third cells. Slight migration of material from the negative plates was evident in the second failed cell.

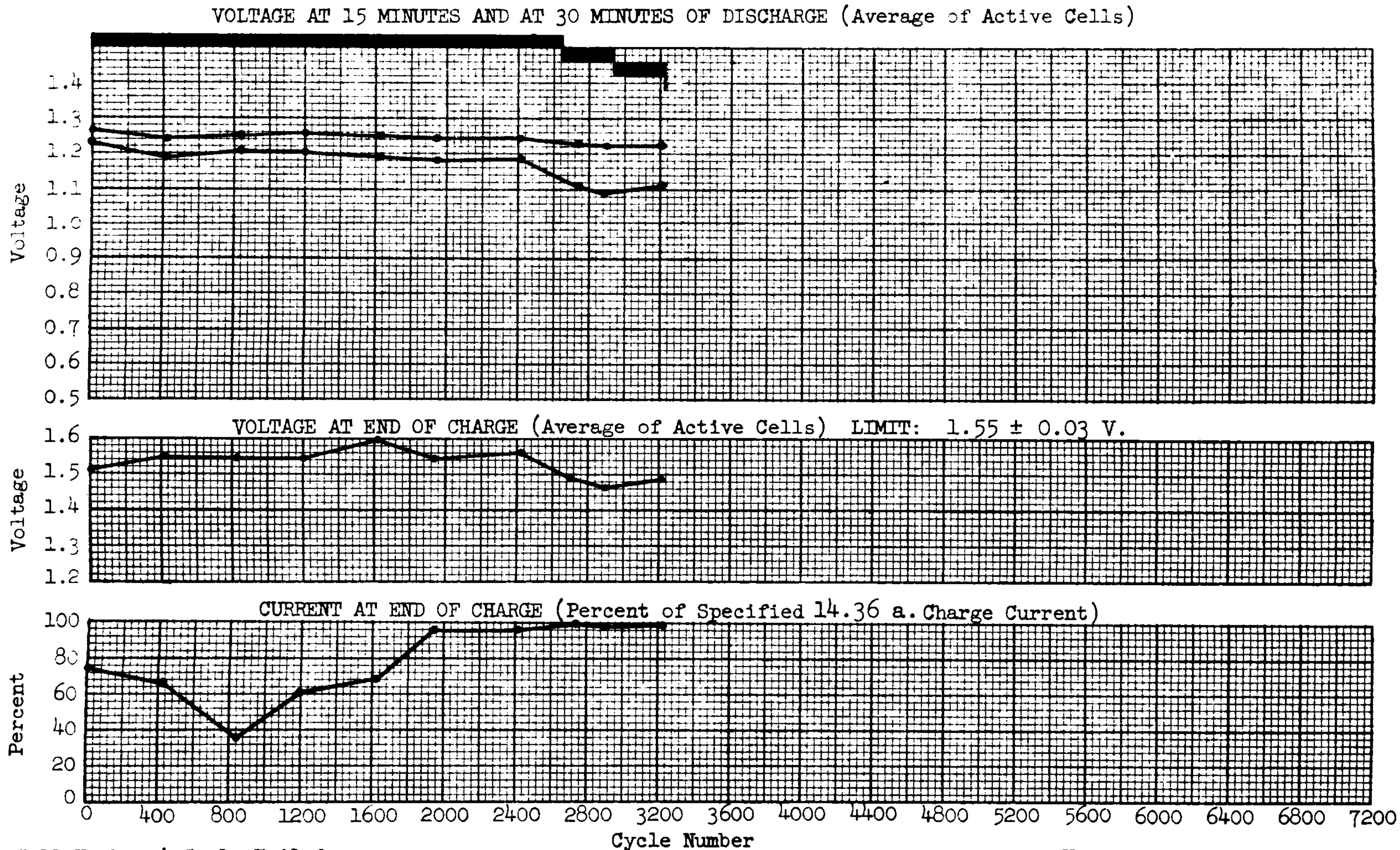
(b) Pack 123 completed 1873 cycles when the first cell failure occurred. Two additional cells went dead while the pack was shut off to remove the first failed cell. The separators of all three cells had deteriorated. The separator of each of two cells had several burned spots where the plates had shorted together. The outside negative plates of two cells were stuck to the cell case. All three failed cells had bulged cases from high internal pressure; two of which were still under pressure, and the third had a carbonate deposit at the positive terminal.

(2) Capacity Checks: The ampere-hour capacities of the cells on the preconditioning and capacity check cycles are as follows:

(a) Pack 95:

Preconditioning	88 Days Discharge #1	88 Days Discharge #2	176 Days Discharge #1	176 Days Discharge #2
54.6	57.5	59.6	21.7	45.4

(b) The preconditioning capacity of Pack 123 at 40° C was 27.9 ampere-hours. 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.



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

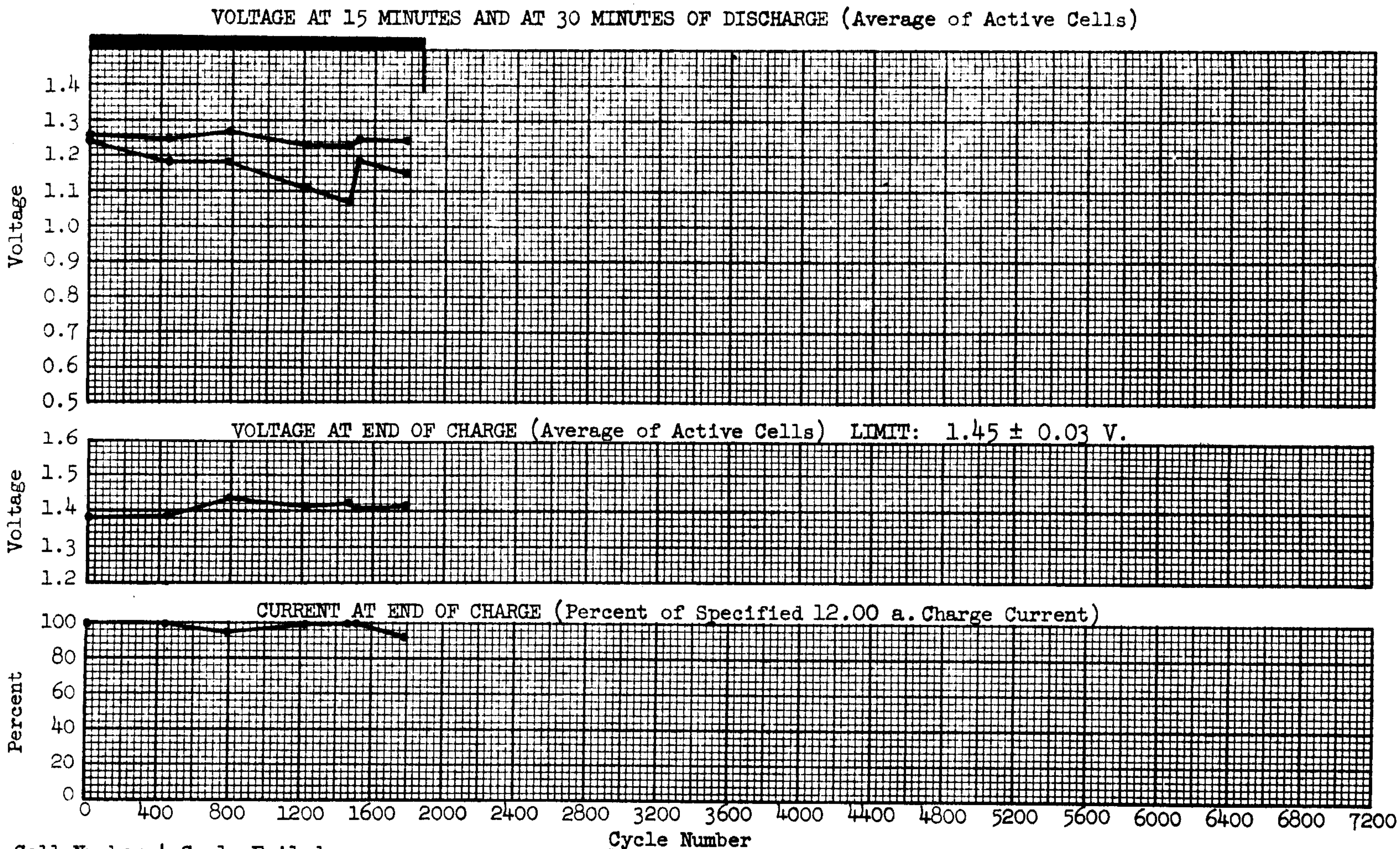
GULTON 50 a.h. (Pack 95)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: Pack Failed: Cycle 3227

Notes

1. Cycles 1229, 2831: Capacity Check.

FIGURE 23(a)



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 23(b)

8. General Electric 5.0 a.h. (NIMBUS), Six 5-cell Packs, 1.5-hour Orbit Period:

a. Cell Description: These cells are cylindrical in shape with a convex base. A threaded stud is fastened to the base to facilitate heat sink mounting. The cell container and the cell cover are made of stainless steel. Two stainless steel tabs, welded to the cover, serve as the contacts for the negative terminal. The positive terminal is insulated from the cell cover by a ceramic bushing and protrudes through the bushing with a solder tab welded to the terminal. Three cells have pressure transducers mounted on the cell to read internal pressure in pounds per square inch absolute. These cells were designed for use in the NIMBUS Satellite.

b. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge	Percent of Recharge	Charge Voltage Limit, Per Cell
103	0° C	15	110	1.49 ± 0.03
107*	0° C	25	110	1.49 ± 0.03
106	25° C	25	120	1.49 ± 0.03
304*	25° C	40	120	1.49 ± 0.03
113	40° C	15	130	1.49 ± 0.03
114*	40° C	25	130	1.49 ± 0.03

* One cell in these packs is equipped with a pressure transducer.

c. Test Results:

(1) Performance on cycling: (Figures 24(a) through 24(f).)

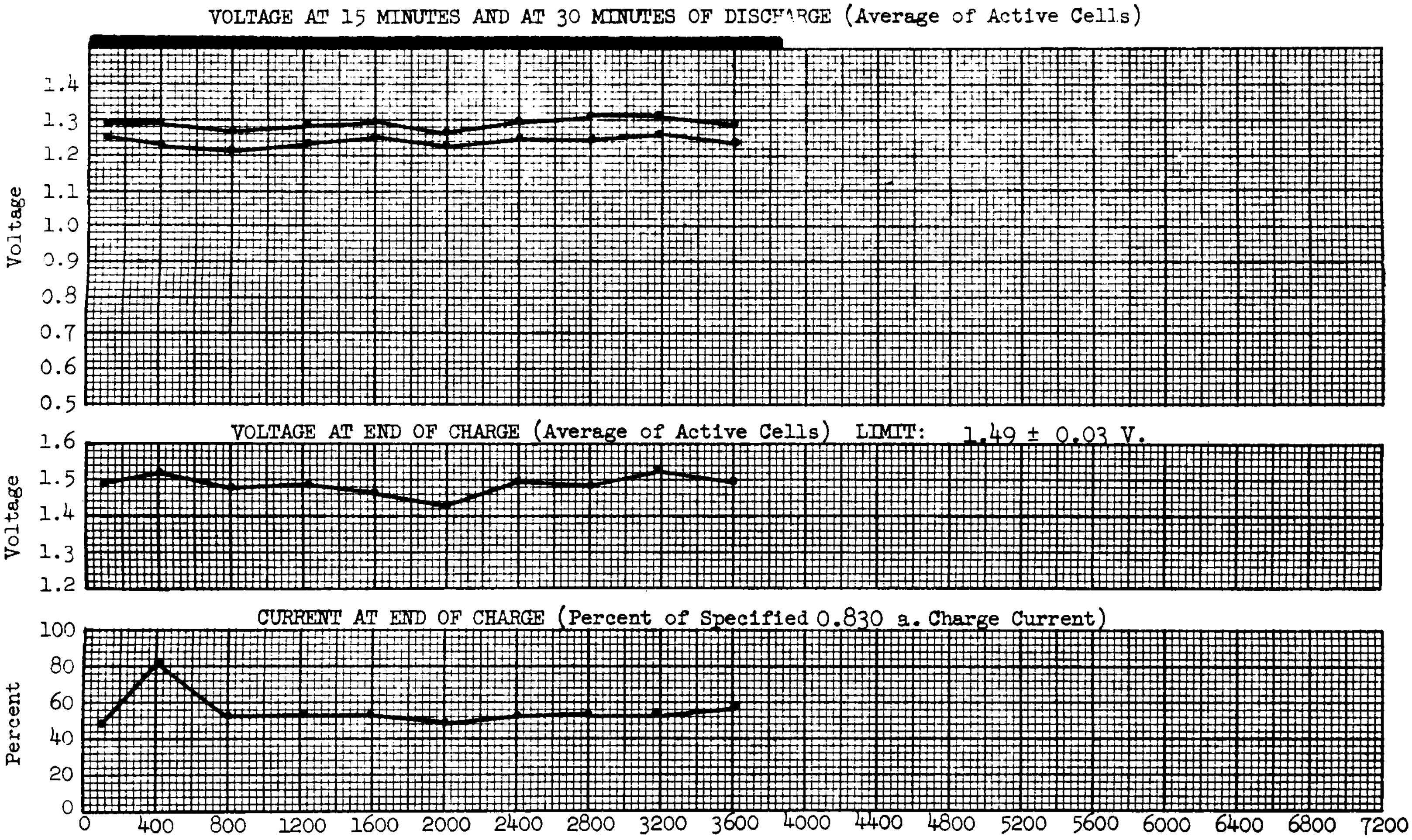
(a) These packs have completed from 3142 to 3874 cycles. The end-of-charge voltages and currents are holding steady. The end-of-discharge voltages show a very slow drop.

(b) There have been no failures since cycling started. One cell failed on the preconditioning cycle due to a short between the positive tab and the top of the negative plate. The manufacturer now uses more insulation on the positive tab inside the cell.

(c) The internal pressure of the cells with pressure transducers showed an increase in pressure with an increase in ambient temperature. The pressure was 11.0 psia at 0° C, 13.8 psia at 25° C, and 33.0 psia at 40° C.

(2) Capacity Checks: The ampere-hour capacities of the cells on the preconditioning and capacity check cycles are as follows:

Pack Number	Preconditioning	88 Days Discharge #1	88 Days Discharge #2	176 Days Discharge #1	176 Days Discharge #2
103	5.42	4.75	5.08	4.70	5.38
107	5.21	5.00	5.50	4.96	5.46
106	4.67	4.13	4.00	3.96	4.13
304	5.58	3.38	3.58	2.25	2.54
113	3.67	2.33	2.42	1.40	2.25
114	3.83	1.67	2.25	1.38	1.71



Cell Number	Cycle Failed
	.

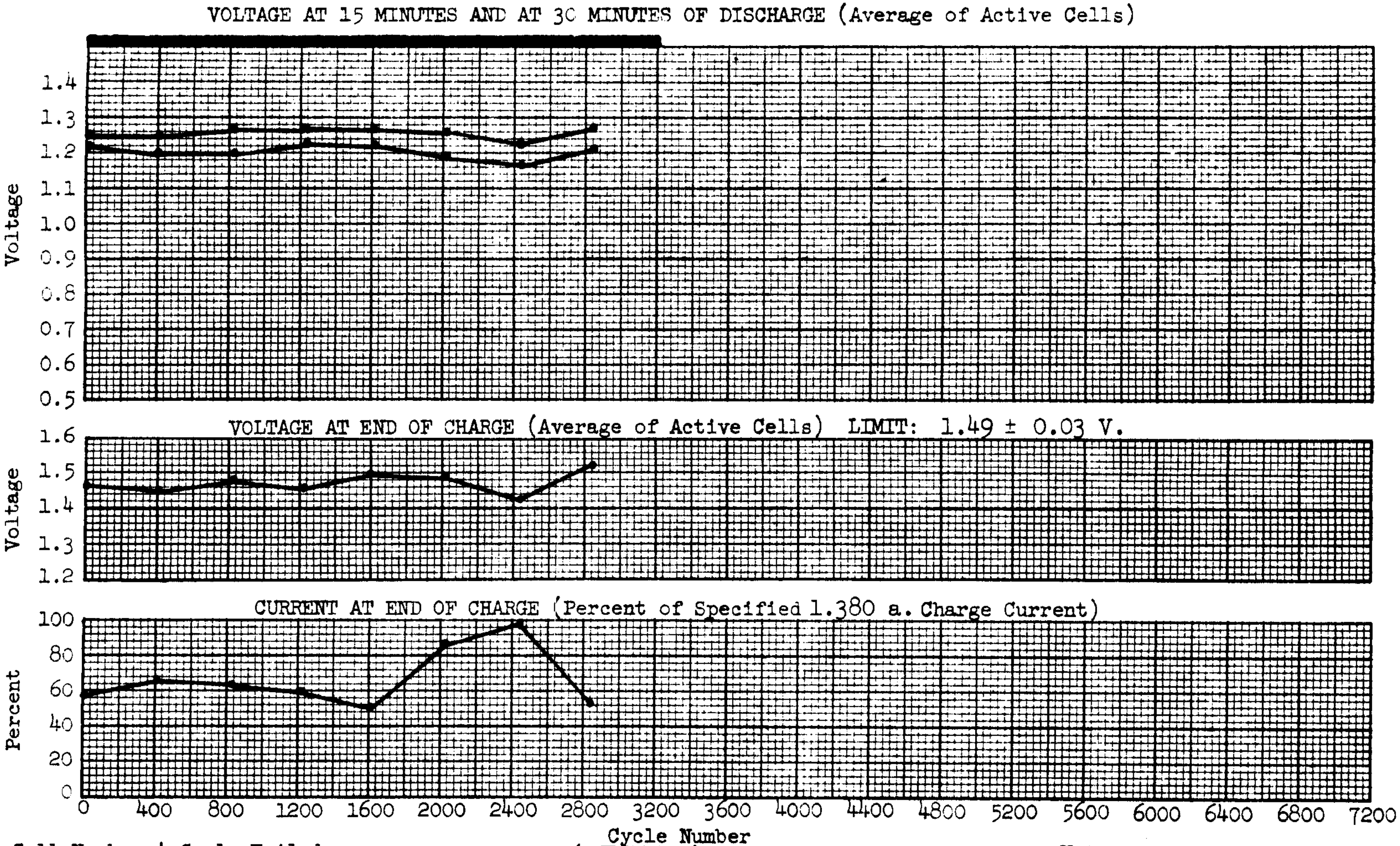
G.E. 5.0 a.h. (Pack 103)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

Status: 5 cells cycling after 3855 cycles.

Notes

1. Cycles 1846, 2987: Capacity Check.

FIGURE 24(a)



Cell Number	Cycle Failed

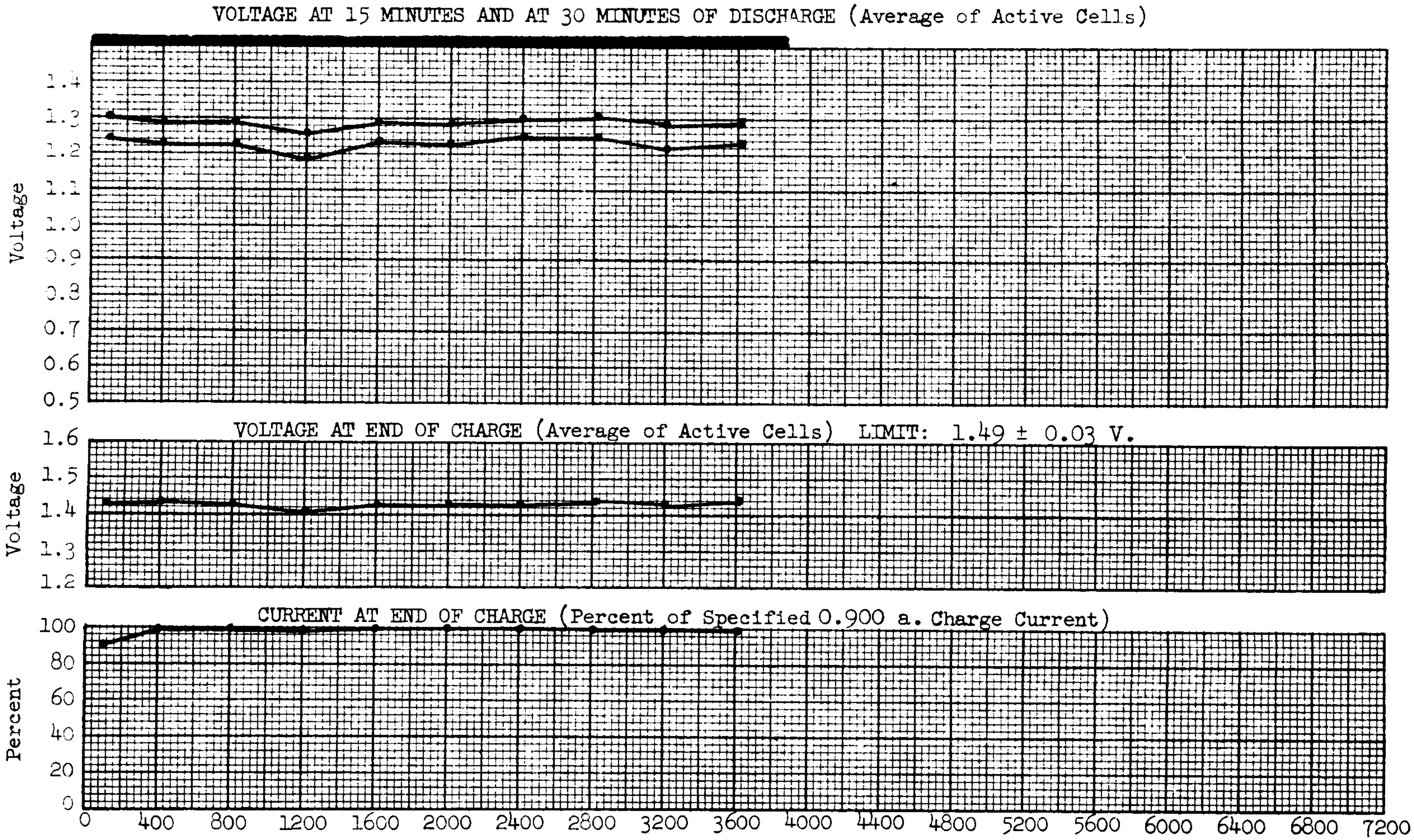
G.E. 5.0 a.h. (Pack 107)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: 5 cells cycling after 3204 cycles.

Notes

1. Cycles 1195, 2336: Capacity Check.

FIGURE 24(b)



Cell Number	Cycle Failed

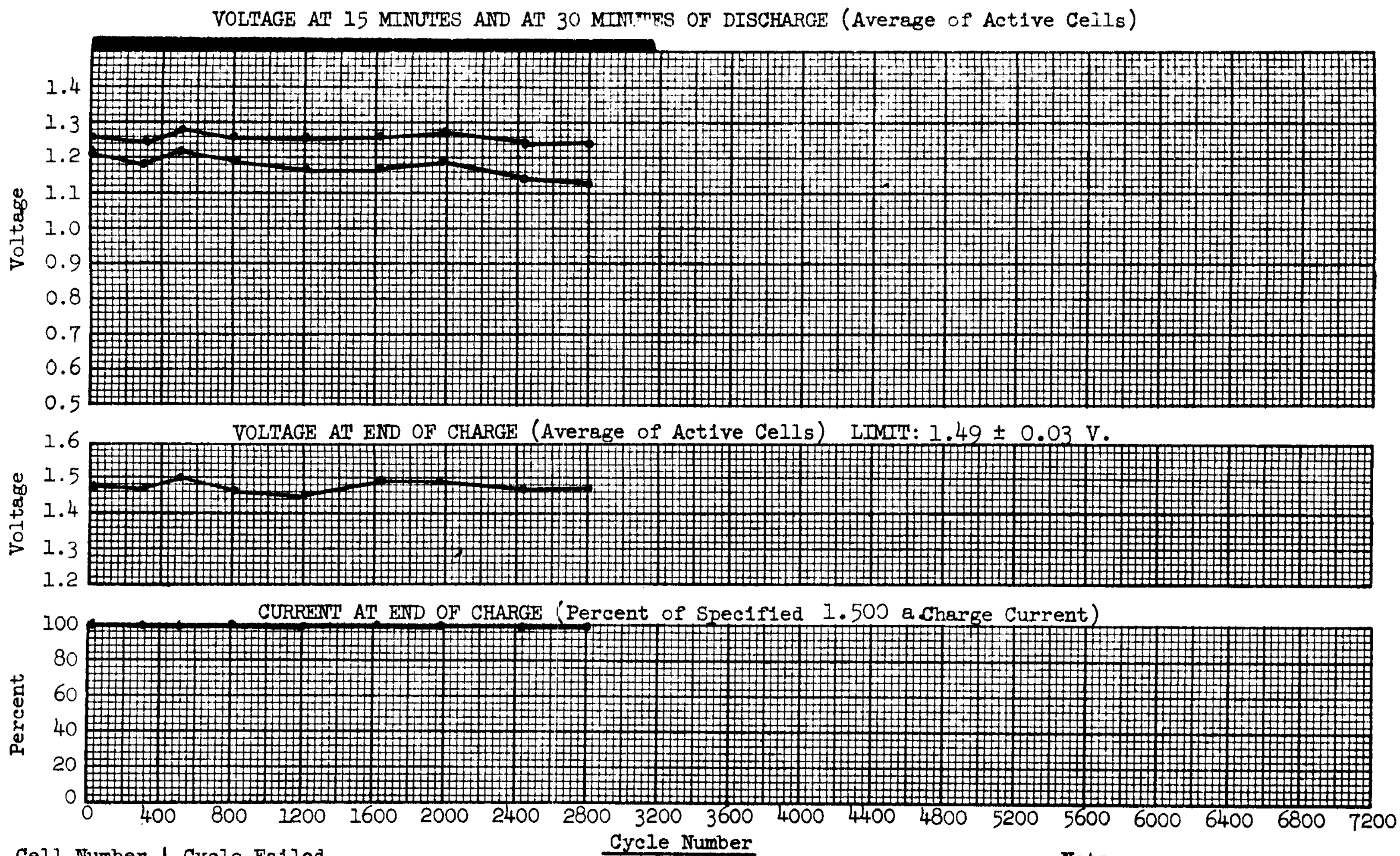
G.E. 5.0 a.h. (Pack 106)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

Status: 5 cells cycling after 3873 cycles.

Notes

1. Cycles 1529, 2356: Capacity Check.

FIGURE 24(c)



Cell Number	Cycle Failed

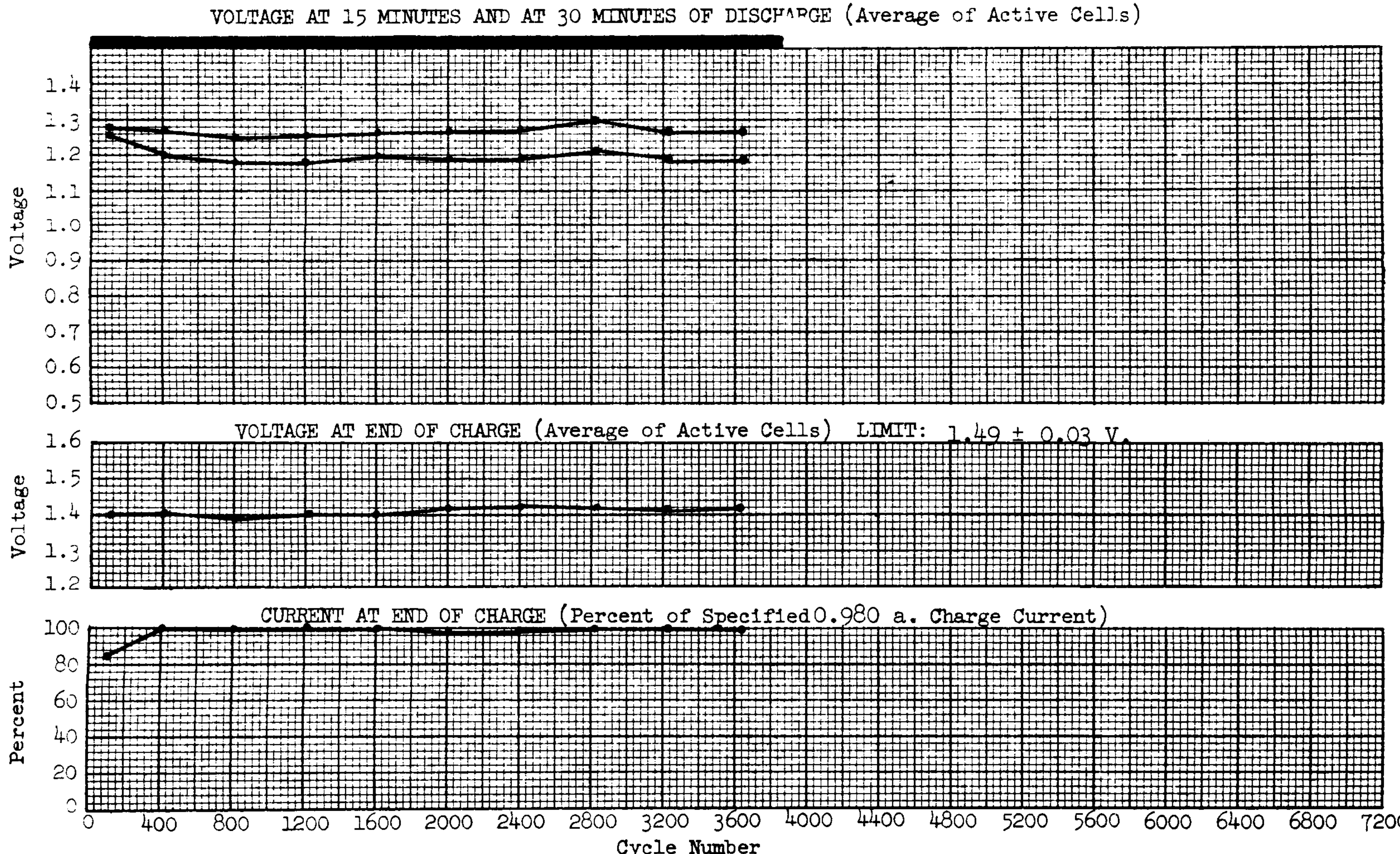
G.E. 5.0 a.h. (Pack 304)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: 5 cells cycling after 3174 cycles.

Notes

1. Cycles 1657: Capacity Check.

FIGURE 24(d)



Cell Number	Cycle Failed

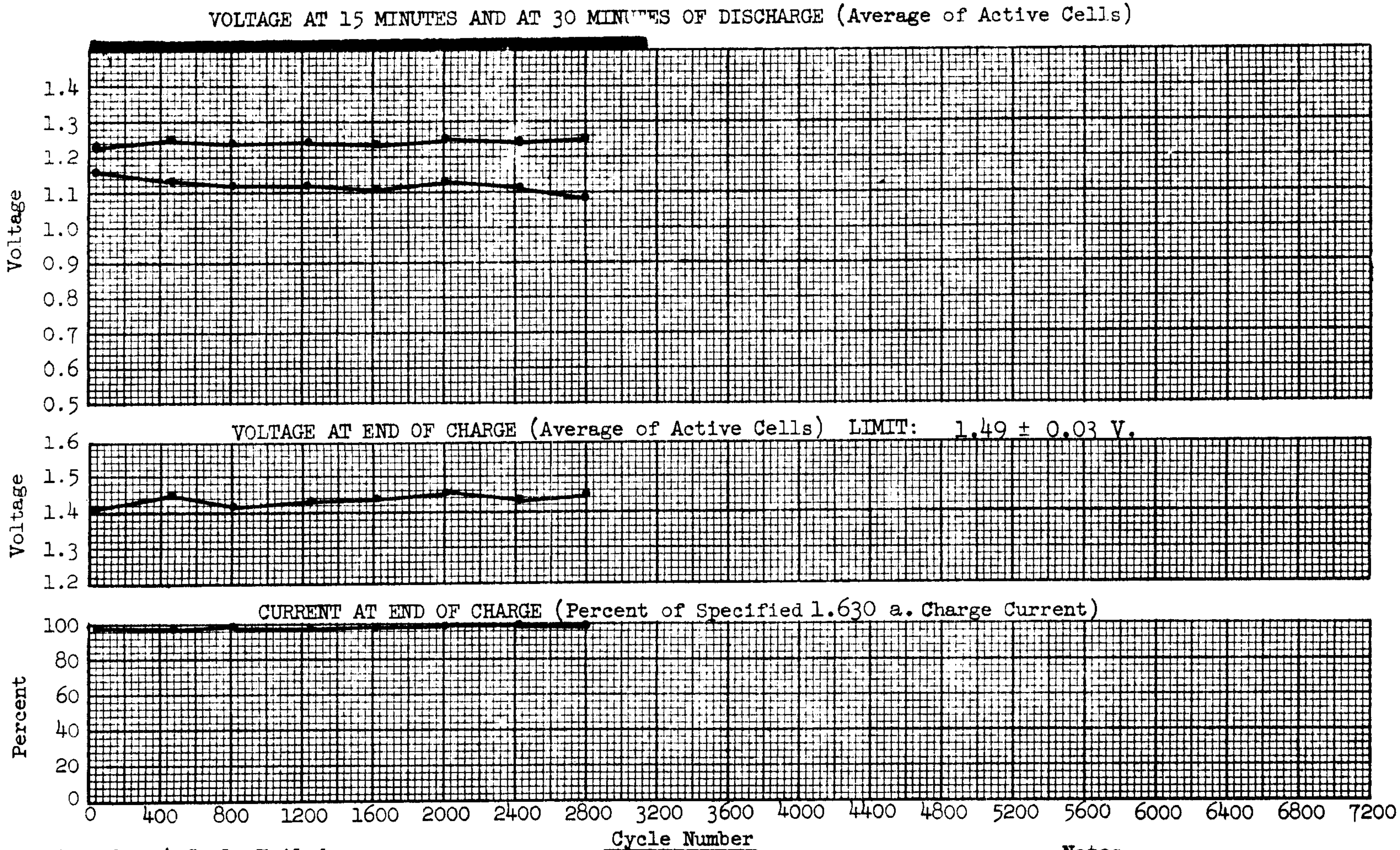
G.E. 5.0 a.h. (Pack 113)
Test Temperature: 40° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

Status: 5 cells cycling after 3874 cycles.

Notes

1. Cycles 1606, 2432: Capacity Check.

FIGURE 24(e)



Cell Number	Cycle Failed

G.E. 5.0 a.h. (Pack 114)
Test Temperature: 40° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: 5 cells cycling after 3142 cycles.

Notes

1. Cycles 1700: Capacity Check.

FIGURE 24(f)

9. General Electric 12 a.h., One 5-cell Pack, 24-hour Orbit Period (Pack 93):

a. Cell Description: The cells are rectangular in shape. 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. They are the same as those described in section I, paragraph II.A.1.b.

b. Test Parameters:

(1) Initial Test Parameters:

(a) Test Temperature: 25° C.

(b) Depth of Discharge: 50%.

(c) Percent of Recharge: 150%.

(d) Charge Voltage Limit: 1.49 ± 0.03 volts per cell, average.

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

(2) Changes in Test Parameters:

(a) Due to low end-of-discharge voltage, recharging was increased, after 57 cycles, to 200 percent. This change improved the operation of the pack.

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

c. Test Results:

(1) Performance on cycling: (Figure 25.)

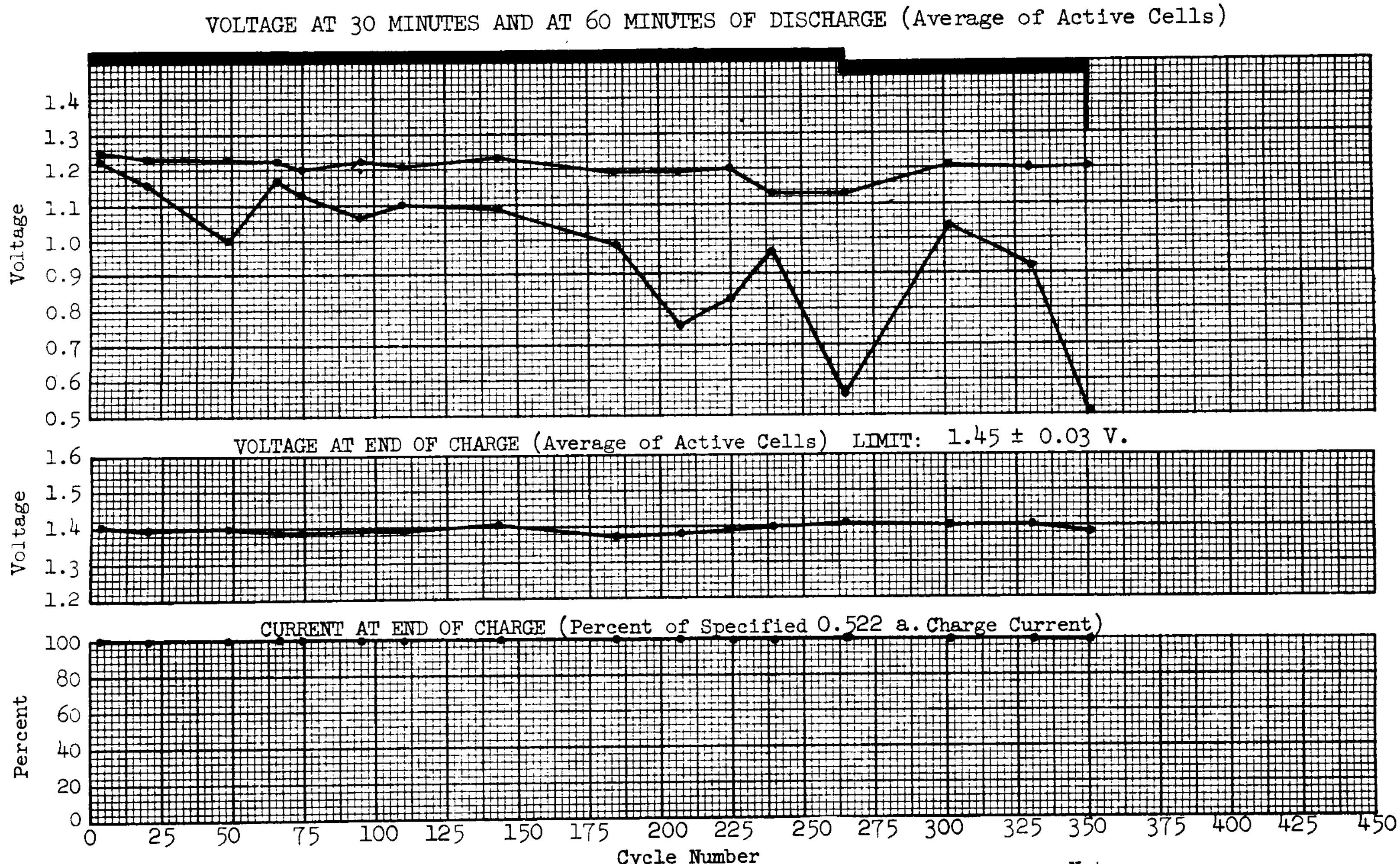
(a) Average end-of-discharge voltage fell to less than 1.0 volt per cell under the original test parameters, but satisfactory operation was obtained with the 200 percent recharge.

(b) At 40° C the pack did not operate as well. End-of-discharge voltages of the pack were low and quite variable. Two cells appeared to have failed on cycle 266. Since the first cell showed no defects upon failure analysis, the second cell was discharged completely and shorted overnight. It was then 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 ampere-hours. It was returned to the pack and continued to cycle until the pack failed at 349 cycles. The cycling behavoir of these two cells was attributed to a combination of memory effect and insufficient percent of recharge. At no time was the on charge voltage limit reached. The end-of-charge voltage remained close to 1.39 volts per cell at both temperatures.

(c) The four remaining cells failed after 349 cycles. All of the cells showed separator deterioration and migration of the negative plate material. All cells showed signs of leakage around the terminals but no weight loss was detected.

(2) Capacity Checks: The ampere-hour capacities of the cells on the preconditioning and capacity check cycles are as follows:

Preconditioning at 25° C	100 Days Discharge at 25° C #1	100 Days Discharge at 25° C #2	231 Days Discharge at 40° C #1	231 Days Discharge at 40° C #2	339 Days Discharge at 40° C #1	339 Days Discharge at 40° C #2
13.0	6.55	7.60	5.20	6.50	5.00	5.00



Cell Number	Cycle Failed
208 (Position 2)	266
204 (Position 1)	349
209 (Position 3)	349
210 (Position 4)	349
211 (Position 5)	349

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

Status: Pack Failed: Cycle 349

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. Cycles 100, 231, 339: Capacity Checks.

FIGURE 25

10. Sonotone 3.0 a.h. (Triple Seal), Six 5-cell Packs, 1.5-hour Orbit Period:

a. Cell Description: The cell container and the cell cover of these cylindrical cells are made of stainless steel. Two stainless steel tabs, welded to the cover, serve as the contacts for the negative terminal. The positive terminal is a solder type extension of the positive plate tab extending through the "negative" cover and insulated by a ceramic seal between two glass to metal seals to form a triple seal. Two ring indentations, about 1/32 inch deep, located about 1/2 inch from each end of the cell, were crimped after cell assembly to hold the element snugly in the cylindrical can to withstand vibration.

b. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge	Percent of Recharge	Charge Voltage Limit, Per Cell
243	0° C	15	115	1.55 ± 0.03
231	0° C	25	115	1.55 ± 0.03
203	25° C	25	125	1.49 ± 0.03
202	25° C	40	125	1.49 ± 0.03
226	40° C	15	160	1.45 ± 0.03
237	40° C	25	160	1.45 ± 0.03

c. Test Results:

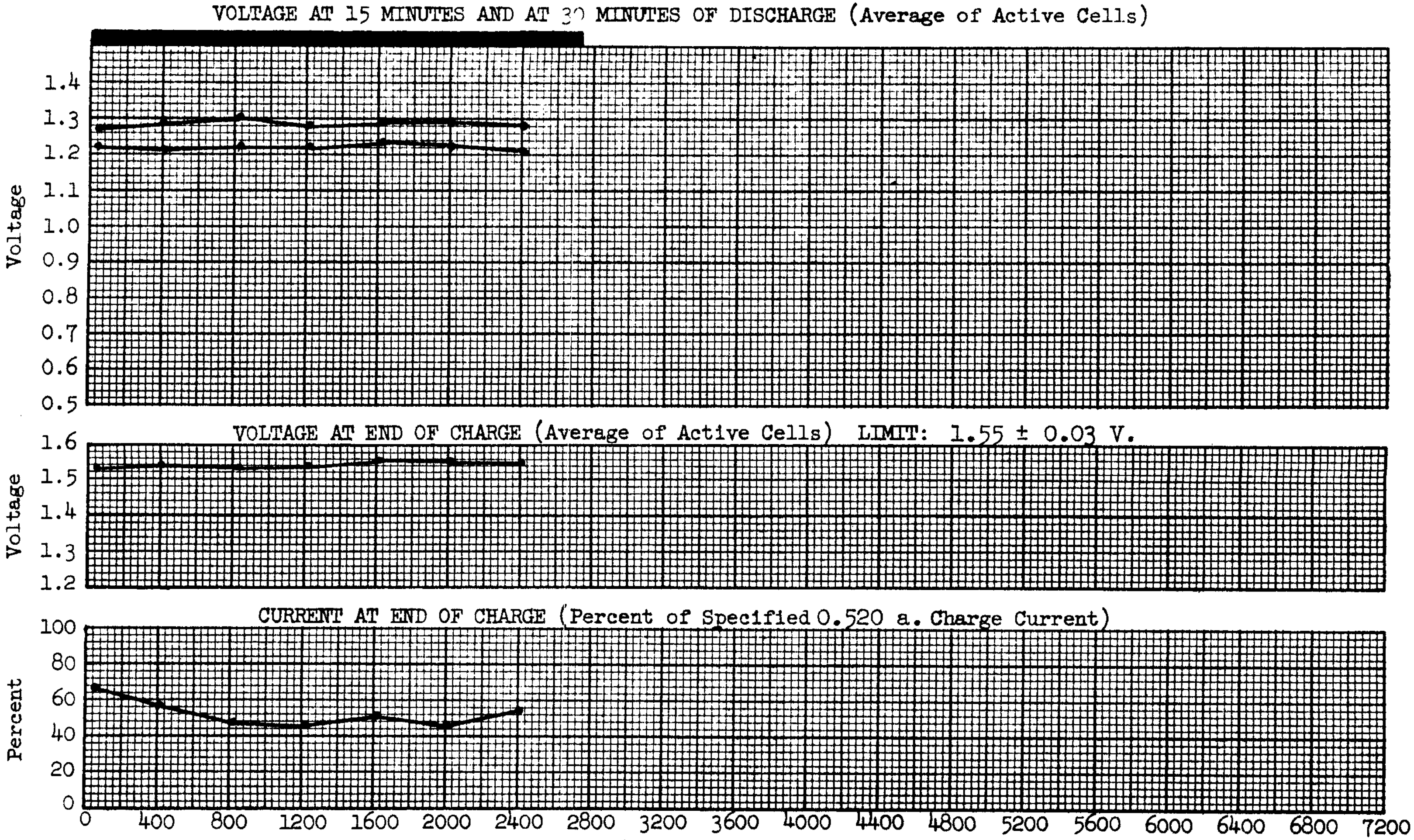
(1) Performance on cycling: (Figures 26(a) through 26(f).)

(a) These packs have completed from 2576 to 2890 cycles. The end-of-charge voltage increased or the end-of-charge current decreased. The end-of-discharge voltage remained steady, between 1.12 and 1.22 volts per cell average, on all packs except Pack 202 (25° C, 40 percent depth of discharge) which decreased to 0.92 volt per cell average. This was caused by the deterioration of one cell which eventually failed after 1630 cycles.

(b) Cell Failures: An analysis of this one cell showed that it was very dry, even though no leak was detectable. There was also migration of negative plate material around the tab and scoring areas. The representative of the manufacturer stated that the failure was probably a decay of capacity due to insufficient electrolyte.

(2) Capacity Checks: The ampere-hour capacities of the cells on the preconditioning and check cycles are as follows:

Pack Number	Preconditioning	88 Days Discharge #1	#2
243	3.23	3.35	3.55
231	2.88	2.72	3.05
203	3.35	1.28	1.40
202	3.60	0.50	1.32
226	3.53	1.02	1.10
237	3.48	0.90	1.05



Cell Number	Cycle Failed

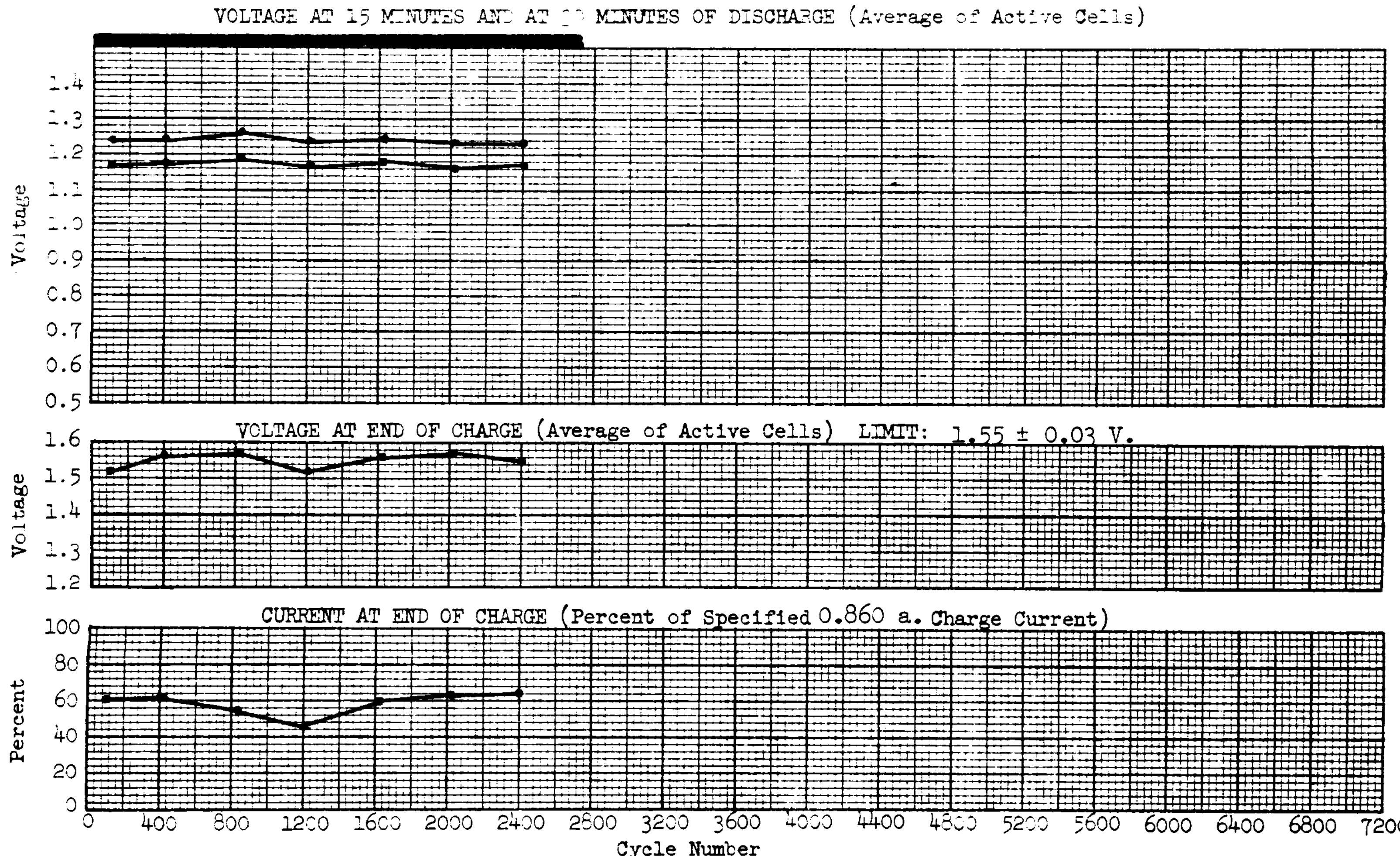
SONOTONE 3.0 a.h. (Pack 243)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

Status: **5 cells cycling after 2731 cycles.**

Notes

1. **Cycles 1274, 2430: Capacity Check.**

FIGURE 26(a)



Cell Number	Cycle Failed

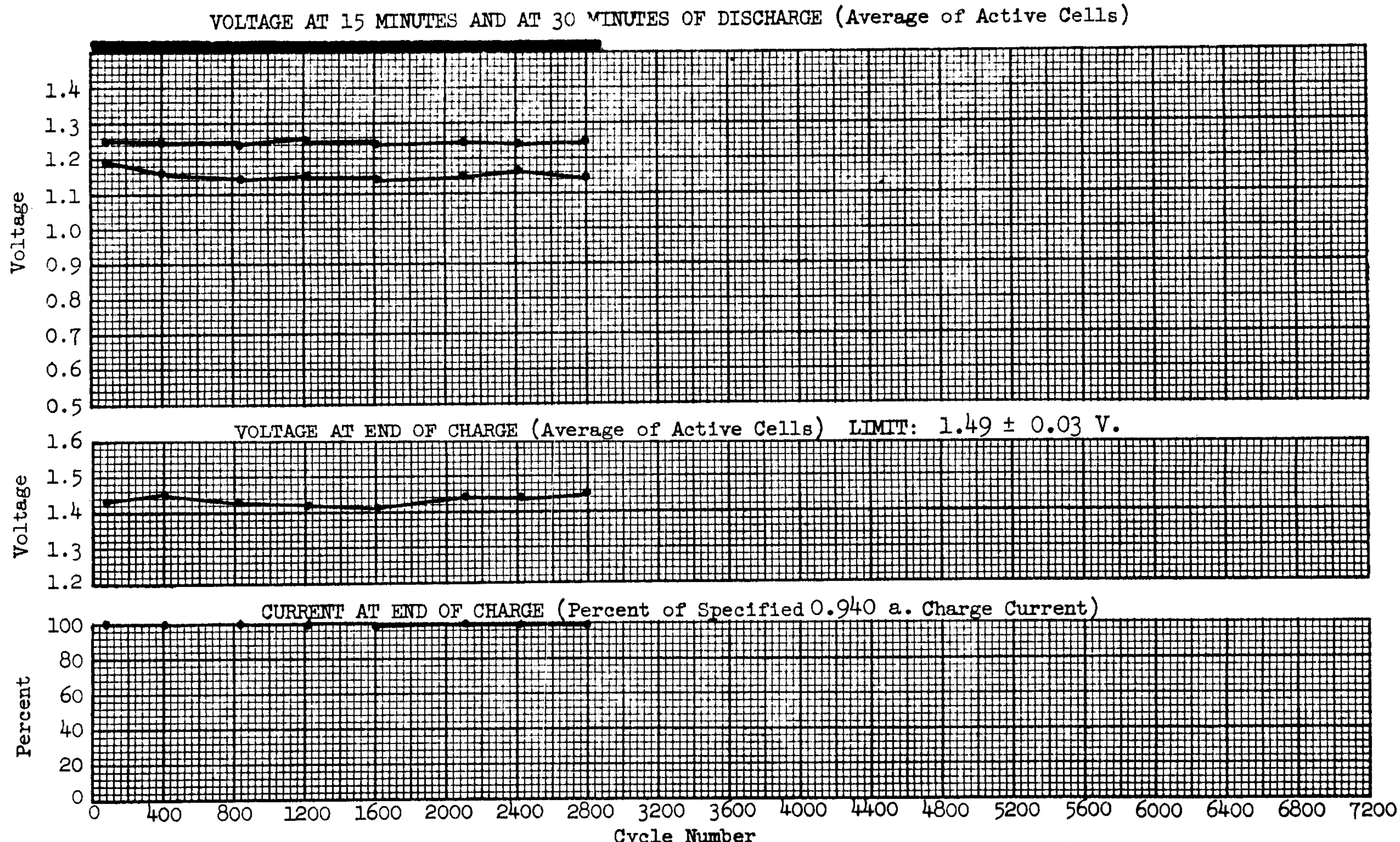
SONOTONE 3.0 a.h. (Pack 231)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: 5 cells cycling after 2731 cycles.

Notes

1. Cycles 1274, 2430: Capacity Check.

FIGURE 26 (b)



Cell Number	Cycle Failed

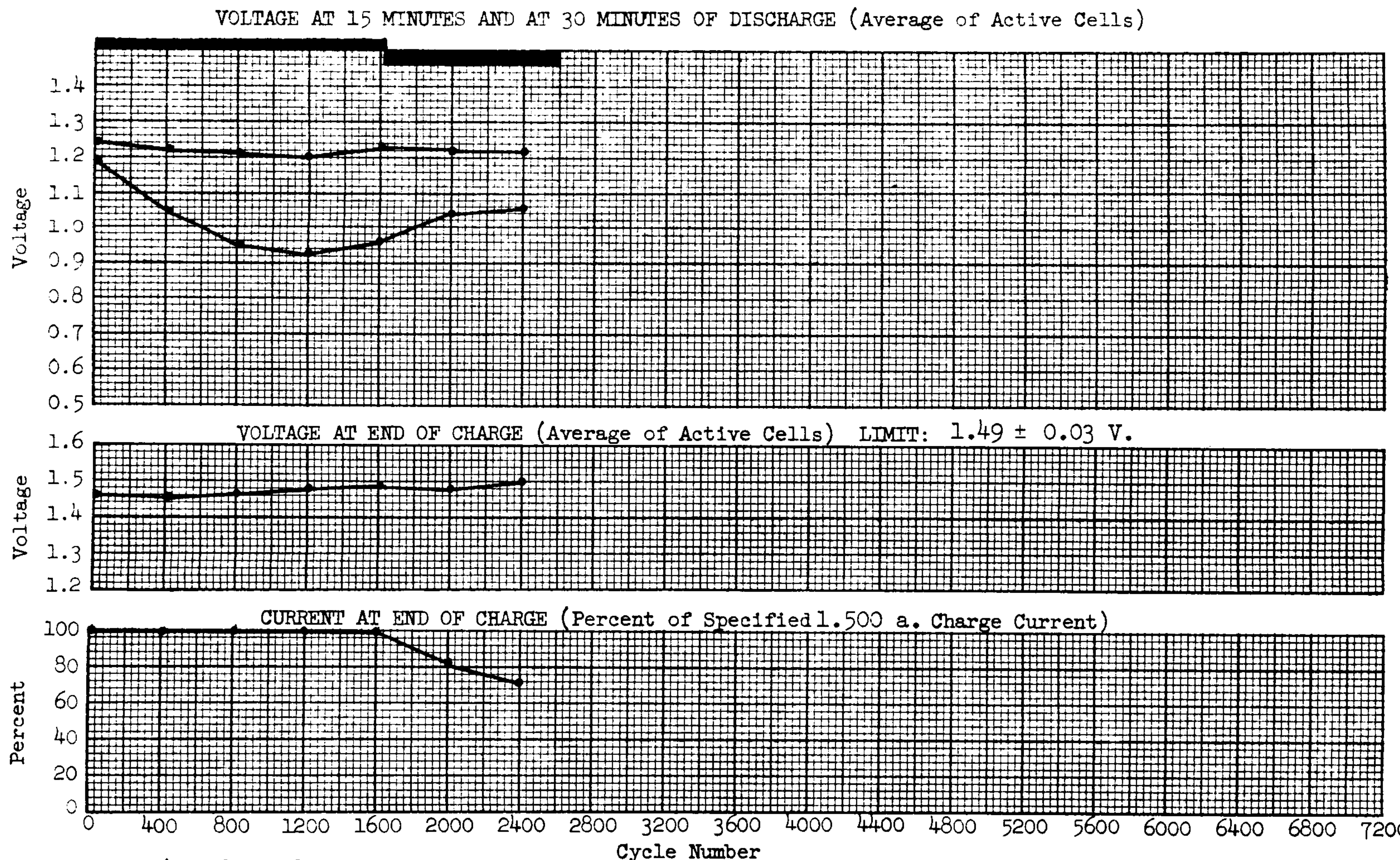
SONOTONE 3.0 a.h. (Pack 203)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: 5 cells cycling after 2890 cycles.

Notes

1. Cycles 1310, 2834: Capacity Check.

FIGURE 26(c)



Cell Number	Cycle Failed
A-3553	1630

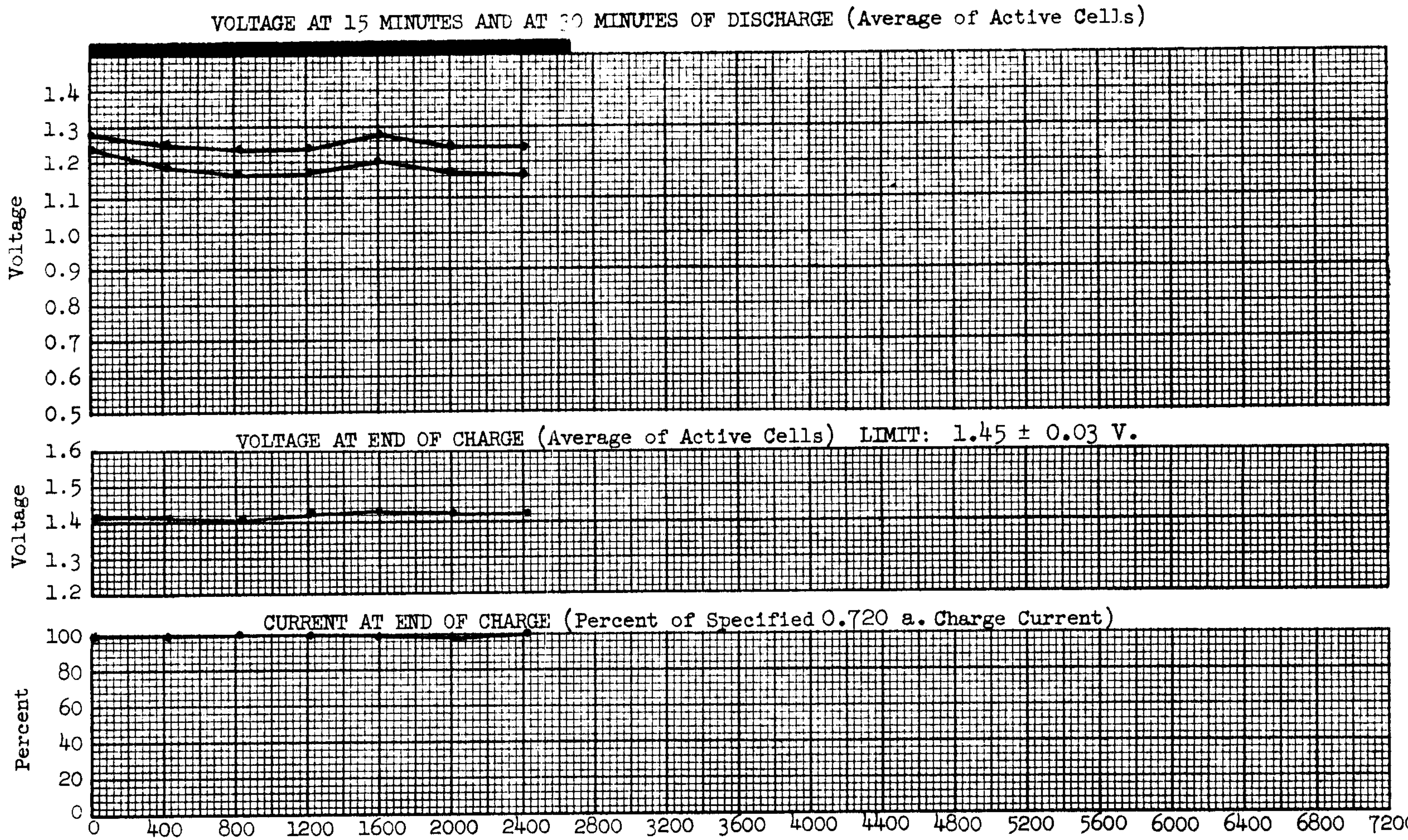
SONOTONE 3.0 a.h. (Pack 202)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 40%

Status: 4 cells cycling after 2576 cycles.

Notes

1. Cycles 1253: Capacity Check.

FIGURE 26(d)



Cell Number	Cycle Failed

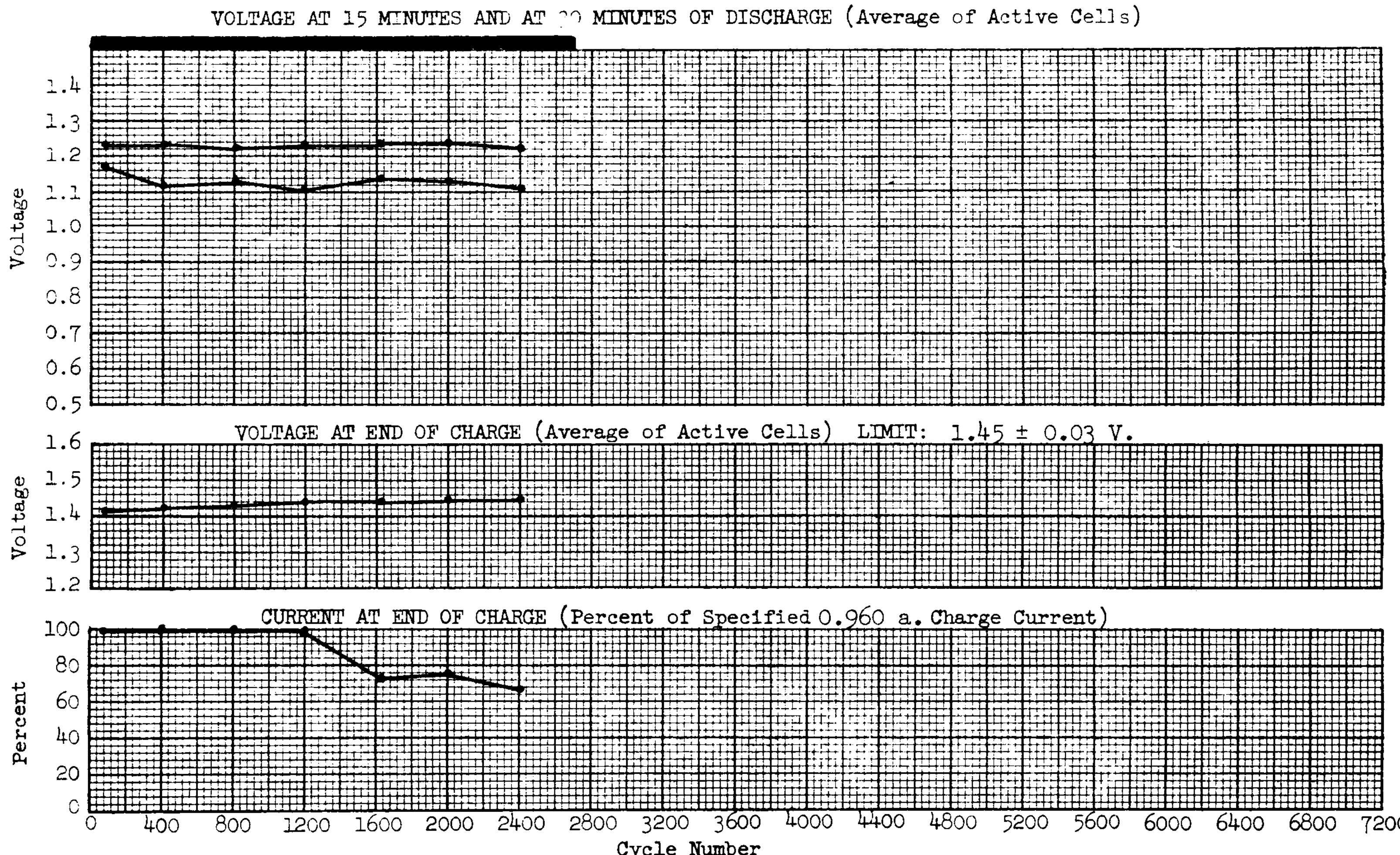
SONOTONE 3.0 a.h. (Pack 226)
Test Temperature: 40° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

Status: 5 cells cycling after 2674 cycles.

Notes

1. Cycles 2024: Capacity Check.

FIGURE 26(e)



Cell Number	Cycle Failed

SONOTONE 3.0 a.h. (Pack 237)
Test Temperature: 40° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: 5 cells cycling after 2693 cycles.

Notes

1. Cycles 1620: Capacity Check.

FIGURE 26(f)

B. Silver-Zinc Types:

1. Delco-Remy 25 a.h., Two 5-cell Packs, 24-hour Orbit Period:

a. Cell Description:

(1) Pack 89: Manufacturer's Standard Model. These cells are rectangular in shape with the cell containers and cell covers of nylon. The cells were epoxy potted into 5-cell packs by the manufacturer.

(2) Pack 75: Same as standard model, Pack 89, except for the addition of one percent of palladium to the positive plate material.

b. Test Parameters: Both packs were cycled at the test parameters listed below:

(1) Test Temperature: 25° C.

(2) Depth of Discharge: 40%.

(3) Charge Voltage Limit: 1.97 ± 0.03 volts per cell, average.

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

c. Test Results:

(1) Pack 89 (Standard Model) failed after 80 cycles.

(2) Pack 75 (Palladium in Positive Plates) failed after 32 cycles.

2. Delco-Remy 25 a.h., Two 5-cell Packs, 3-hour Orbit Period:

a. Cell Description:

(1) Pack 288: Standard model as Pack 89, except for the addition of one percent palladium in the positive plate material and the use of 2.2xH Radiation Application Company's separators.

(2) Pack 188: Standard model as Pack 89, except for the addition of one percent palladium in the positive plate

material, and the use of a 45 percent NaOH solution as the electrolyte.

b. Test Parameters: Both packs were cycled at the test parameters listed below:

(1) Test Temperature: 25° C.

(2) Depth of Discharge: 40%.

(3) Charge Voltage Limit: 1.97 ± 0.03 volts per cell, average.

(4) Orbit Period: 30-minute discharge, 2.5-hour charge.

c. Test Results:

(1) Pack 288: One cell failed after 100 cycles. The remaining cells were still functioning after 120 cycles, at which time the pack was removed from cycling.

(2) Pack 188: Pack 188 failed after 325 cycles.

3. Delco-Remy 40 a.h., One 5-cell Pack, 24-hour Orbit Period (Pack 275):

a. Cell Description:

(1) Manufacturer's Standard Model. These cells are rectangular in shape with the cell containers and cell covers of nylon. These cells were epoxy potted into one 5-cell pack by the manufacturer.

b. Test Parameters:

(1) Test Temperature: 25° C.

(2) Depth of Discharge: 40%.

(3) Charge Voltage Limit: 1.97 ± 0.03 volts per cell, average.

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

c. Test Results: One cell failed while the pack was being prepared for test; a second cell failed after 34 cycles. The remaining three cells were still functioning after 139 cycles, at which time the pack was removed from cycling.

4. Yardney 12 a.h., One 10-cell Pack, 24-hour Orbit Period (Pack 9):

a. Cell Description:

(1) These are vented cells, rectangular in shape, with the containers and covers of plastic material. They contained a limited amount of electrolyte. The cells were individually epoxy potted to hermetically seal them.

b. Test Parameters:

(1) Test Temperature: 25° C.

(2) Depth of Discharge: 42%.

(3) Charge Voltage Limit: 1.97 ± 0.03 volts per cell, average.

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

c. Test Results: One cell failed after 53 cycles. Three additional cells failed after 57 cycles. Following removal of the failed cells, the remaining cells did not respond to cycling, thus failing the pack.

C. Silver-Cadmium Types:

1. Yardney 5.0 a.h. (C-3 Separator), Three 5-cell Packs, 24-hour Orbit Period:

a. Cell Description:

(1) These are vented cells, rectangular in shape, with the cell containers and cell covers of plastic material. The plates were insulated with C-3 separators. The cells were epoxy potted into 5-cell packs, at the Goddard Space Flight Center, in order to hermetically seal them.

b. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge	Charge Voltage Limit, Per Cell
257	0° C	20	1.50 ± 0.03
21	25° C	20	1.50 ± 0.03
45	40° C	20	1.50 ± 0.03

c. Test Results: Pack 257 has completed 104 successful cycles to date. Pack 45 failed after 61 cycles because of severe leakage. Pack 21 had one cell fail after 90 cycles and two cells fail at 98 cycles. The two failed packs were returned to Goddard Space Flight Center.

2. Yardney 5.0 a.h. (Radiated Separator), Two 5-cell Packs, 24-hour Orbit Period:

a. Cell Description:

(1) These are vented cells, rectangular in shape, with the cell containers and cell covers of plastic material. The plates of the cells were insulated with C-3 separator material which had been radiated. The cells were epoxy potted into 5-cell packs at the Goddard Space Flight Center in order to hermetically seal them.

b. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge	Charge Voltage Limit, Per Cell
409	25° C	20	1.50 ± 0.03
233	25° C	20	1.50 ± 0.03 (Control Pack)

c. Test Results: Pack 233 has completed 63 successful cycles to date. Pack 409 failed after 34 cycles and was returned to Goddard Space Flight Center.

3. Yardney 5.0 a.h. (Pellon Control Separator), One 5-cell Pack, 24-hour Orbit Period (Pack 69):

a. Cell Description:

(1) These are vented cells, rectangular in shape, with the cell containers and cell covers of plastic material. The plates of the cells are insulated with Pellon control separator material. Each cell has a pressure gage for monitoring internal cell pressure. The cells were individually epoxy potted to hermetically seal them.

b. Test Parameters:

(1) Test Temperature: 25° C.

(2) Depth of Discharge: 20%.

(3) Charge Voltage Limit: 1.50 ± 0.03 volts per cell, average.

c. Test Results: The pack has completed 63 cycles and is still cycling.

4. Yardney 12 a.h., Two 10-cell Packs, 24-hour Orbit Period:

a. Cell Description: These are rectangular cells, double sealed. That is, each sealed nylon cell is encased in a hermetically sealed stainless steel container.

b. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge	Charge Voltage Limit, Per Cell
33	40° C	50	1.50 ± 0.03
57	0° C	50	1.50 ± 0.03

c. Test Results:

(1) Performance on cycling:

(a) Pack 33: The plateau voltage of the non-failing 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, the plateau voltage began to drop steadily and the end-of-discharge voltage became quite erratic. This pack failed after 210 cycles. All of the failed cells had dried out because of electrolyte leakage.

(b) Pack 57: Low end-of-discharge voltages occurred as early as after completion of 31 cycles, and persisted erratically until the pack failed after 166 cycles. Although cell voltages had frequently fallen below the 0.5 volt failure point, they had not been classed as failures earlier because of their erratic behavoir. After 162 cycles, electrolyte had leaked out and formed a pool over the tops of the cells, thus shorting them out. The 10 cells were cleaned, after which seven were returned to cycling, but after four additional cycles the condition had recurred. All seven cells were leaking.

(c) Capacity Checks: The ampere-hour capacities of the cells on the preconditioning and check cycles are as follows:

Pack Number	Preconditioning	140 Days Discharge #1	#2
33	13.5	11.2	12.0
57	13.8	5.9	8.6

II. CELLS USING CHARGE CONTROL METHODS AND DEVICES. As a continuing effort to improve the cells and cell life, new types of charge control methods and devices are being developed. The new means of charge control that are being tested at NAD Crane are as follows: auxiliary electrode, stabistor, coulometer, Sherfey upside-down cycling, and the two step regulator.

A. Auxiliary Electrode: Nickel-cadmium cells have been developed with an auxiliary electrode whose voltage, with respect to the negative cell terminal, is a function of the number of oxygen molecules in the cell. When a nickel-cadmium cell is being charged, it generates oxygen very slowly until it nears 80 percent of the required recharge; then suddenly, the amount of oxygen generated internally increases rapidly. The increased oxygen pressure causes a fast rise in voltage between the auxiliary electrode and the negative cell terminal. This increasing voltage is used to signal a control circuit to change the charge rate.

1. Test Equipment: The charge-current control circuit used on this test utilized the auxiliary electrode voltage from each cell in the pack to determine when the cells have received the predetermined

amount of recharge. The circuit is designed to monitor the auxiliary electrode voltage of each cell in a 5-cell pack while they are being charged. As the auxiliary electrode voltage in any one cell of the pack rises above a preset value, the circuit begins reducing the charge current to that pack, so that when the auxiliary electrode voltage of any cell reaches the predetermined maximum (trip voltage) the charge current will have been reduced to a preset trickle charge or to zero. The charge and discharge current is supplied by a unit described in section I, paragraph V.B.

2. Gulton 6.0 a.h. (Nickel-Cadmium), Six 5-cell Packs, 1.5-hour Orbit Period:

a. Cell Description: These cells are rectangular in shape. The cell container and cell cover are made of stainless steel. Both terminals are insulated from the cell cover by a ceramic seal and protrudes through the cover as solder type terminals. A stainless steel tab is welded to the cell cover for the auxiliary electrode terminal. The auxiliary electrode is welded to the cell container. A resistor is mounted externally between the auxiliary electrode and the negative terminal. The resistor permits the recombination rate of the auxiliary electrode to be adjusted by changing the resistance.

b. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge	Signal Voltage Level (Millivolts)	Resistors On Cells (Ohms) 1	2	3	4	5
59	0° C	25	150	10	10	10	10	10
71	0° C	40	150	10	10	10	10	10
23	25° C	25	300	12	12	20	29	24
11	25° C	40	300	24	24	10	8	24
35	40° C	15	300	47	47	47	47	47
47	40° C	25	300	11	11	12	11	11

c. Test Results:

(1) Performance on cycling: (Figures 27(a) through 27(f).)

(a) Pack 71 has completed 3732 cycles. The percent of recharge has averaged 103 percent. The end-of-discharge voltage has decreased from 1.20 volts per cell to 1.15 volts, average. One cell failure occurred after 2993 cycles due to weight loss (8.7 grams).

(b) Pack 59 has completed 3673 cycles. The percent of recharge was 107 percent but after 800 cycles it decreased to 102 percent and has remained there. The end-of-discharge voltage decreased from 1.27 volts per cell to 1.20 volts, average. One cell failure occurred after 3202 cycles when the auxiliary electrode shorted to the negative plates and could not give a signal.

(c) Pack 23 has completed 4838 cycles. The percent of recharge increased from 98 percent to 120 percent after the resistors on the cells were adjusted to the value that gave the best operation. The end-of-discharge voltage decreased from 1.20 volts per cell to 1.15 volts, average. There have been no cell failures.

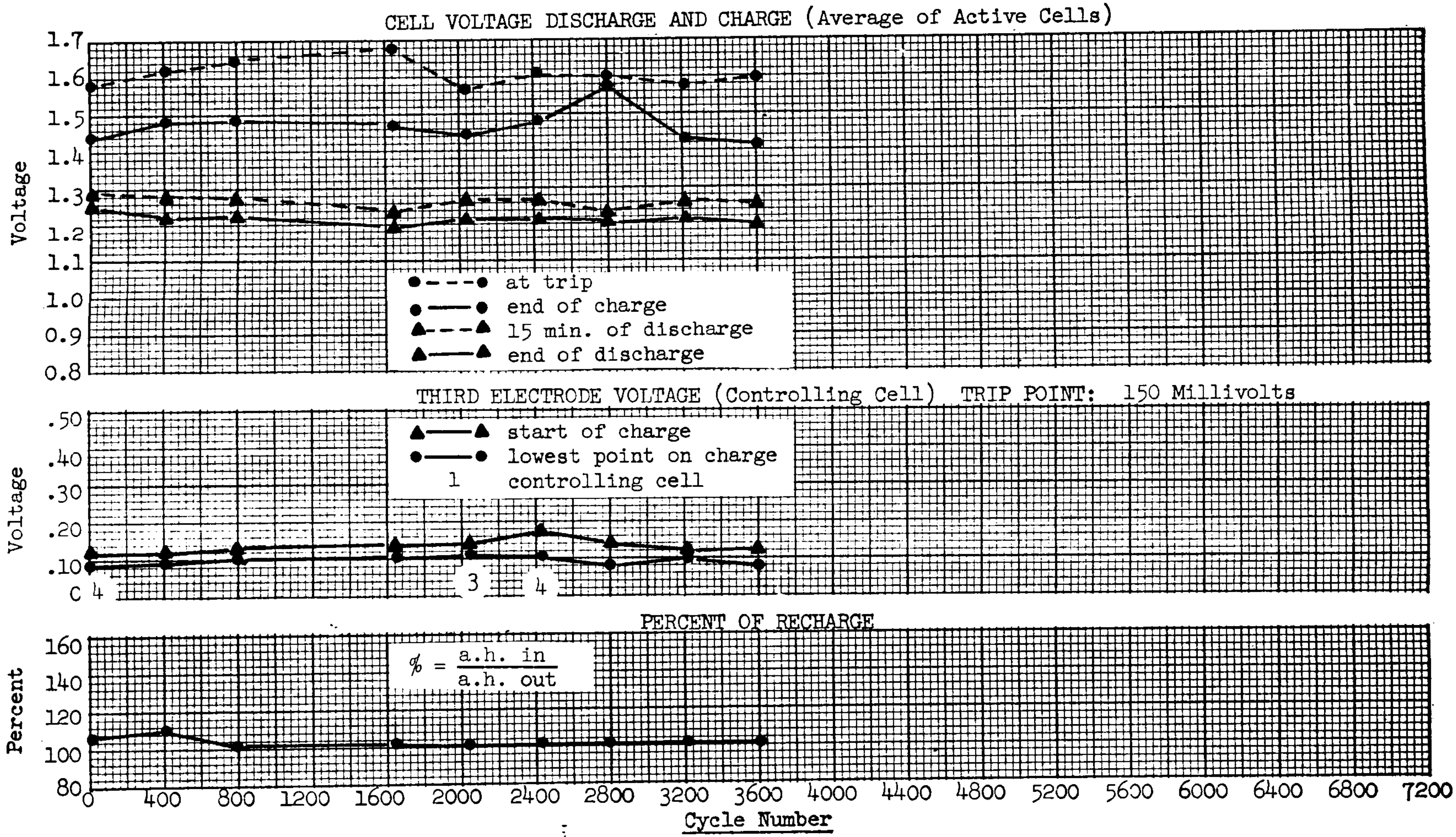
(d) Pack 11 has completed 4855 cycles. The percent of recharge increased from 94 percent to 115 percent after the resistors on the cells were adjusted to the value that gave the best operation. The end-of-discharge voltage ranged from 1.27 volts per cell to 0.98 volts before it stabilized at 1.11 volts, average. One cell failure occurred after 2754 cycles due to ceramic short (see section I, paragraph IV.E.3.b.(13)).

(e) Pack 47 has completed 3455 cycles. The percent of recharge started at 126 percent and decreased to 92 percent before it stabilized at 132 percent after the resistors on the cells were adjusted to the value that gave the best operation. The end-of-discharge voltage decreased from 1.28 volts per cell to 1.06 volts before it began to rise to its present value of 1.23 volts, average. There have been no cell failures.

(f) Pack 35 has completed 2785 cycles. The percent of recharge started at 118 percent then increased to 144 percent before it stabilized at 130 percent. The end-of-discharge voltage decreased slowly from 1.26 volts per cell to 1.14 volts, average. There have been no cell failures:

(2) Capacity Checks: The ampere-hour capacities after 100 cycles and capacity check cycles are as follows:

Pack Number	100 Cycles	88 Days Discharge #1	88 Days Discharge #2	176 Days Discharge #1	176 Days Discharge #2
59	7.15	6.25	7.00	6.20	3.50
71	7.25	6.70	7.50	6.60	7.00
23	5.95	2.25	3.85	1.90	5.20
11	7.10	2.50	3.15	2.70	6.20
35	2.95	1.80	2.25	1.45	1.60
47	3.95	1.70	2.10	2.05	1.70



GULTON 6.0 a.h. (Pack 59) with Auxiliary Electrode

Cell Number	Cycle Failed
140 (Position 3)	3202

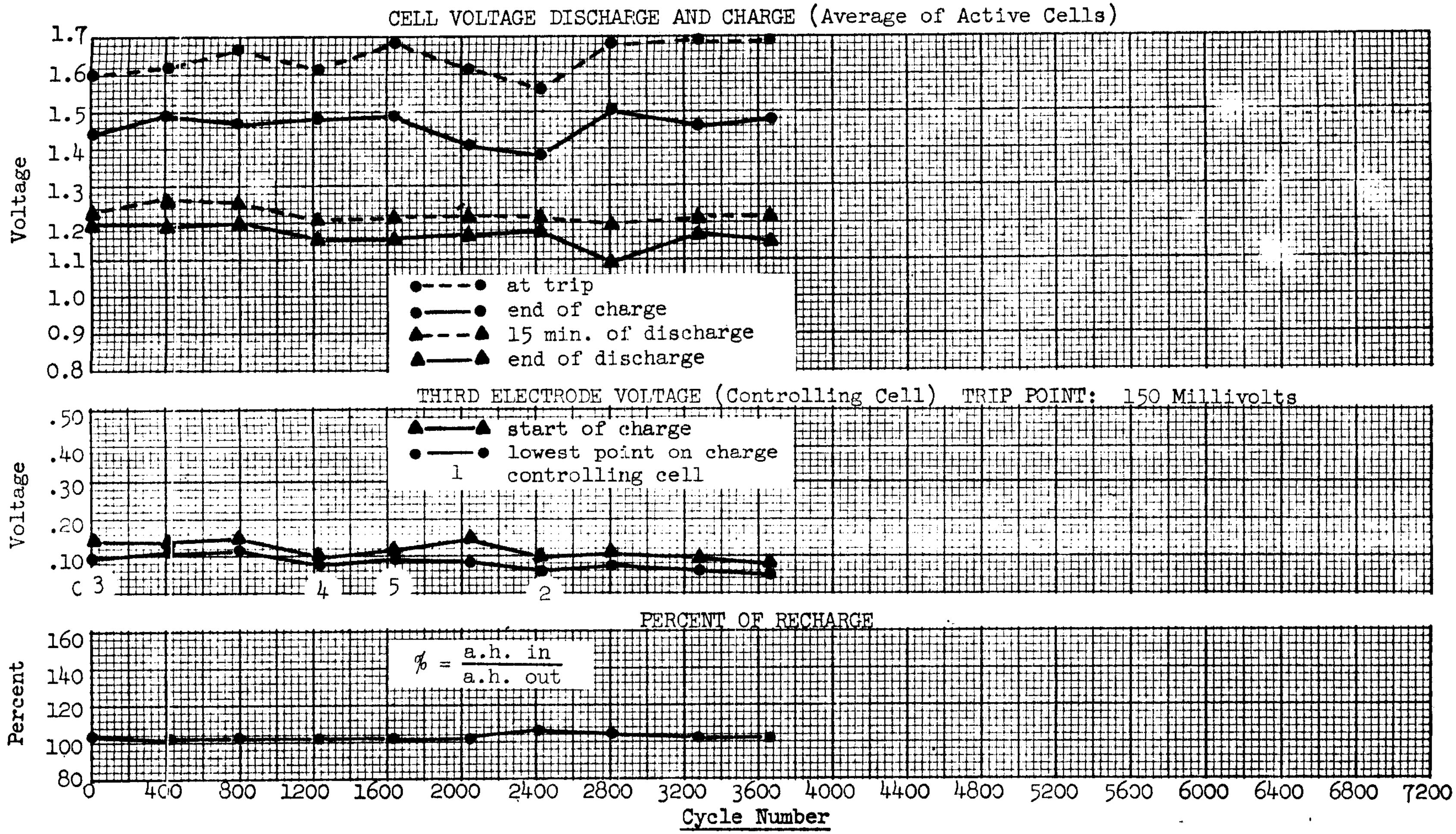
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: 4 cells cycling after 3673 cycles.

Notes

1. Resistor values; 10, 10, 10, 10, 10 ohms.
2. Cycles 635, 2040, 3104: Capacity Check.

FIGURE 27(a)



GULTON 6.0 a.h. (Pack 71) with Auxiliary Electrode

Cell Number	Cycle Failed
130 (Position 5)	2993

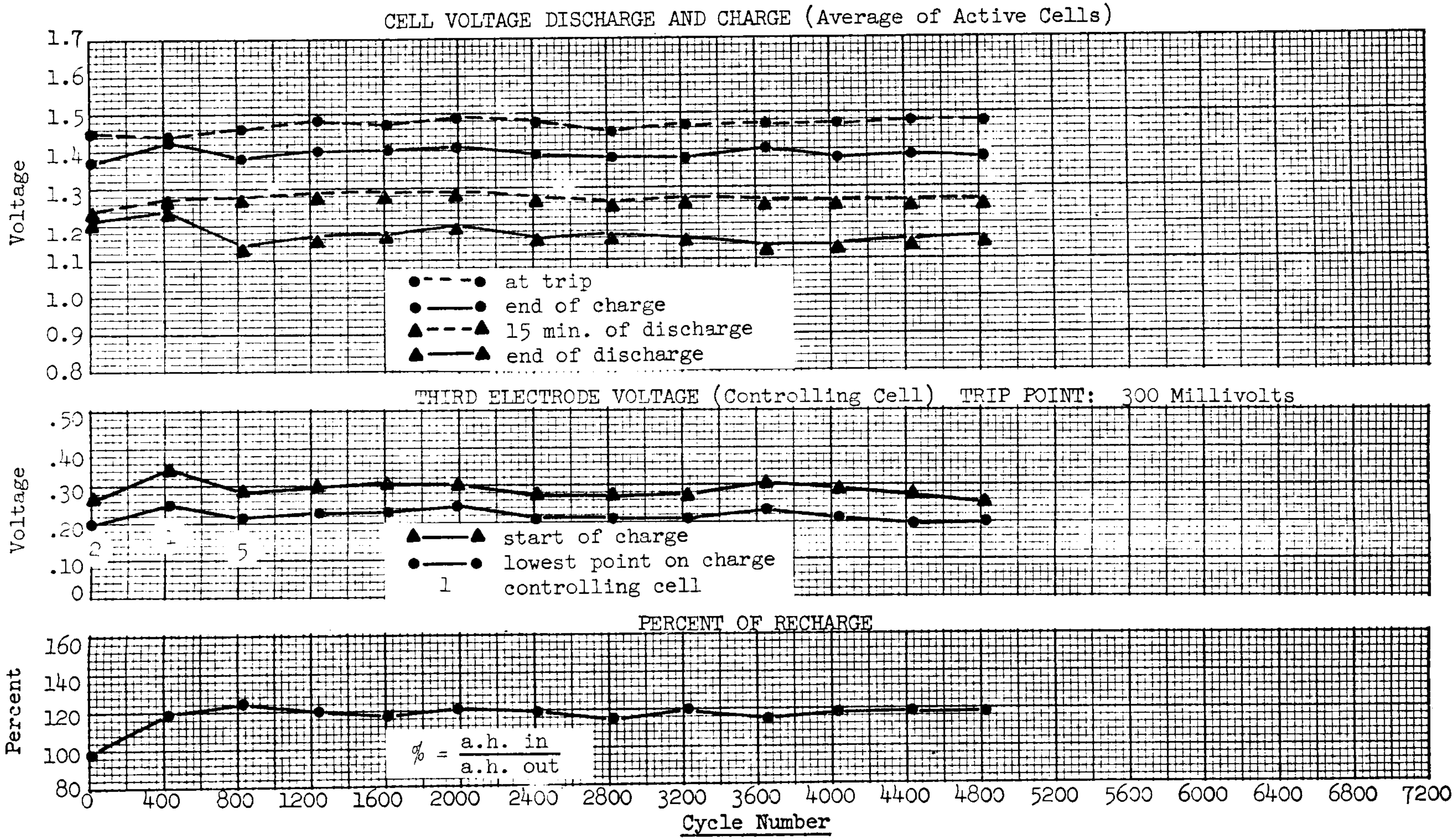
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 40%

Status: 4 cells cycling after 3732 cycles.

Notes

1. Resistor values; 10, 10, 10, 10, 10 ohms.
2. Cycles 635, 1955, 3163: Capacity Check.

FIGURE 27(b)



GULTON 6.0 a.h. (Pack 23) with Auxiliary Electrode

Cell Number	Cycle Failed

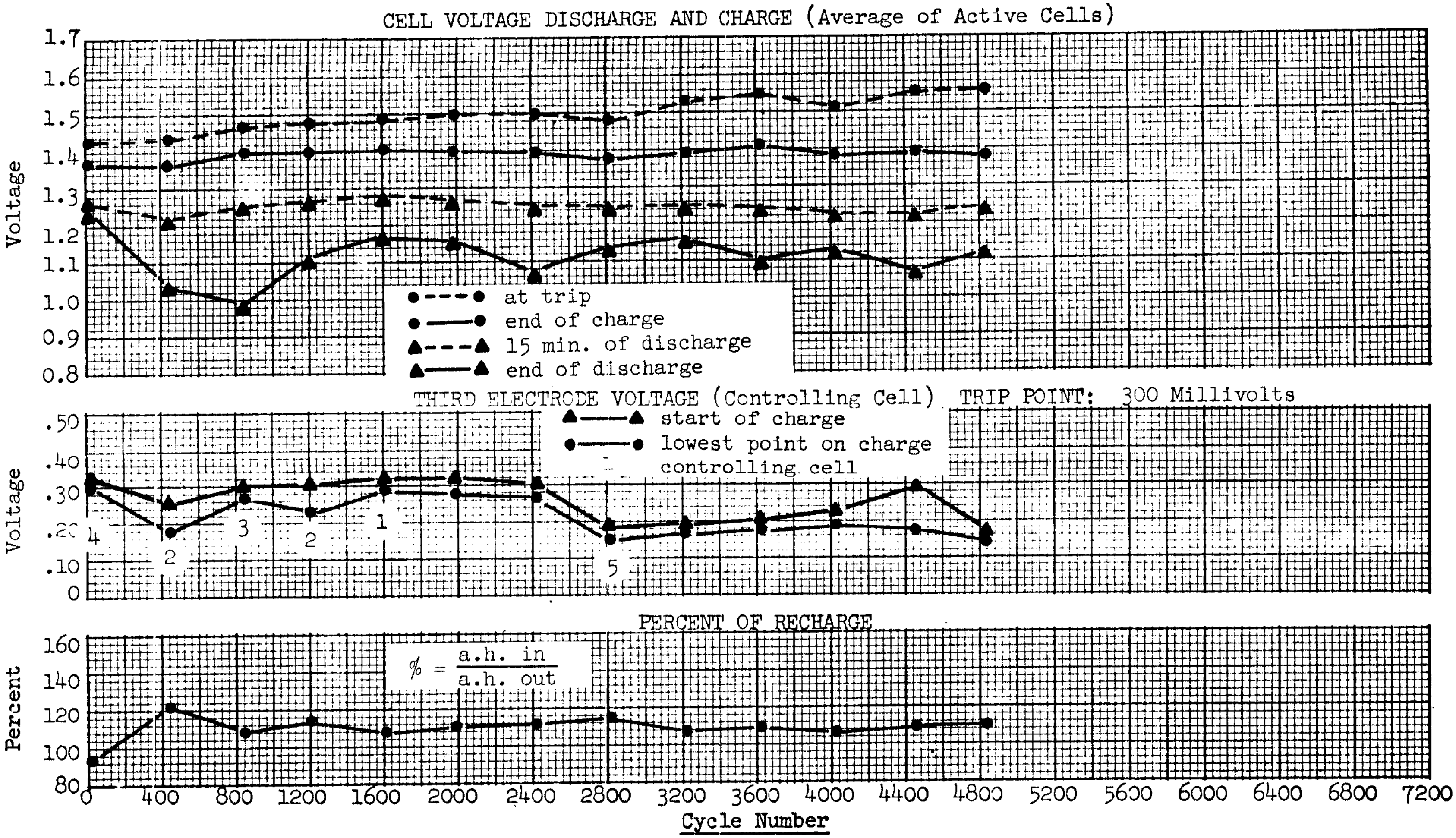
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: 5 cells cycling after 4838 cycles.

Notes

1. Resistor values after 853 cycles: 12, 12, 20, 29, 24 ohms.
2. Cycles 103, 332, 1268, 2752, 3897: Capacity Check.

FIGURE 27(c)



GULTON 6.0 a.h. (Pack 11) with Auxiliary Electrode

Cell Number	Cycle Failed
147 (Position 3)	2754

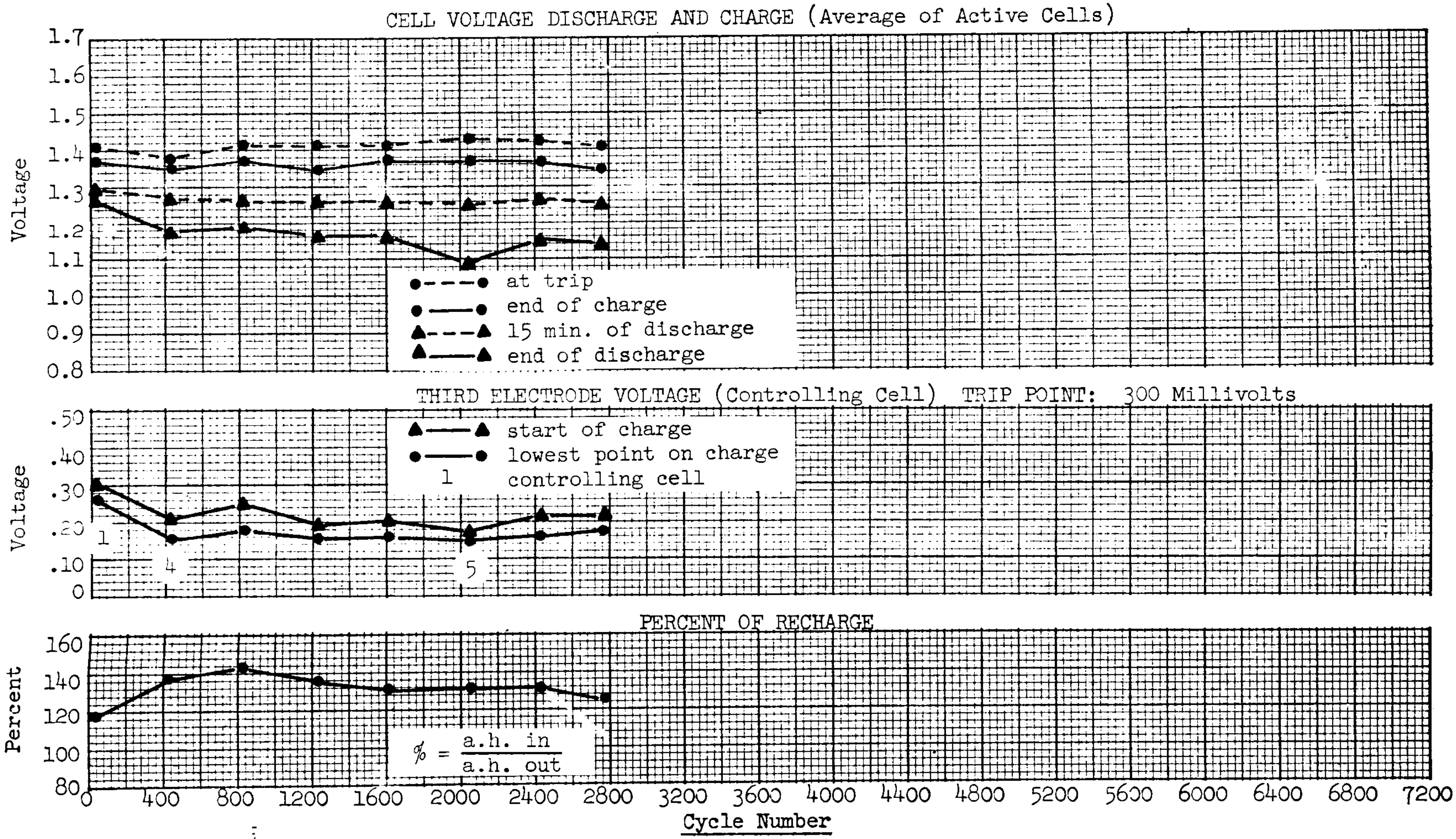
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 40%

Status: 4 cells cycling after 4855 cycles.

Notes

1. Resistor values after 1076 cycles; 24, 24, 10, 8, 24 ohms.
2. Cycles 93, 253, 1281, 2753, 3886: Capacity Check.

FIGURE 27(d)



Cell Number	Cycle Failed

GUITON 6.0 a.h. (Pack 35) with Auxiliary Electrode

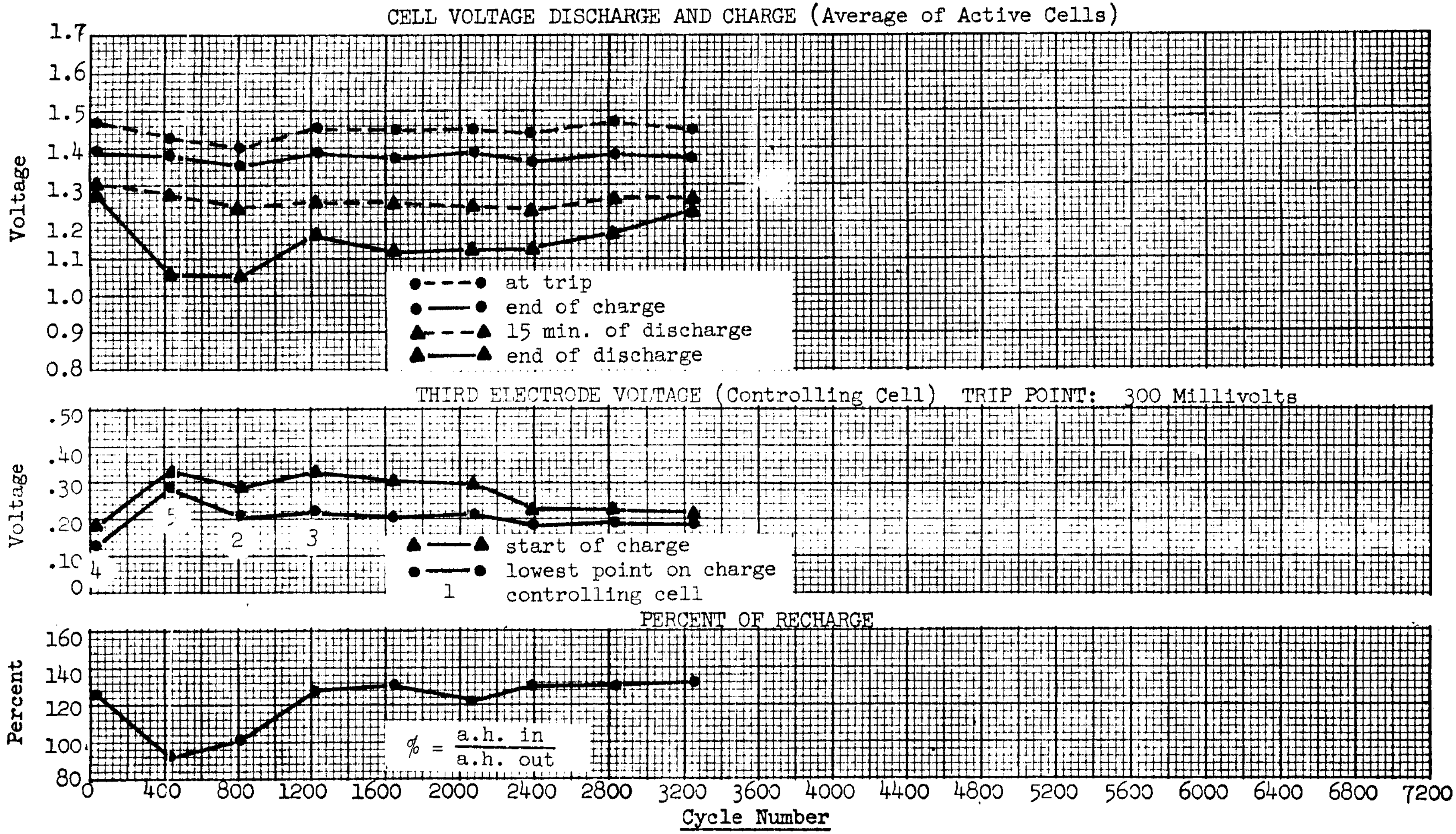
Test Temperature: 40° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

Status: 5 cells cycling after 2785 cycles.

Notes

1. Resistor values; 47, 47, 47, 47, 47 ohms.
2. Cycles 271, 1111, 2473: Capacity Check.

FIGURE 27(e)



GULTON 6.0 a.h. (Pack 47) with Auxiliary Electrode

Cell Number	Cycle Failed

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

Status: 5 cells cycling after 3455 cycles.

Notes

1. Resistor values after 990 cycles; 11, 11, 12, 11, 11 ohms.
2. Cycles 242, 1781, 3143: Capacity Check.

FIGURE 27(f)

3. General Electric 12 a.h. (Nickel-Cadmium), Four 5-cell Packs, 1.5-hour Orbit Period:

a. Cell Description: These cells are rectangular in shape. 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 1/4-20 threaded posts. A stainless steel tab is welded to the cell cover for the auxiliary electrode terminal. The auxiliary electrode is welded to the cell container. A resistor is mounted externally between the auxiliary electrode and the negative terminal. The resistor permits the recombination rate of the auxiliary electrode to be adjusted by changing the resistance.

b. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge	Signal Voltage Level (Millivolts)	Resistors On Cells (Ohms) 1	2	3	4	5
60	0° C	25	400	3	3	3	3	3
12	25° C	25	400	1	1	1	1	1
24	25° C	40	400	1	1	1	1	1
48	40° C	25	400	.5	.5	.5	.5	.5

(1) Pack 48 was changed to 0° C after 528 cycles with the following parameters: Depth of Discharge, 40 percent; Resistors, 3 ohms on each cell.

c. Test Results:

(1) Performance on cycling: Due to the low capacity of the negative plates, cycling of packs at 25° C and 40° C was discontinued.

(a) Pack 12, at 25° C, had completed 1698 cycles before it was discontinued. The end-of-discharge voltage fell below 1.0 volt per cell, average, after 486 cycles. The pack was reconditioned and returned to cycling. After 872 cycles, the voltage again dropped below 1.0 volt per cell, average. The pack was again reconditioned. After 1051 cycles, the pack again lost capacity and was reconditioned for the third time. After 1698 cycles the pack was discontinued.

(b) Pack 24, at 25° C, had completed 665 cycles before it was discontinued. The end-of-discharge voltage on all cells in the pack was below 1.0 volt.

(c) Pack 48 had completed 528 cycles at 40° C before it was changed to the new test parameters. It is still cycling at 0° C after a total of 709 cycles without any cell failures.

(c) Pack 60, at 0° C, has completed 1305 cycles without any cell failures.

B. Stabistor: The stabistor is a semiconductor device that is used to shunt current around a fully charged cell. The stabistor will pass current when the voltage across it has reached the breakdown value. The breakdown voltage depends upon the temperature of the stabistor. At higher temperatures the breakdown voltage is lower than at cold temperatures.

1. Test Equipment: The charge and discharge current and cycling is done with equipment described in section I, paragraph V.B. Each cell has a 5-ampere stabistor and an antireversal diode mounted across the terminals of the cell to limit the charge current and prevent cell reversal damage on discharge.

2. Sonotone 5.0 a.h. (Nickel-Cadmium), Eight 5-cell Packs, 1.5-hour Orbit Period:

a. Cell Description: These are cylindrical cells made of stainless steel. Two stainless steel tabs are welded to the cover for the negative connections. The positive terminal is an extension of the positive plate tab and is insulated from the "negative" cover by a ceramic 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. This cell construction was used for cells in the TIROS satellite.

b. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge
175	-20° C	25
289	-20° C	40
92	0° C	25
322	0° C	40
273	25° C	25
287	25° C	40
299	40° C	25
312	40° C	40

(1) Pack 312 did not cycle satisfactorily at 40 percent depth of discharge so it was reduced to 15 percent, with all other parameters unchanged. All packs are recharged at the c/1 rate (5 amps) because of the 5-ampere stabistor in parallel with each cell.

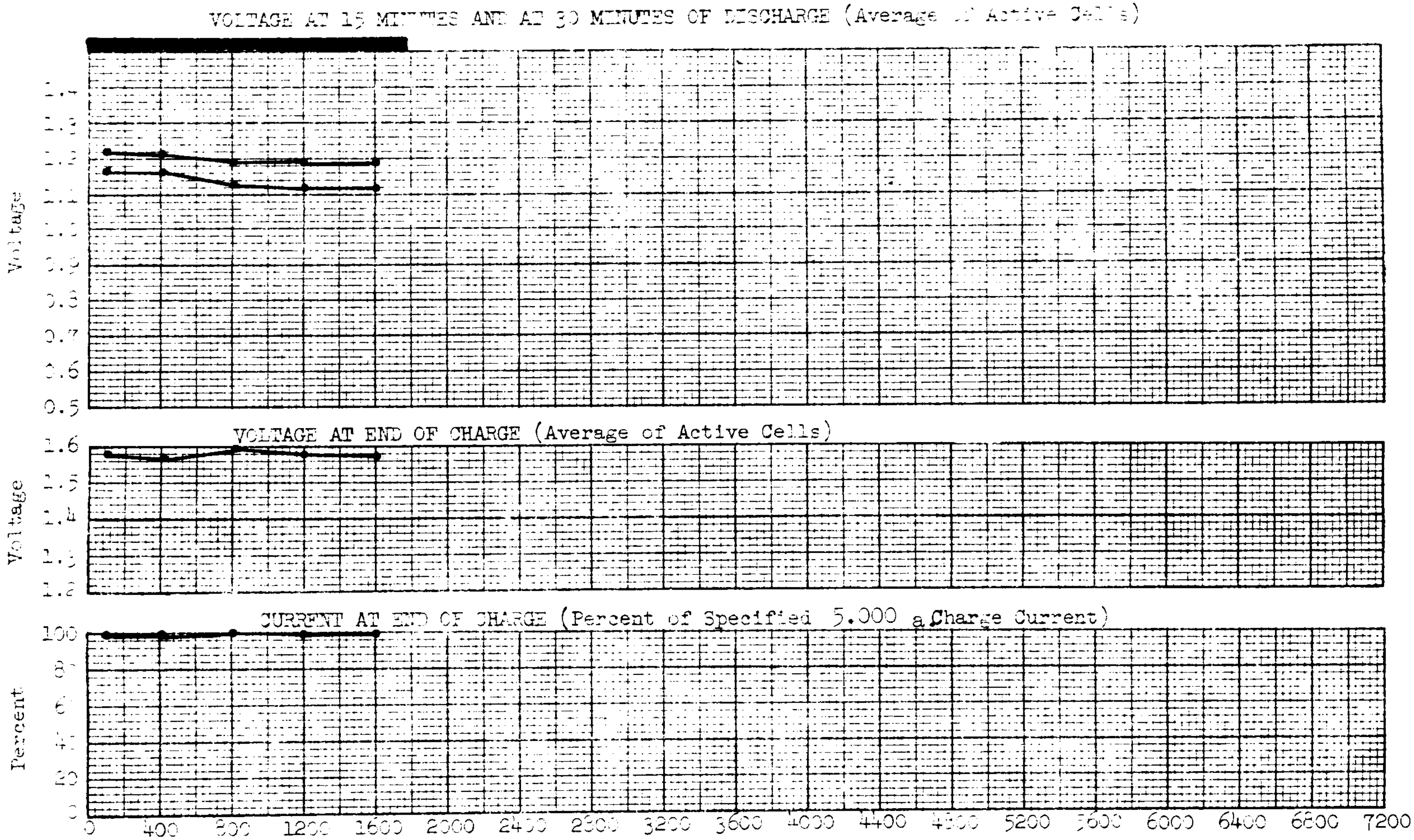
c. Test Results:

(1) Performance on cycling: (Figures 28(a) through 28(f).)

(2) These packs have completed from 747 to 2133 cycles, with four cell failures at the cold temperatures. The breakdown voltage of the stabistors was too high for operation at the lower temperatures and resulted in excessive gassing which broke the ceramic seal of four cells.

(2) Capacity Checks: Ampere-hour capacities on preconditioning and capacity check cycles are as follows:

Pack Number	Preconditioning	88 Days Discharge #1	88 Days Discharge #2
175	4.92	1.42	1.21
289	4.96	3.13	2.58
92	3.38	2.92	2.75
322	4.13	2.42	2.33
273	5.33	1.25	2.33
287	5.50	1.96	3.66
299	4.21	1.71	1.88
312	3.71	0.42	1.04



Cell Number	Cycle Failed

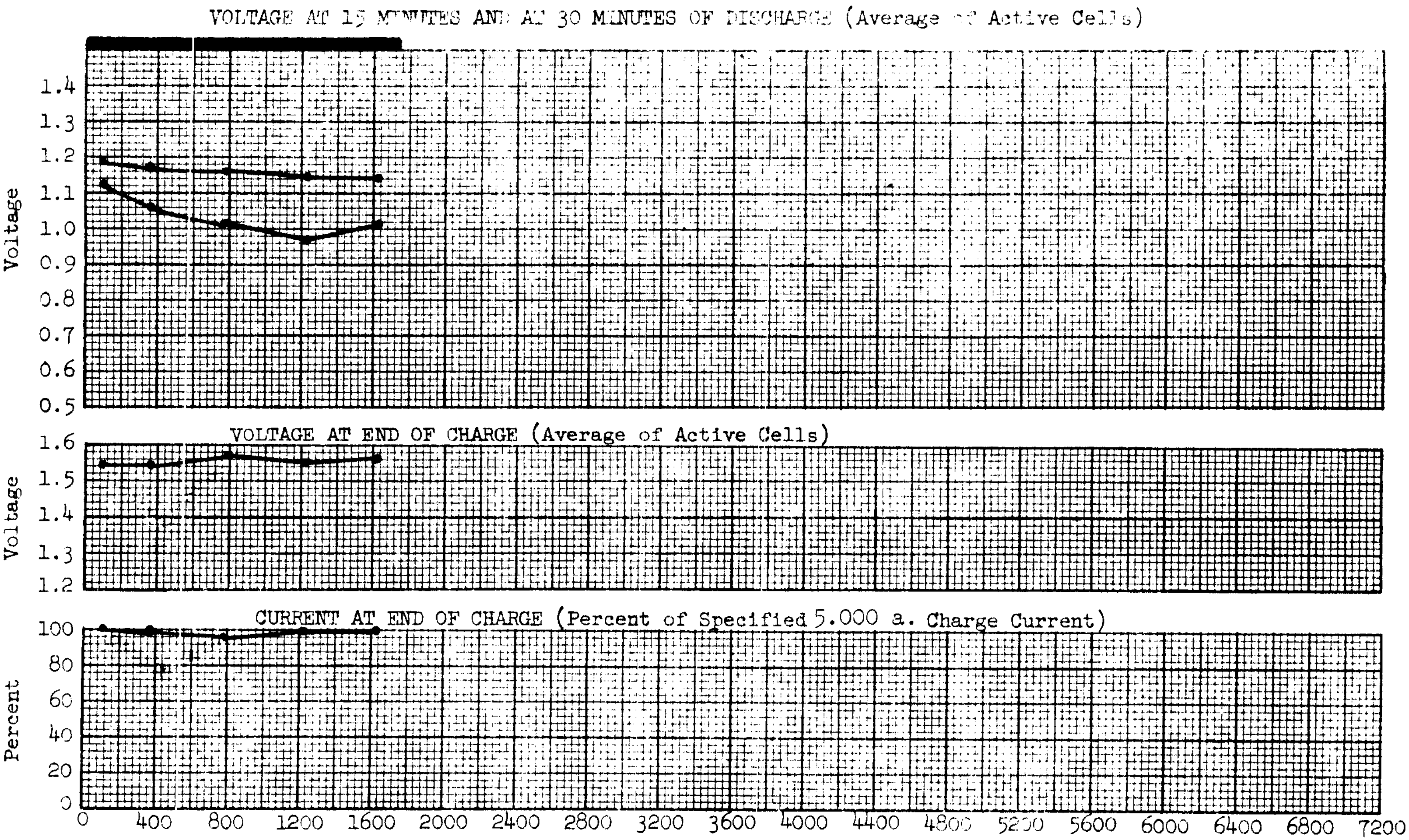
SONOTONE 5.0 a.h. (Pack 92)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: 5 cells cycling after 1772 cycles.

Notes

1. Charge current changed from 2.5 a to 5.0 a after cycle 54.
2. Cycles 1314: Capacity Check.

FIGURE 28(a)



Cell Number	Cycle Failed

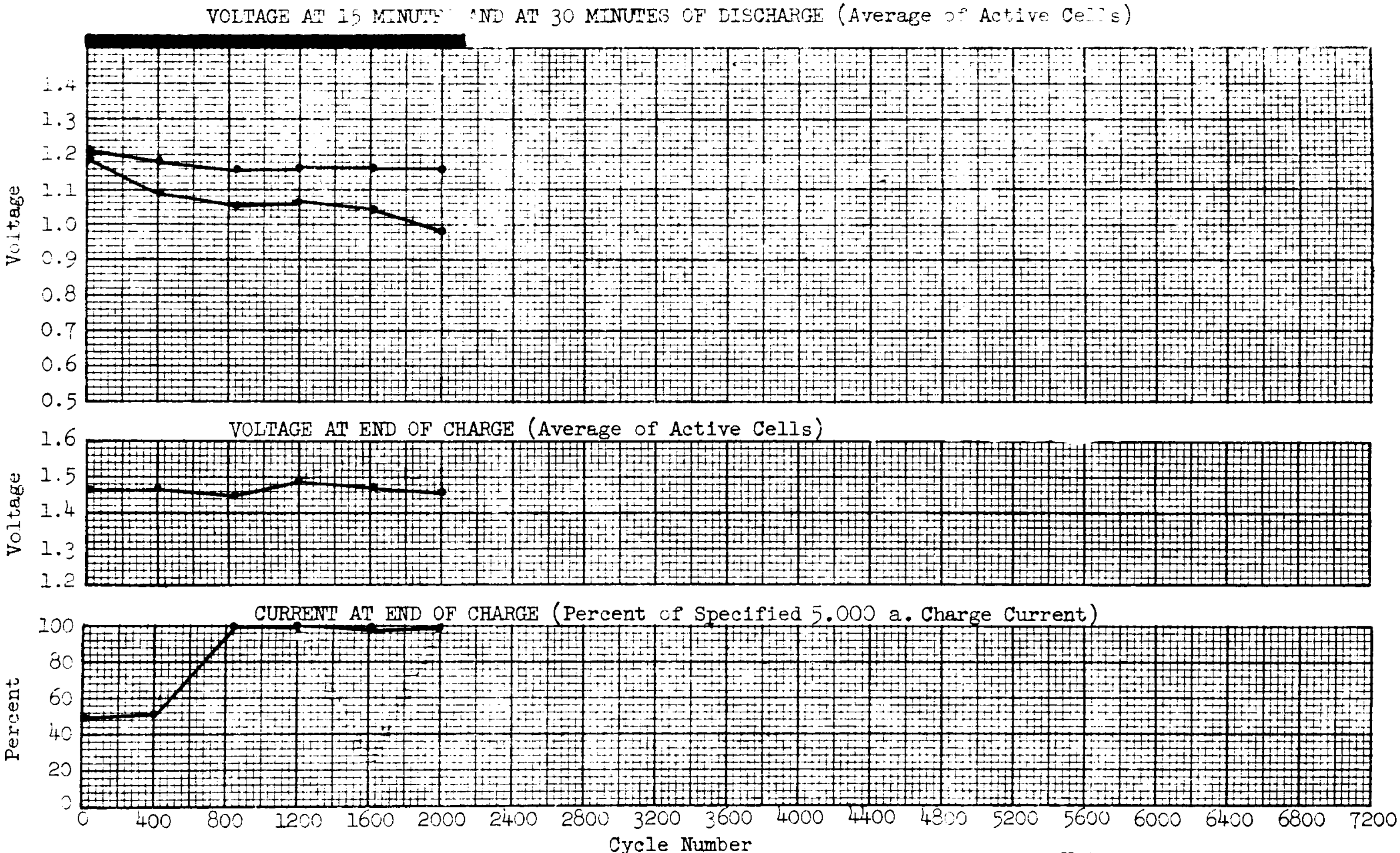
SONOTONE 5.0 a.h. (Pack 322)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 40%

Status: 5 cells cycling after 1743 cycles.

Notes

1. Charge current changed from 2.5 a to 5.0 a after cycle 54.
2. Cycles 1285: Capacity Check.

FIGURE 28(b)



Cell Number	Cycle Failed

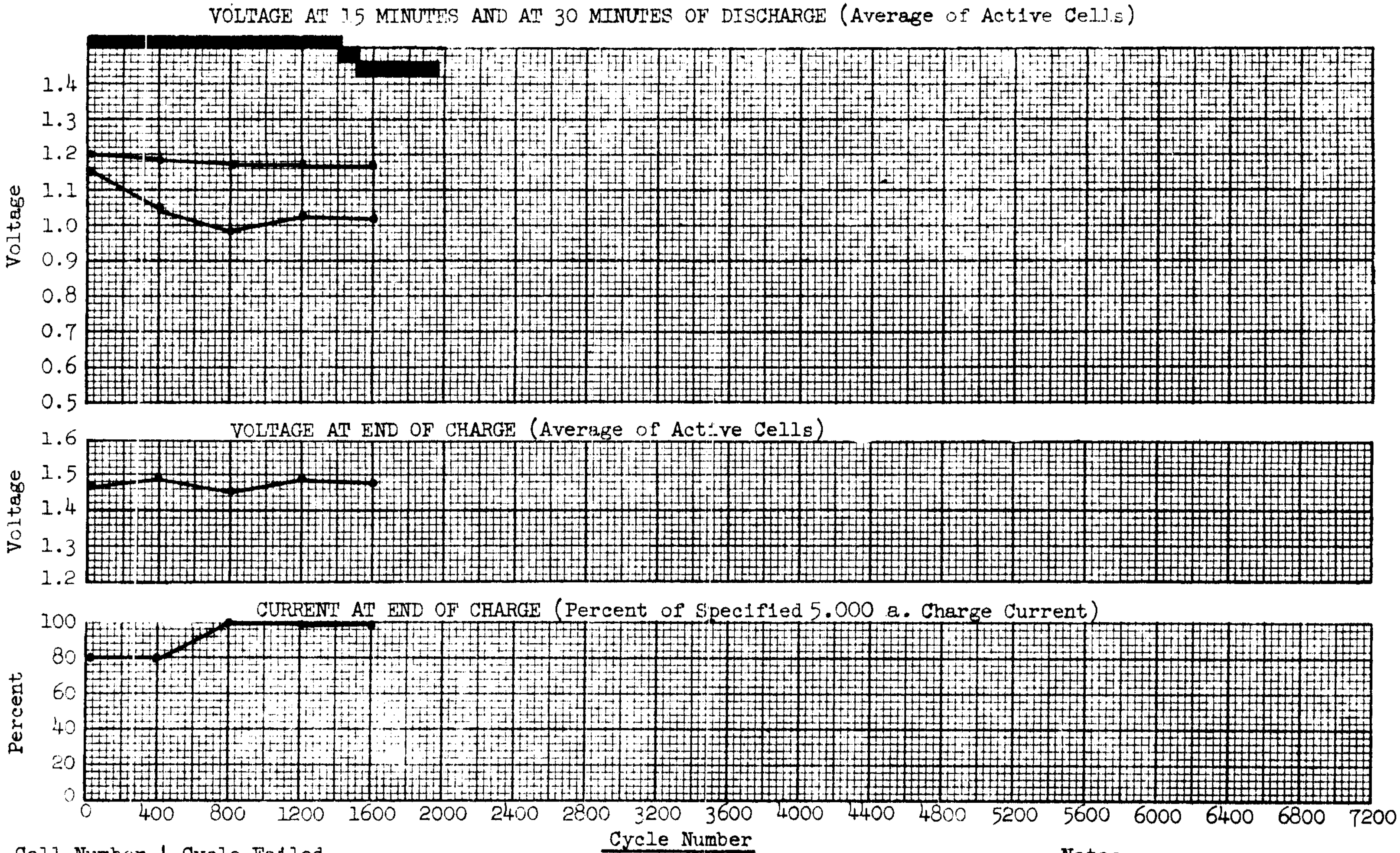
SONOTONE 5.0 a.h. (Pack 273)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: 5 cells cycling after 2133 cycles.

Notes

1. Charge current changed from 2.5 a to 5.0 a after cycle 539.
2. Cycles 1198: Capacity Check.

FIGURE 28(c)



Cell Number	Cycle Failed
A-2432	1407
A-2445	1513

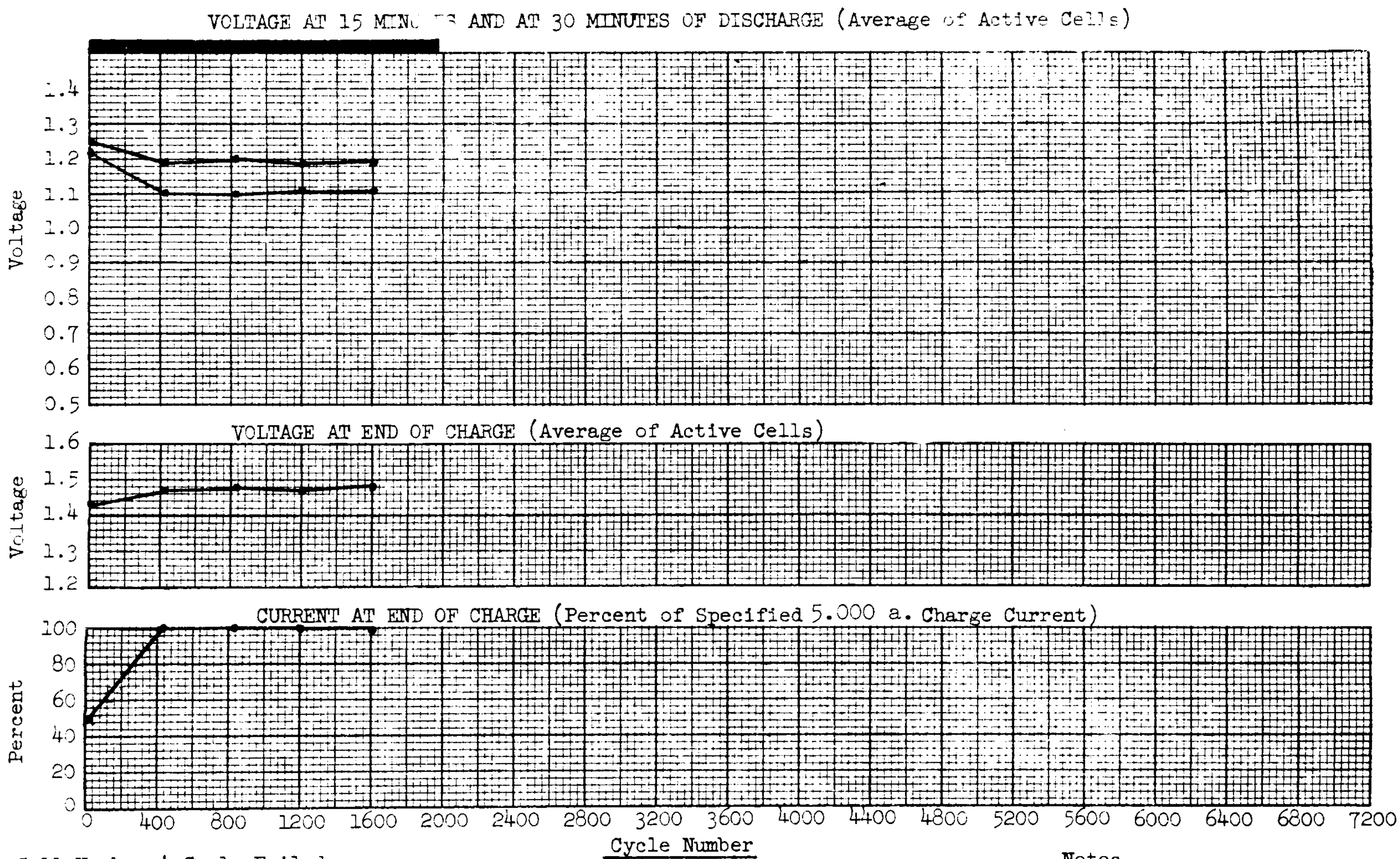
SONOTONE 5.0 a.h. (Pack 287)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 40%

Status: 3 cells cycling after 1969 cycles.

Notes

1. Charge current changed from 4.0 a to 5.0 a after cycle 542.
2. Cycles 1087: Capacity Check

FIGURE 28(d)



Cell Number	Cycle Failed

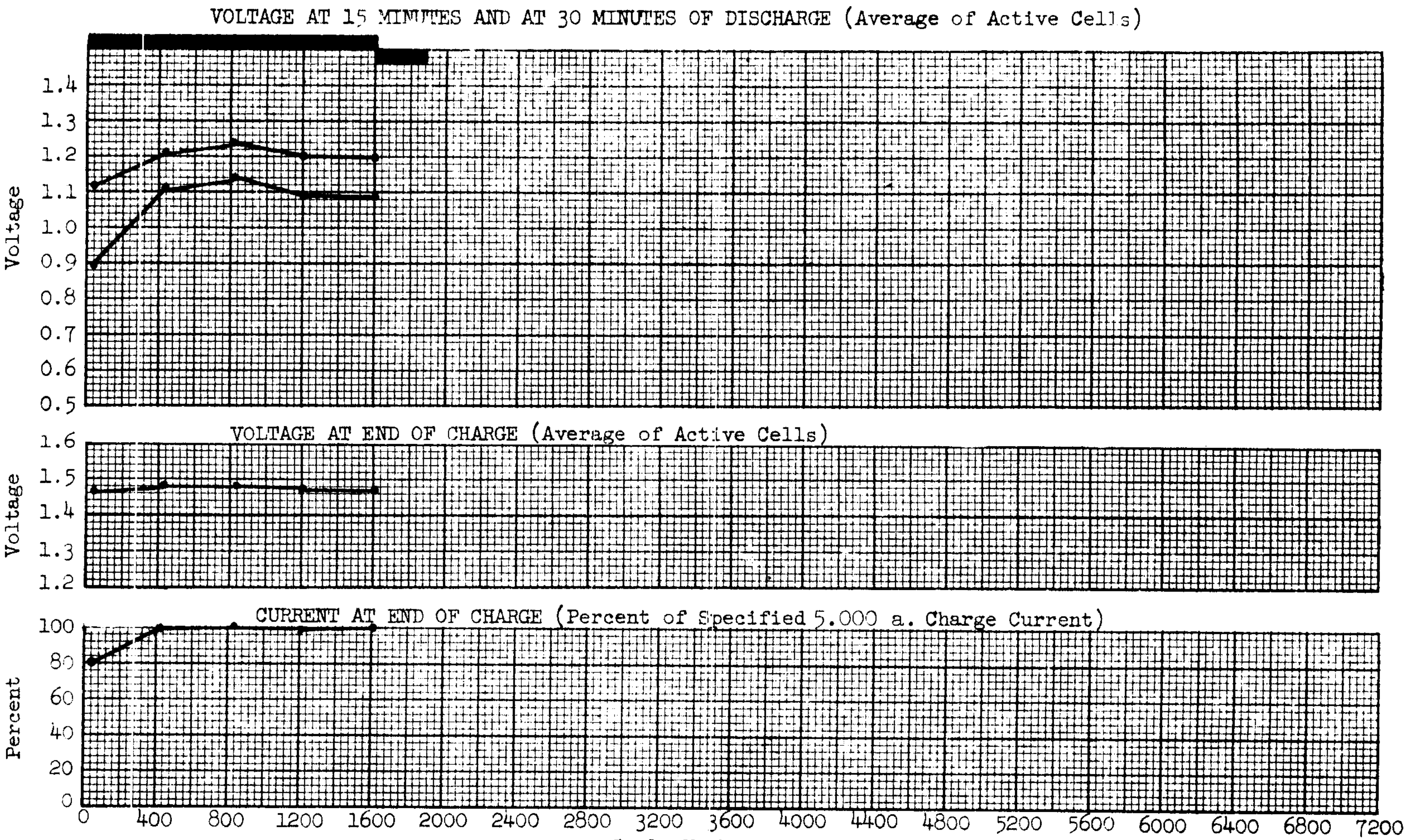
SONOTONE 5.0 a.h. (Pack 299)
Test Temperature: 40° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: 5 cells cycling after 1970 cycles.

Notes

1. Charge current changed from 2.5 a to 5.0 a after cycle 364.
2. Cycles 1655: Capacity Check.

FIGURE 28(e)



Cell Number	Cycle Failed
A-2411	1613

SONOTONE 5.0 a.h. (Pack 312)
Test Temperature: 40° C
Orbit Period: 1.5 hours
Depth of Discharge: 40%

Status: 4 cells cycling after 1874 cycles.

Notes

1. Charge current changed from 4.0 a to 5.0 a after cycle 268.
2. Cycles 1559: Capacity Check.

FIGURE 28(f)

C. Coulometer: The coulometer is a device which measures the amount of electrical charge (coulombs or ampere-hours) passed through it. It accomplishes this by means of an electrochemical reaction which is directly proportional to the product of the magnitude of the current and the time for which it is passed. The coulometer used with nickel-cadmium cells is made from two sets of cadmium hydroxide plates bathed in KOH electrolyte, and constructed in a similar manner to a nickel-cadmium cell. Coulometer action is obtained by imbalancing the two sets of plates, so that when one set is completely coverted to cadmium by the passage of charge, the other set is totally converted to cadmium hydroxide. This reaction continues at a low voltage on the coulometer until the imbalance is complete. Then the coulometer voltage rises very sharply. The coulometer reaction can take place in either direction, charge or discharge, because the coulometer reaction is completely reversable. Thus it is easy to detect when 100 percent of the discharge has been returned to the cells.

1. Sonotone 5.0 a.h., One 5-cell Pack, 1.5-hour Orbit Period:

a. Cell Description:

(1) The cells used were of the type described in section I, paragraph II.A.4.a.

b. The coulometer used was built by the Goddard Space Flight Center.

c. Test Equipment: This pack uses a power supply and electronic timer for charge and discharge cycling. The charge is constant current with a preset voltage limit. The voltage limit is set so that a predetermined amount of trickle current is supplied to the pack after the coulometer is fully charged. A transistor is mounted across the coulometer to keep the voltage below 1.0 volt.

d. Test Parameters:

(1) Test Temperature: 25° C.

(2) Depth of Discharge: Started at 80 percent but was lowered by steps of 10 percent until the pack operated satisfactorily at 30 percent depth of discharge.

e. Test Results:

(1) At 80 percent, the pack completed 59 cycles. The end-of-discharge voltage dropped below 1.0 volt.

(2) At 70 percent, the pack completed 61 cycles. The end-of-discharge voltage again dropped below 1.0 volt.

(3) At 60 percent, the pack completed 55 cycles before the end-of-discharge voltage fell below 1.0 volt.

(4) At 50 percent, the pack completed 90 cycles before the end-of-discharge voltage fell below 1.0 volt.

(5) At 40 percent, the pack completed 250 cycles before the end-of-discharge voltage fell below 1.0 volt.

(6) At 30 percent, the pack has completed 6579 cycles to date. The end-of-discharge voltage is about 1.07 volts average per cell and the end-of-charge voltage 1.42 volts per cell, average.

2. Gulton 3.6 a.h., One 10-cell Pack, 1.5-hour Orbit Period (Pack 239):

a. Cell Description: These are cylindrical cells with a folded neoprene seal as described in section II, paragraph I.A.3.a.

b. The coulometer used was built by General Electric with a capacity of 6.0 ampere-hours.

c. Test Equipment: The charge and discharge current for the pack is supplied by a unit which is described in section I, paragraph V.B. The charge is constant current with a preset voltage limit. The voltage limit is set so that a predetermined amount of trickle current is supplied to the pack after the coulometer is fully charged. A diode is mounted across the coulometer to keep the voltage below 1.0 volt.

d. Test Parameters:

(1) Test Temperature: 25° C.

(2) Depth of Discharge: 40%.

e. Test Results:

(1) The pack completed 805 cycles to date. The end-of-discharge voltage averages about 1.06 volts per cell. The end-of-charge voltage averages 1.42 volts per cell. There have been no failures.

(2) The capacity of the preconditioning cycle was 3.06 ampere-hours.

D. Sherfey Upside-Down Cycling: This type of cycling starts with the cells in a completely discharged condition. Each cycle consists of a charge of 60 percent followed by a discharge of 40 percent of the cell's rated capacity. Upon completion of each fifth cycle, the cells are discharged through resistors for 90 minutes to return the cells to the completely discharged condition for the start of the next sequence of five cycles. In this manner, the cells operate below the 100 percent charged state much of the time thereby preventing overcharging and buildup of excessive gas pressure.

1. Test Equipment: The charge and discharge currents for the pack are supplied by a power supply. The rates and cycling regimen are controlled by the Sherfey cycling unit which contains the resistors used to completely discharge the cells after each fifth cycle. The cycle timing is done by using a synchronous motor timer.

2. Gulton 3.6 a.h. (Neoprene Seal), One 10-cell Pack, 1.5-hour Orbit Period:

a. Cell Description: These are cylindrical cells with a folded neoprene seal as described in section II, paragraph I.A.3.a.

b. Test Parameters:

(1) Test Temperature: 25° C.

(2) Depth of Discharge: 40%.

c. Test Results: The pack has completed 1864 cycles to date. There have been no failures although there are eight cells which have deposits around the outer edge of the top of the cell where the top is welded to the side. Six cells show signs of high pressure. The end-of-charge voltage shows that some of the leaking cells are drying out because the on-charge voltage is up to 1.62 volts on three cells whereas that of the remaining cells have an on-charge voltage of 1.54 volts. On each successive discharge following the bleed cycle the end-of-discharge voltage increases about 0.02 volt per cell.

E. Two Step Charge Regulator. When silver-cadmium and silver-zinc cells are put on a long charge period with only a voltage limit, the cells begin to unbalance when the pack goes into overcharge. A new method of charging cells of these types was developed at Goddard Space Flight Center. The cell pack is charged until it reaches the pack upper voltage limit. At this time, the charge current is reduced to maintain this voltage limit. When the charge current decreases to 350 milliamperes, the on-charge voltage limit is then reduced to the lower pack voltage limit which is equal to the open circuit voltage of the cell pack. In this method, the pack receives no more charge until there is a sufficient drop in the pack voltage to reset the pack voltage limit to the upper value. This method prevents the cells from becoming unbalanced during long charge periods.

1. Test Equipment: The charge and discharge current is supplied by a unit described in section I, paragraph V.B. The two step regulator, designed by the Goddard Space Flight Center, is used to control the rate of charge and the voltage limits.

2. Delco-Remy 25 a.h. (Silver-Zinc), One 10-cell Pack, 24-hour Orbit Period:

a. Cell Description: These cells are rectangular in shape with sealed nylon cases. Each cell was individually epoxy potted by the manufacturer. The positive plates have one percent of palladium added to the active material.

b. Test Parameters:

(1) Test Temperature: 25° C.

(2) Depth of Discharge: 40%.

(3) Upper Voltage Limit: 1.97 ± 0.03 volts per cell, average.

(4) Low Current Limit: 0.35 amps.

(5) Overcharge Voltage Limit: 1.87 ± 0.03 volts per cell, average.

c. Test Results: The pack has completed 19 cycles. There is insufficient data to indicate whether this new method will work satisfactorily over a long period of cycling.

III. <u>TESTS TO BE ADDED TO THE CYCLE LIFE TEST PROGRAM</u>

A. Nickel-Cadmium:

1. Gulton 1.25 ampere-hour. These cells have high charge current capabilities.

2. General Electric 12 ampere-hours. Both an active and passive auxiliary electrode are built into these cells.

3. Sonotone 20 ampere-hour. A mechanical device is built into the cells to maintain pressure on the plate pile.

4. Commercial grade cell with auxiliary electrodes added.

5. Commercial grade cell controlled by a coulometer.

B. Silver-Cadmium:

1. The Electric Storage Battery Company 11 ampere-hour.

2. Yardney Electric Corporation 11 ampere-hour.

3. Yardney Electric Corporation 12 ampere-hour.

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81 The Electric Storage Battery Company, Missile Battery Division (Mr. A. Chreitzberg), 2510 Louisburg Road, Raleigh, North Carolina 27604

82 The Electric Storage Battery Company, Carl F. Norberg Research Center (Dr. R. A. Schaefer and Mr. W. S. Herbert), 19 West College Avenue, Yardley, Pennsylvania 19068

83 Electrochimica Corporation (Dr. Morris Eisenberg), 1140 O'Brien Drive, Menlo Park, California 94025

84 Electro-Optical Systems, Inc. (Mr. E. Findl), 300 North Halstead, Pasadena, California 91107

85 Emhart Manufacturing Company (Dr. W. P. Cadogan), Box 1620, Hartford, Connecticut 06101

86 Engelhard Industries, Inc. (Dr. J. G. Cohn), 497 DeLancy Street, Newark, New Jersey 07105

87 Dr. Arthur Fleischer, 466 South Center Street, Orange, New Jersey 07050

88 General Electric Company, Advanced Technology Laboratory (Dr. R. C. Osthoff and Dr. W. Carson), Schenectady, New York 12301

89 General Electric Company, Missile and Space Division, Spacecraft Department (Mr. E. W. Kipp, Room T-2513), P. O. Box 8555, Philadelphia, Pennsylvania 19101

90 General Electric Company, Battery Products Section, P. O. Box 114, Gainesville, Florida 32601

91 General Electric Company, Research Laboratories (Dr. H. Liebhafsky), Schenectady, New York 12301

92 General Electric Company, Research Laboratory, P. O. Box 1088, Schenectady, New York 12301

93 General Motors, Defense Research Labs. (Dr. J. S. Smatko and Dr. C. R. Russell), 6767 Hollister Street, Santa Barbara, California 93105

94 Globe-Union, Incorporated, 900 East Keefe Avenue, Milwaukee, Wisconsin 53201

95 Gould-National Batteries, Inc., Engineering and Research Center (Mr. J. F. Donahue), 2630 University Avenue, S.E., Minneapolis, Minnesota 55418

96 Gulton Industries, Alkaline Battery Division (Dr. Robert Shair), 212 Durham Avenue, Metuchen, New Jersey 08840

97 Hughes Aircraft Corporation (Mr. T. V. Carvey), Centinda Avenue and Teale Street, Culver City, California 90230

98 Hughes Aircraft Corporation (Mr. R. B. Robinson, Bldg. 366, M.S. 524, El Segundo, California 90245

99 Hughes Research Laboratories Corporation, 3011 Malibu Canyon Road, Mailbu, California 90265

100 ITT Research Institute (Dr. H. T. Francis), 10 West 35th Street, Chicago, Illinois 60616

101 Institute for Defense Analyses, R & E Support Division (Mr. R. Hamilton and Dr. Szego), 400 Army-Navy Drive, Arlington, Virginia 22202

102 Idaho State University, Department of Chemistry (Dr. G. Myron Arcand), Pocatello, Idaho 83201

103 Institute of Gas Technology (Mr. B. S. Baker), State and 34th Street, Chicago, Illinois 60616

104 Johns Hopkins University, Applied Physics Laboratory (Mr. Richard Cole), 8621 Georgia Avenue, Silver Spring, Maryland 20910

105 Johns Hopkins University, Applied Physics Laboratory (Mr. Louis Wilson), 8621 Georgia Avenue, Silver Spring, Maryland 20910

106 Johns-Manville R & E Center (Mr. J. S. Parkinson), P. O. Box 159, Manville, New Jersey 08835

107 Leesona Moos Laboratories (Dr. H. Oswin), Lake Success Park, Community Drive, Great Neck, New York 11021

108 Livingston Electronic Corporation (Mr. Willima F. Meyers), Route 309, Montgomeryville, Pennsylvania 18936

109 Lockheed Missiles and Space Company (Library), 3251 Hanover Street, Palo Alto, California 93404

110 Mallory Battery Company (Mr. R. R. Clune), 60 Elm Street, North Tarryton, New York 10593

111 P. R. Mallory & Co., Inc. (Dr. Per Bro), Northwest Industrial Park, Burlington, Massachusetts 02103

112 P. R. Mallory & Co., Inc. (Technical Librarian), 3029 E. Washington Street, Indianapolis, Indiana 46206

113 Melpar, Technical Information Center, 3000 Arlington Boulevard, Falls Church, Virginia 22046

114 Metals and Controls Division, Texas Instruments, Inc. (Dr. E. J. Jost), 34 Forest Street, Attleboro, Massachusetts 02703

115 Midwest Research Institute (Dr. B. W. Beadle), 425 Volker Boulevard, Kansas City, Missouri 64110

116 Monsanto Research Corporation (Dr. J. O. Smith), Everett, Massachusetts 02149

117 North American Aviation, Inc., Rocketdyne Division (Library), 6633 Canoga Avenue, Canoga Park, California 91303

118 North American Aviation, Inc. (Mr. Burton M. Otzinger), 12214 Lakewood Boulevard, Downey, California 90241

119 Dr. John Owen, P. O. Box 87, Bloomfield, New Jersey 07003

120 Paul Howard Associates Inc., Centerville, Maryland 21617

121 Power Information Center, University of Pennsylvania, Moore School Building, 200 South 33rd Street, Philadelphia, Pennsylvania 19104

122 Power Sources Division, Whittaker Corporation (Dr. M. Shaw), 9601 Canoga Avenue, Chatsworth, California 91311

123 Philco Corporation, Division of the Ford Motor Company (Dr. Phillip Cholet), Blue Bell, Pennsylvania 19422

124 Radiation Applications, Inc., 36-40 37th Street, Long Island City, New York 11101

125 Radio Corporation of America, Astro Division (Mr. Seymour Winkler), Hightstown, New Jersey 08520

126 Radio Corporation of America (Mr. I. Schulman), P. O. Box 800, Princeton, New Jersey 08540

127 Radio Corporation of America (Dr. H. S. Lozier), Sommerville, New Jersey 08873

128 Republic Aviation Corporation, SMSD Division (Mr. Sam Abrahams), Farmingdale, Long Island, New York 11735

129 Southwest Research Institute (Dr. Jan Al), 8500 Culebra Road, San Antonio, Texas 78206

130 Sonotone Corporation (Mr. A. Mundel), Saw Mill River Road, Elmsford, New York 10523

131 Texas Instruments, Inc. (Dr. Isaac Trachtenberg), 13500 North Central Expressway, Dallas, Texas 75222

132 The Martin Company (Mr. Leslie Long, Mail #600), Middle-River, Maryland 21203

133 Thomas A. Edison Research Laboratory, McGraw Edison Company (Dr. P. F. Grieger), Watchung Avenue, West Orange, New Jersey 07052

134 TRW Systems, Inc. (Dr. A. Krausz, Bldg. 60, Room 929), One Space Park, Redondo Beach, California 90278

135 TRW Systems Inc. (Dr. Herbert P. Silverman), One Space Park, Redondo Beach, California 90278

136 TRW, Inc. (Librarian), 23555 Euclid Avenue, Cleveland, Ohio 44117

137 Tyco Laboratories, Inc. (Mr. W. W. Burnett), Bear Hill, Hickory Drive, Waltham, Massachusetts 02154

138 Union Carbide Corporation, Development Laboratory Library, P. O. Box 6056, Cleveland, Ohio 44101

139 Union Carbide Corporation, Parma Research Center (Library), P. O. Box 6116, Cleveland, Ohio 44101

140 University of California, Space Science Laboratory (Dr. C. W. Tobias), Berkley, California 94720

141 University of Pennsylvania, Electrochemistry Laboratory, Philadelphia, Pennsylvania 19104

142 Western Electric Company (Mr. R. T. Fiske), Suite 802, RCA Building, Washington, D. C. 20006

143 Westinghouse Electric Corporation, Research and Development Center, Churchill Borough, Pittsburg, Pennsylvania 15235

144 Whittaker Corporation (Mr. John Rhyne), P. O. Box 337, Newbury Park, California 91320

145 Whittaker Corporation, Power Sources Division (Mr. Burch Winder), 3850 Olive Street, Denver, Colorado 80237

146 Yardney Electric Corporation (Dr. George Dalin), 40-50 Leonard Street, New York, New York 10013