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N69-37830
CR # 105830

EVALUATION PROGRAM

for

SECONDARY SPACECRAFT CELLS

ACCEPTANCE TEST
OF
GENERAL ELECTRIC COMPANY
12 AMPERE–HOUR AUXILIARY ELECTRODE
NICKEL–CADMIUM CELLS

prepared for
GODDARD SPACE FLIGHT CENTER
CONTRACT W12–397

QUALITY EVALUATION LABORATORY
NAD CRANE, INDIANA

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QUALITY EVALUATION LABORATORY
NAVAL AMMUNITION DEPOT
CRANE, INDIANA 47522

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FOR
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OF
GENERAL ELECTRIC COMPANY
12 AMPERE-HOUR AUXILIARY ELECTRODE
NICKEL-CADMIUM CELLS

QE/C 69-553   15 JULY 1969

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Enclosure (1)

REPORT BRIEF
GENERAL ELECTRIC COMPANY
12 AMPERE-HOUR AUXILIARY ELECTRODE
NICKEL-CADMIUM SECONDARY SPACECRAFT CELLS

Ref: (a) National Aeronautics and Space Administration Purchase Order Number W12-397
(b) NASA ltr BRA/VBK/pad of 25 September 1969 w/BUWEPS first end FQ-1:WSK of 2 October 1961 to CO NAD Crane
(c) Preliminary Work Statement for Battery Evaluation Program of 25 August 1961

I. TEST ASSIGNMENT BRIEF

A. In compliance with references (a) and (b), evaluation of General Electric 12 ampere-hour auxiliary electrode secondary spacecraft cells was begun according to the program outline of reference (c).

B. The purpose of this acceptance test program is to insure that all cells put into the life cycle program are of high quality by the removal of cells found to have electrolyte leakage, internal shorts, low capacity, or inability of any cell to recover its open circuit voltage above 1.15 after the cell short test.

C. Thirty cells were purchased from General Electric Company, Gainesville, Florida, by National Aeronautics and Space Administration (NASA). These cells are rated at 12 ampere-hours by the manufacturer. The total consists of 17 type 42B012AB09 cells which have an auxiliary electrode, and 13 type 42B012AB10 cells which have no auxiliary electrode.

II. CONCLUSIONS

A. From the results of this test, it can be concluded that:

1. The ceramic seals of these cells are satisfactory for this test as only three of the 60 seals indicated a slight leak.

2. The capacity of the cells was in the acceptable range of 13.6 to 15.4 ampere-hours with an average of 14.6 ampere-hours.

III. RECOMMENDATIONS

A. It is recommended that these 30 General Electric Company 12 ampere-hour cells be accepted for life cycle testing under the simulated equatorial synchronous orbit.

RESULTS OF ACCEPTANCE TESTS OF 12.0 AMPERE-HOUR NICKEL-CADMIUM SECONDARY SPACECRAFT CELLS WITH AUXILIARY ELECTRODE MANUFACTURED BY GENERAL ELECTRIC COMPANY

I. INTRODUCTION

A. On 30 December 1968, this activity began acceptance tests on 30 cells of the type used in the ASTRONOMICAL TELESCOPE SATELLITE (ATS). The tests were completed on 18 February 1969.

B. Goddard Space Flight Center's work sheet, of 18 December 1968, called for acceptance testing of 30 General Electric 12 ampere-hour, nickel-cadmium, auxiliary electrode type cells, General Electric's catalog numbers 42B012AB09 and 42B012AB10.

C. Upon receipt of the cells, it was noted that 17 were identified by catalog number 42B012AB09 and 13 by catalog number 42B012AB10. The cells of both catalog numbers displayed the auxiliary electrode tab and had identical physical appearance. They were all tested as auxiliary electrode cells until incompatible data prompted an investigation which revealed that the 17 cells of catalog number 42B012AB09 were of an auxiliary electrode type whereas the 13 cells of catalog number 42B012AB10 were without an auxiliary electrode.

II. TEST CONDITIONS

A. All acceptance tests were performed at an ambient temperature between 23° C and 27° C at existing relative humidity and atmospheric pressure, and consisted of the following:

1. Phenolphthalein Leak Test.
2. Capacity Test.
3. Cell Short Test.
4. Immersion Seal Test.
5. Overcharge Test.
6. Internal Resistance Test of the Auxiliary Electrode.
7. Immersion Seal Test.

B. All charging and discharging was done at constant current (± 5 percent). Cells were charged and discharged in series. The discharge of each cell was individually terminated when its voltage reached 1.00.

III. CELL IDENTIFICATION AND DESCRIPTION

A. Cells were identified by the manufacturer's serial numbers in addition to their catalog numbers. The 17 cells with the auxiliary electrode (catalog number 42B012AB09) had serial numbers from 3 through 16 and 18 through 20. The 13 cells without the auxiliary electrode (catalog number 42B012AB10) had serial numbers from 3 through 15. Cells, serial numbers 3, 4 and 5 of each type were equipped with pressure gages.

B. These 12 ampere-hour cells are rectangular in shape, and their cases and covers are made of stainless steel. The positive and negative terminals are insulated from the cover by ceramic seals, and protrude through the cover as solder type terminals. Each ceramic seal is set in an expansion joint to minimize stresses on the seal by movement of the plates or cell cover. A stainless steel tab, for the auxiliary electrode terminal, is welded to the cover of each of the cells of both catalog numbers.

C. The average height (base to top of positive terminal), length, and width (all cells) were 4.587, 0.899 and 2.993 inches respectively. The average weight of the 14 auxiliary electrode type cells (without gages) is 476.7 grams, whereas that of the 10 cells without the auxiliary electrode (without gages) is 486.2 grams, or about 10 grams heavier. The average weight of the six cells with pressure gages (three of each type) was 825.0 grams. The individual cell dimensions and weights are given in Table I.

D. These cells were received in a discharged condition with shorting wires connecting the terminals and auxiliary electrode tabs.

IV. TEST PROCEDURE AND RESULTS

A. Phenolphthalein Leak Test:

1. The phenolphthalein leak test is a determination of the condition of the welds and ceramic seals. The test was performed with a phenolphthalein spray indicator solution of one-half of one percent concentration on the individual cells when received, and on the cells in packs of 10 after the overcharge test.

2. On the initial test, one cell indicated leakage around the ceramic seal of the positive terminal post but showed no evidence

of leakage after the overcharge test. Following the overcharge test, two other cells showed some leakage around the ceramic seal of the negative terminal post. The three cells were allowed to complete the acceptance tests, and are identified in Table I.

B. Capacity Test:

1. The capacity test is a determination of the cell capacity at the c/2 discharge rate, where c is the manufacturer's rated capacity, to a cutoff voltage of 1.00 volt per cell. The discharge was made after a 1-hour open circuit period following the 16-hour charge at the c/10 rate. A total of three capacity checks were made at this activity. The cells were charged and discharged in series. The discharge of each cell was individually terminated when its voltage reached 1.00.

2. The primary purpose of the auxiliary electrode is to control the recharge of the cells by use of the increase of oxygen as the end of charge approaches. This increase causes a fast rise in voltage between the auxiliary electrode and the negative terminal which signals a control circuit to reduce the current or terminate the charge. Thus a maximum change in signal voltage during the last portion of the charge is desirable. To find this maximum voltage deflection, Goddard Space Flight Center conducted experiments in which the auxiliary electrode voltage is plotted against the resistance loading of the auxiliary electrode under a constant pressure. A series of curves corresponding to the several test pressures was obtained. Since the amount of pressure due to increase of oxygen causes the signal voltage to change, it is desirous to determine the resistance giving the greatest voltage change per pressure change. Goddard found this resistance value, for the ATS cell, to be 300 ohms which was used during the overcharge portions of the test at NAD Crane.

3. The individual cell capacities ranged from 13.6 to 15.3 ampere-hours on the first capacity check, for an average of 14.8 ampere-hours. The second capacity check ranged from 13.7 to 15.4 ampere-hours, for an average of 15.0 ampere-hours. The third capacity check ranged from 13.1 to 14.8 ampere-hours, for an average of 13.9 ampere-hours. The capacities and the end of charge auxiliary electrode voltages preceding each capacity discharge check are tabulated in Table II. Characteristic 2-hour rate discharge curves are shown in Figure 1.

4. In order to gather data on the on-charge voltage characteristics of the auxiliary electrode, each charge-discharge cycle was run with a resistor between the auxiliary electrode and the negative terminal of each cell. All the resistors for a given

charge-discharge cycle were of the same value, being 10, 100 and 1000 ohms respectively for the three charge-discharge (capacity check) cycles. These three resistance values were chosen because they covered the range of resistances incorporated in similar testing at Goddard Space Flight Center. Figures 2, 3 and 4 are curves of the auxiliary electrode voltages and cell pressures versus time on the three charge-discharge (capacity check) cycles of three representative cells.

5. Prior to verification that cells with catalog number 42B012AB10 contained no auxiliary electrode, the nonauxiliary electrode type behavior of the voltages across the loading resistor between the auxiliary electrode tab and the negative terminal of these cells indicated that a plot of all "auxiliary" electrode voltages of all cells would distinguish between the two cell types. It was originally believed that each catalog number represented a different type auxiliary electrode. Figure 5 is a histogram showing auxiliary electrode voltage increments and distribution of the cells (by catalog number) into three packs for the three capacity checks. In all three capacity checks, the cells of pack L-1-8 (catalog number 42B012AB10) showed low auxiliary electrode voltage whereas the cells of pack L-2-8 (catalog number 42B012AB09) showed high auxiliary electrode voltage. The cells of pack L-3-8 contained three cells of the former and seven cells of the latter type. The "auxiliary" electrode voltage differences between these types were particularly noticeable in the last two capacity checks with 100 ohm and 1000 ohm loading resistors repectively between the auxiliary electrode tab and the negative terminal. Verification from Goddard Space Flight Center confirmed that the cells of one type (catalog number 42B012AB10) contained no auxiliary electrode even though they had the external auxiliary electrode terminal.

C. Cell Short Test:

1. The cell short test is a means of detecting slight shorting conditions which may exist in a cell because of imperfections in the insulating materials, or damage to the element in handling or assembly.

2. Following completion of the third capacity discharge test, each individual cell was loaded with a 0.5 ohm resistor across the cell terminals. This gave a c/5 discharge rate. The pack stood 16 hours with the resistor acting as a shorting device. At the end of 16 hours, the resistors were removed and the cells were placed on open circuit stand for 24 hours. Any cell whose voltage did not recover to 1.15 volts or higher was rejected.

3. The open circuit cell voltage, 24 hours after removal of the shorting resistors, ranged from 1.15 to 1.23 volts for an average of 1.18 volts.

4. There were no rejects of any of the cells subjected to the short test. The voltage values for the 30 accepted cells are shown in Table II.

D. Immersion Seal Test:

1. The immersion seal test is a means of detecting leakage of a seal or weld. The test was performed before the overcharge test and after the internal resistance test to determine the presence and cause of leaks.

2. The cells were placed under water in a bell jar container. A vacuum of 20 inches of mercury was held for 3 minutes. Cells discharging a steady stream of bubbles were considered rejects.

3. There were no rejects in the 30 cells subjected to the immersion seal test.

E. Overcharge Test:

1. The overcharge tests were performed to determine the steady state voltage at specified rates. The steady state voltage is a result of equilibrium between oxygen being produced as charging proceeds and being recombined by the charged negative plates. The test specified two constant current charges; the first at c/20 for 48 hours followed by one at c/10 for an additional 48 hours.

2. The cells were monitored hourly throughout the test. Charging was to be discontinued on cells which exceeded 1.50 volts while on charge. There was no need to remove any cells from the charging sequence.

3. The voltages of representative cells during the two consecutive 48-hour overcharge periods at c/20 and c/10 respectively are shown in Figure 6.

F. Internal Resistance Test of the Auxiliary Electrode:

1. During the c/10 charge rate portion of the overcharge test, the voltage drop across the 300-ohm resistor connecting the auxiliary electrode to the negative terminal was measured. The 300-ohm resistor was then shunted with a 1-ohm resistor for 10 seconds. The auxiliary electrode voltage of each cell was recorded

before and after the 10-second shunting and the voltage drop across the two parallel resistors (0.9967 ohms) was measured. The internal resistance of the auxiliary electrode in ohms was then calculated according to the formula:

$$R = \frac{V_1 - V_2}{I_2 - I_1}$$

where:

V_1 = voltage drop in volts across the 300-ohm resistor.
V_2 = voltage drop in volts across the 0.9967-ohm resistor.
I_1 = current flow in amperes through the 300-ohm resistor.
I_2 = current flow in amperes through the 0.9967-ohm resistor.

2. The internal resistance of the auxiliary electrode of the 17 cells is shown in Table III. The values ranged from 14.7 milliohms to 26.1 milliohms for an average of 19.9 milliohms.

G. Internal Resistance Test of the Cell:

1. At the completion of the overcharge test, the cells were returned to the c/20 charging rate and given a short pulse (5 to 10 seconds) at the rate of c/1 in amperes. The cell voltages, V_1, immediately prior to the pulse; and V_2, 5 milliseconds after the initiation of the pulse, were read on a CEC high speed oscillograph (direct print) recorder--16.0 inches of paper per second. The internal resistance of the cell in ohms was calculated according to the formula:

$$R = \frac{V_2 - V_1}{I_c - I_{c/20}}$$

V_1 and V_2 are in volts; I_c and $I_{c/20}$ are in amperes.

2. Due to the number of significant figures in the voltage measurements (as read from the chart paper), the error in the resistance value is very large (on the order of 10 milliohms). Therefore, it is difficult to obtain meaningful results for comparative purposes from the resistance data. The distinct difference in the internal cell resistance of 10 cells in one pack from those of the other 20 cells can be attributed to difference in interpretation of the data by two operators.

3. In addition to calculating the internal resistance of the cells as above, the internal resistance was also measured directly

on 10 of the 30 cells. This was accomplished through the use of a Hewlett-Packard milliohmmeter (Model 4328A). The results of both methods are tabulated in Table III. The values ranged from 2.15 to 2.34 milliohms for an average of 2.26 milliohms for the 10 cells sampled by the milliohmmeter.

TABLE I

General Electric 12.0 ah Auxiliary Electrode Cells

Type 42B012AB09 (with auxiliary electrode)					Type 42B012AB10 (without auxiliary electrode)					Cell Weights With Pressure Gages	
Cell Number	Weight Grams	Height Inches	Length Inches	Width Inches	Cell Number	Weight Grams	Height Inches	Length Inches	Width Inches	Cell Number	Weight Grams
3*		4.575	0.896	2.990							
4*		4.592	0.912	3.000							
5*		4.595	0.894	3.003							
6	478.2	4.592	0.895	2.996	3**		4.589	0.903	2.989		
7	477.2	4.584	0.896	3.000	4**		4.583	0.900	2.988		
8	478.8	4.590	0.902	3.00	5**		4.580	0.904	2.987		
9	477.8	4.590	0.897	3.001	6	487.9	4.588	0.904	2.990		
10	475.8	4.593	0.900	2.997	7	489.3	4.584	0.898	2.988		
11	478.3	4.579	0.903	2.993	8	491.6	4.585	0.900	2.990		
12	475.9	4.590	0.896	2.993	9	478.8	4.585	0.895	2.989		
13	474.7	4.578	0.896	2.995	10	483.7	4.587	0.890	2.994	3*	830.7
14	472.8	4.608	0.900	2.989	11	487.3	4.597	0.902	2.995	4*	848.5
15	477.8	4.594	0.905	2.993	12	489.1	4.580	0.891	2.991	5*	801.0
16	475.7	4.590	0.905	2.990	13	487.1	4.579	0.900	2.990	3**	837.8
18	475.6	4.592	0.894	2.993	14	487.0	4.580	0.895	2.992	4**	827.6
19	476.5	4.584	0.903	2.994	15	479.7	4.580	0.890	2.995	5**	804.3
20	479.3	4.585	0.908	2.882							
Average	476.7	4.589	0.900	2.995		486.2	4.584	0.898	2.991		825.0
		4.584	0.898	2.991							
Grand Average		4.587	0.899	2.993							

	Leak Test Initial	Leak Test Final	Location
4	√	-	Around + Term Post
18	-	√	Around - Term Post (very slight)

	Leak Test Initial	Leak Test Final	Location
14	-	√	Around - Term Post

TABLE II

Type	Cell Number	CAPACITY TESTS (with 10, 100 and 1000 ohm resistors between auxiliary electrode tab and negative terminal): End of Charge w/10 ohm resistor (volts)	Capacity No. 1 ah	End of Charge w/100 ohm resistor (volts)	Capacity No. 2 ah	End of Charge w/1000 ohm resistor (volts)	Capacity No. 3 ah	CELL SHORT TEST: Voltage After 24 Hr OC	OVERCHARGE TEST Steady State Voltages (300 ohms between AE and neg term): c/20 Cell	for 48 Hrs Auxiliary Electrode	c/10 Cell	for 48 Hrs Auxiliary Electrode	Remarks
42B012AB10	4*		13.6		13.8		13.2	1.23	1.39		1.40		w/o AE
42B012AB10	5*		13.8		14.6		13.5	1.21	1.37		1.36		w/o AE
42B012AB10	6		13.8		14.0		13.3	1.21	1.38		1.38		w/o AE
42B012AB10	7		13.8		13.9		13.1	1.21	1.37		1.36		w/o AE
42B012AB10	8		13.9		14.8		13.8	1.19	1.37		1.36		w/o AE
42B012AB10	9		13.7		14.2		13.6	1.20	1.37		1.36		w/o AE
42B012AB10	10		13.9		14.8		13.9	1.19	1.37		1.36		w/o AE
42B012AB10	11		13.8		13.7		13.0	1.22	1.37		1.37		w/o AE
42B012AB10	12		13.9		14.7		13.9	1.19	1.38		1.38		w/o AE
42B012AB10	13		13.5		14.6		13.9	1.21	1.40		1.41		w/o AE
42B012AB09	4*	0.053	15.0	0.387	14.9	0.596	13.9	1.18	1.39	0.339	1.39	0.398	w/AE
42B012AB09	5*	0.017	15.2	0.291	15.2	0.593	13.7	1.17	1.38	0.310	1.36	0.377	w/AE
42B012AB09	6	0.027	15.3	0.376	15.0	0.611	13.7	1.17	1.38	0.356	1.37	0.428	w/AE
42B012AB09	7	0.051	15.3	0.396	15.0	0.655	13.4	1.17	1.38	0.387	1.35	0.455	w/AE
42B012AB09	8	0.028	15.2	0.404	14.9	0.652	13.3	1.17	1.38	0.366	1.35	0.428	w/AE
42B012AB09	9	0.020	15.2	0.359	15.0	0.614	13.3	1.15	1.38	0.328	1.35	0.410	w/AE
42B012AB09	10	0.025	15.3	0.373	15.1	0.591	13.4	1.17	1.38	0.324	1.35	0.389	w/AE
42B012AB09	11	0.034	15.3	0.385	15.0	0.633	13.3	1.17	1.38	0.359	1.36	0.414	w/AE
42B012AB09	12	0.029	15.3	0.384	15.2	0.690	13.8	1.18	1.38	0.370	1.36	0.469	w/AE
42B012AB09	13	0.054	15.2	0.358	14.9	0.568	13.8	1.18	1.39	0.335	1.38	0.396	w/AE
42B012AB10	3*		15.3		15.4		14.8	1.16	1.42		1.40		w/o AE
42B012AB09	3*	0.035	15.3	0.384	15.2	0.619	14.6	1.17	1.41	0.337	1.38	0.412	w/AE
42B012AB10	14		15.1		14.8		13.8	1.19	1.41		1.38		w/o AE
42B012AB10	15		15.3		15.3		14.6	1.16	1.41		1.38		w/o AE
42B012AB09	14	0.018	15.2	0.342	14.9	0.562	14.3	1.15	1.41	0.297	1.38	0.310	w/AE
42B012AB09	15	0.027	15.3	0.391	15.1	0.624	14.4	1.15	1.40	0.350	1.38	0.435	w/AE
42B012AB09	16	0.039	15.3	0.445	15.2	0.705	14.5	1.17	1.41	0.449	1.38	0.556	w/AE
42B012AB09	18	0.016	15.3	0.404	15.3	0.691	14.6	1.17	1.41	0.412	1.38	0.523	w/AE
42B012AB09	19	0.009	15.2	0.346	15.2	0.593	14.4	1.15	1.41	0.334	1.38	0.429	w/AE
42B012AB09	20	0.030	15.3	0.397	15.3	0.627	14.8	1.18	1.41	0.364	1.39	0.457	w/AE

* Cells with Pressure Gage

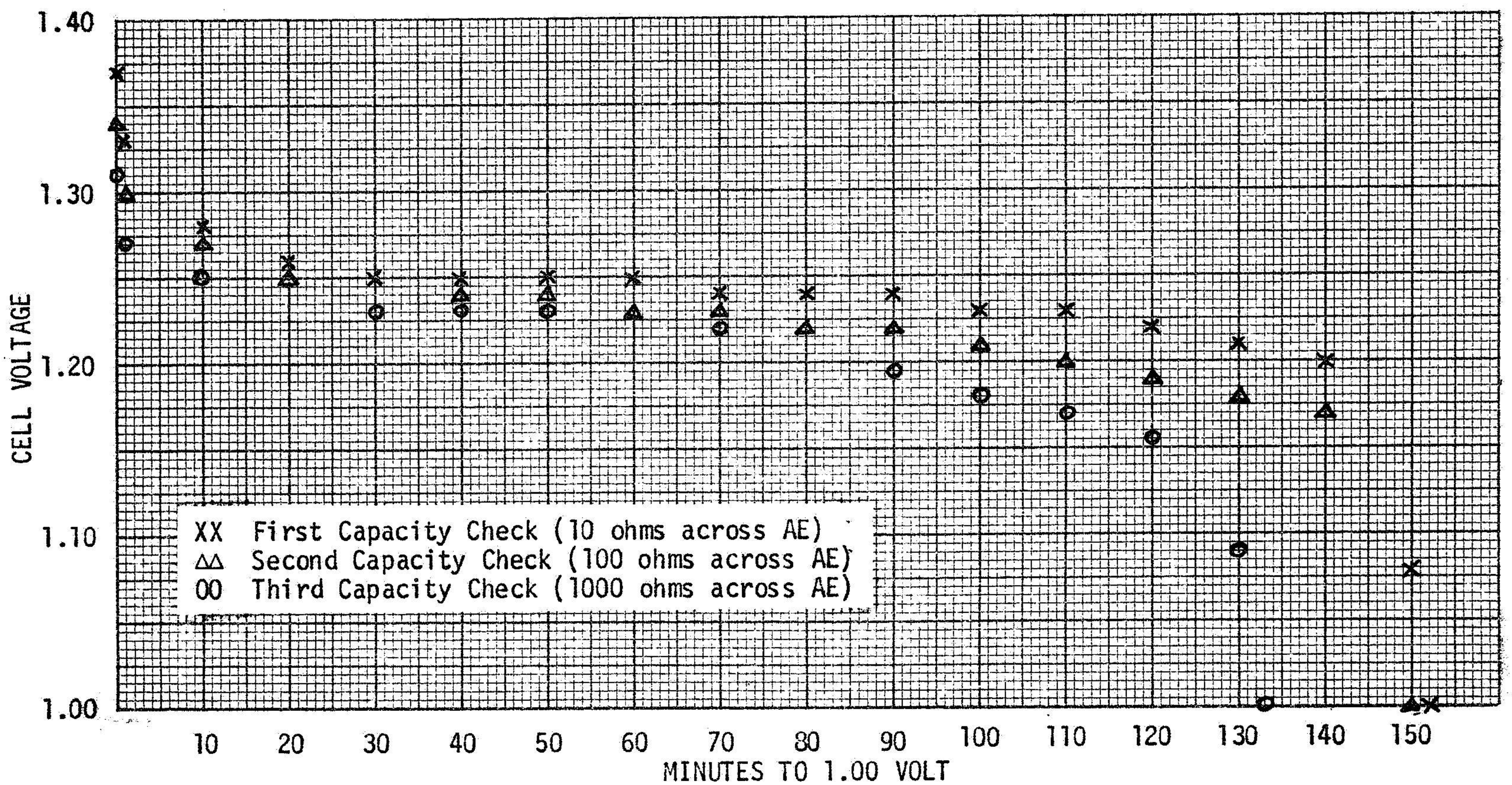
TABLE III

General Electric 12.0 Ampere-Hour Nickel-Cadmium Cells

With Auxiliary Electrode Catalog Number 42B012AB09				Without Aux Electrode Catalog Number 42B012AB10		
Cell Number	Auxiliary Electrode Resistance (Ohms) (Calc)	Cell Resistance (Milliohms) (Calc)	Cell Resistance (Milliohms) (Meter)	Cell Number	Cell Resistance (Milliohms) (Calc)	Cell Resistance (Milliohms) (Meter)
	PACK L-2-8				PACK L-1-8	
4	14.7	1.75	2.15	4	1.75	**
5	*	1.75	2.27	5	2.63	**
6	17.2	1.75	2.25	6	1.75	**
7	17.6	1.75	2.29	7	2.63	**
8	20.6	1.75	2.34	8	1.75	**
9	21.8	1.75	2.18	9	2.63	**
10	23.0	1.75	2.33	10	2.63	**
11	19.4	1.75	2.30	11	2.63	**
12	23.8	1.75	2.25	12	1.75	**
13	16.0	0.88	2.24	13	1.75	**
		PACK L-3-8				
3	18.4	9.65	**	3	7.89	**
14	26.1	8.77	**	14	7.89	**
15	17.9	8.77	**	15	7.89	**
16	23.4	7.89	**			
18	*	8.77	**			
19	20.1	7.02	**			
20	18.6	8.77				

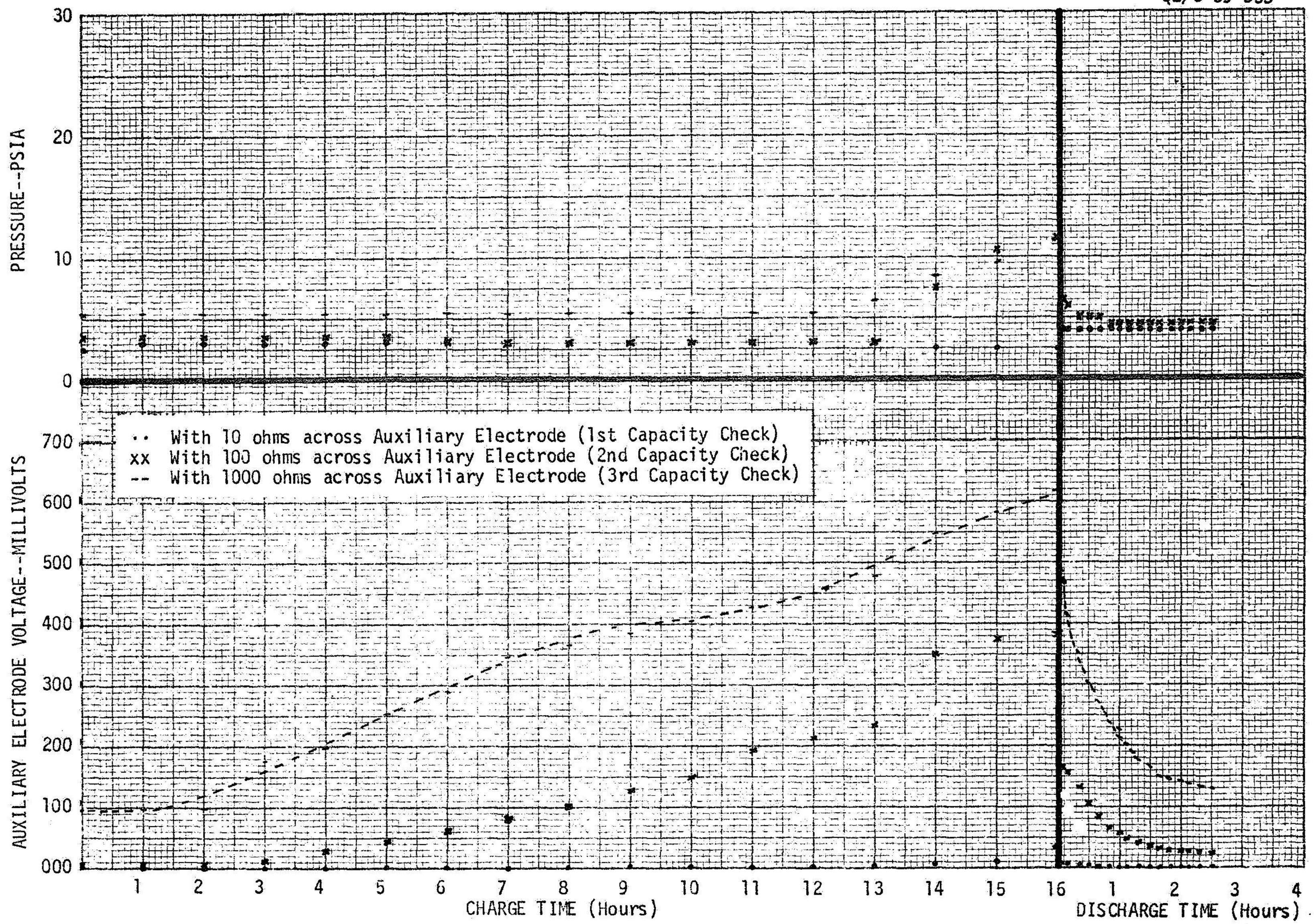
* Botched Data

** Did not obtain millohmmeter readings



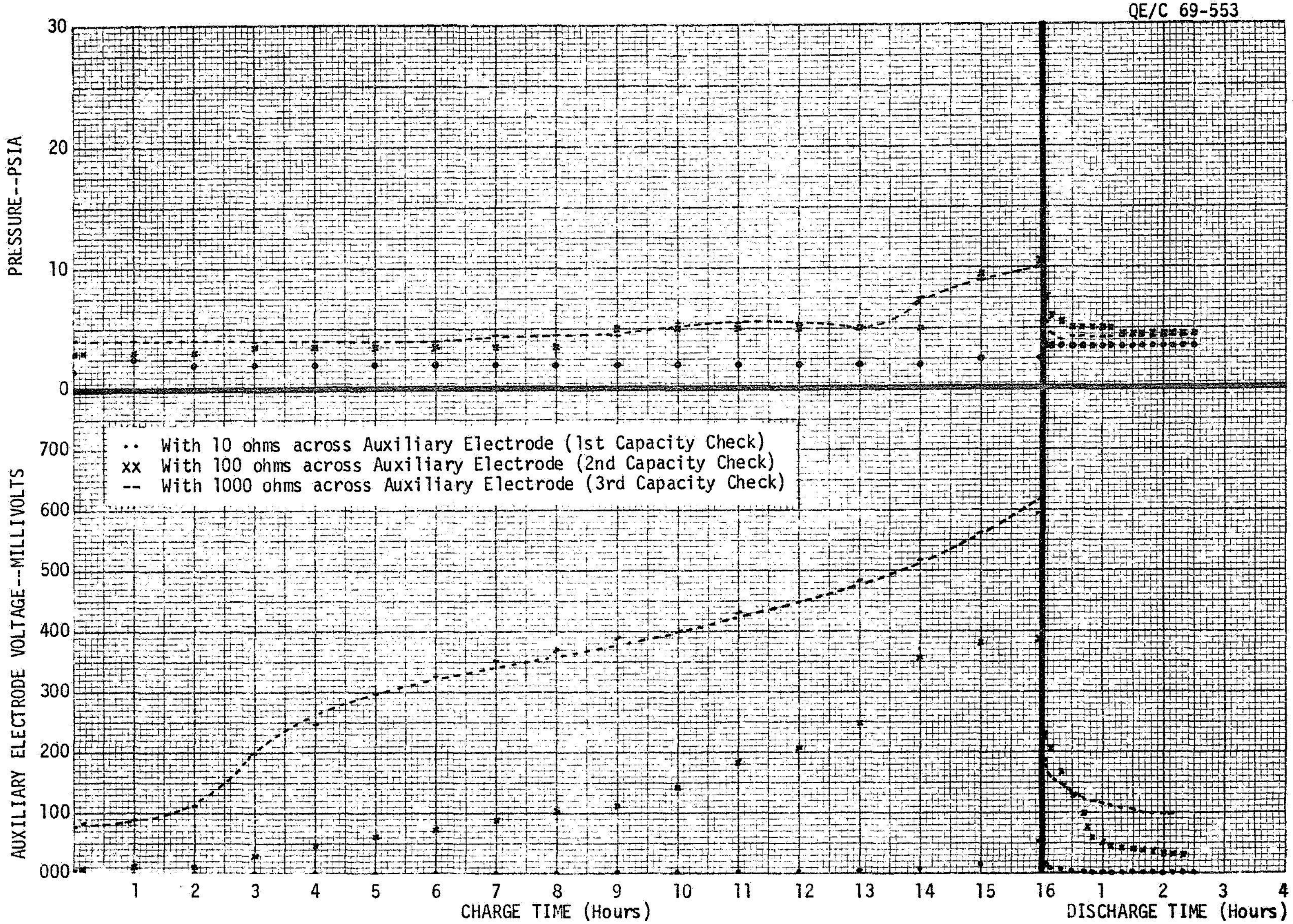
GE 12 AMPERE-HOUR AUXILIARY ELECTRODE NICKEL-CADMIUM CELLS
CHARACTERISTIC 2-HOUR RATE DISCHARGE CURVES

FIGURE 1



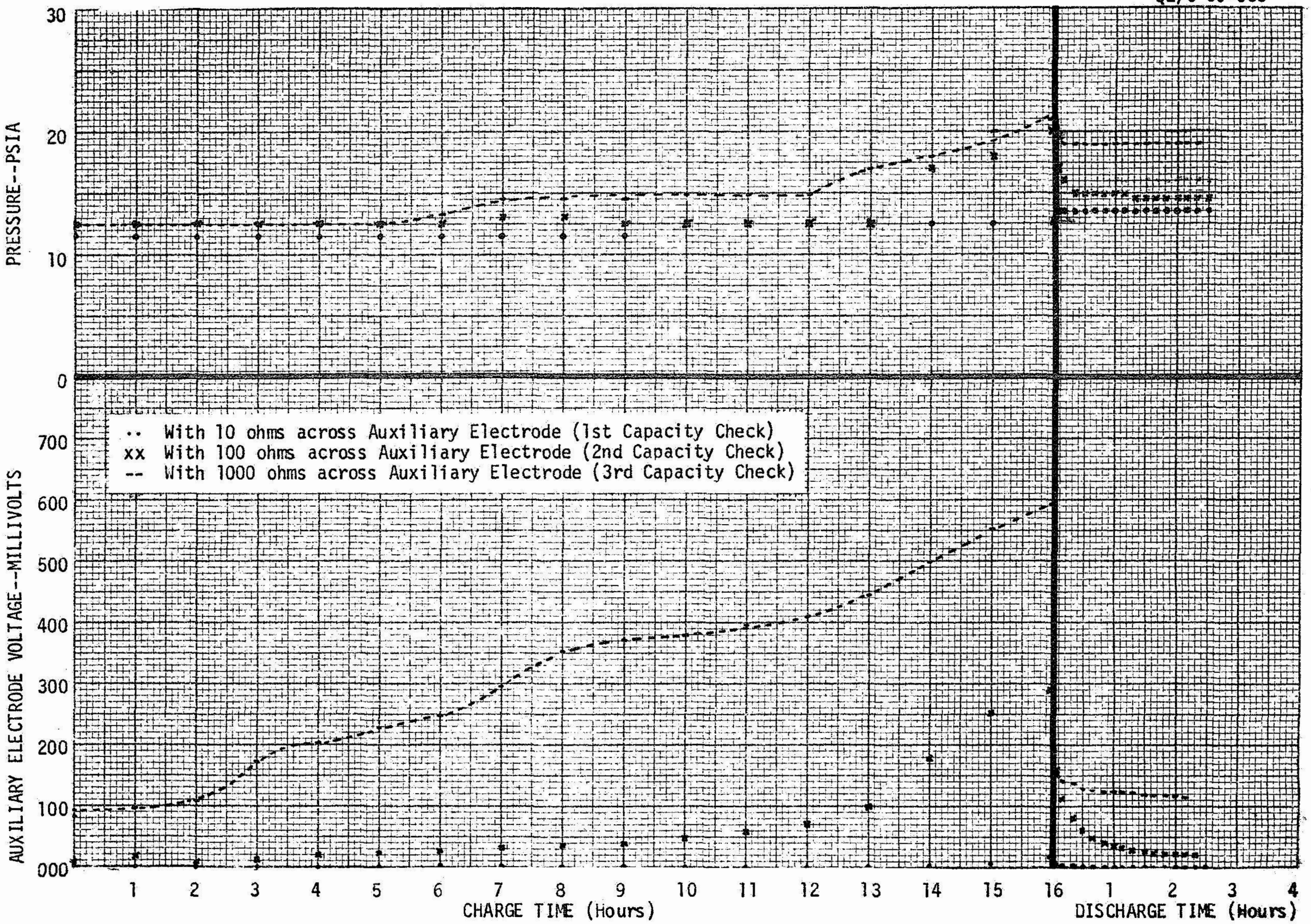
AUXILIARY ELECTRODE VOLTAGES AND CELL PRESSURES VERSUS TIME (CELL #3)

FIGURE 2



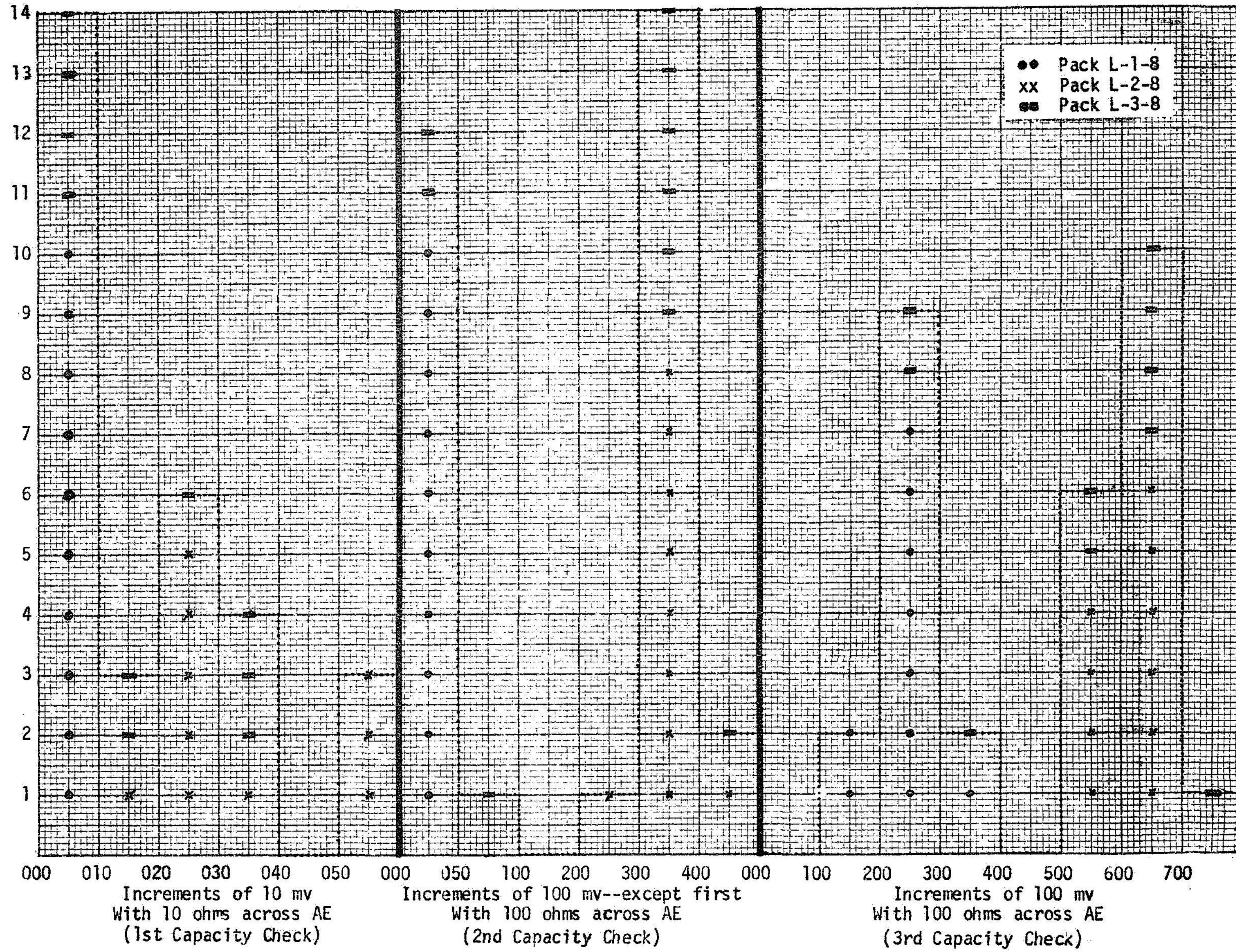
AUXILIARY ELECTRODE VOLTAGES AND CELL PRESSURES VERSUS TIME (CELL #4)

FIGURE 3



AUXILIARY ELECTRODE VOLTAGES AND CELL PRESSURES VERSUS TIME (CELL #5)

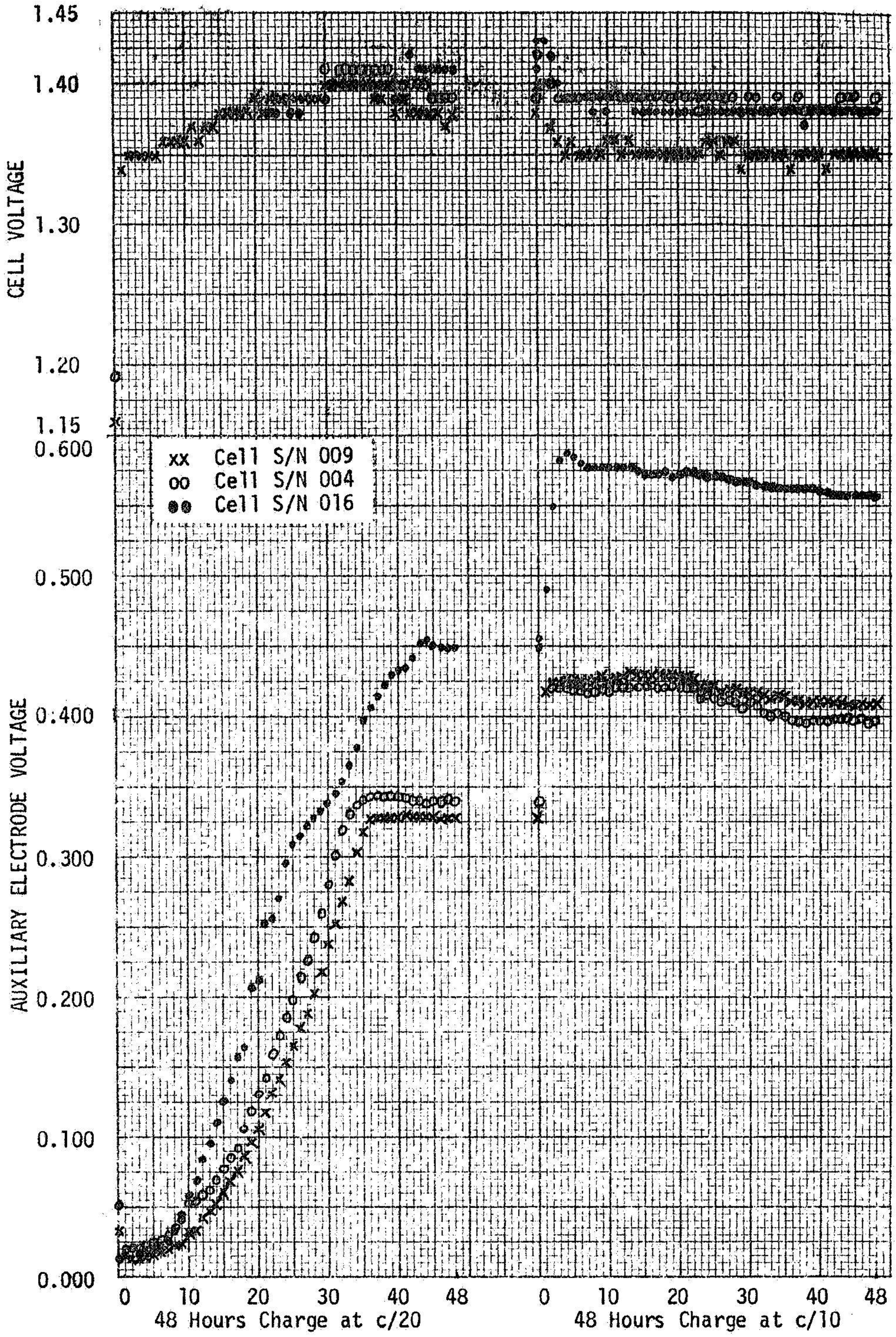
FIGURE 4



HISTOGRAM

To Separate the two types of Cells by differences in their Auxiliary Electrode Voltages

FIGURE 5



GE 12 AMPERE-HOUR AUXILIARY ELECTRODE NICKEL-CADMIUM CELLS
CHARACTERISTIC OVERCHARGE CURVES
(300-ohm resistors between Auxiliary Electrode Tab and Negative Terminal)
FIGURE 6

DISTRIBUTION LIST

COPY NO.	
1-6	National Aeronautics and Space Administration, Goddard Space Flight Center (Mr. Thomas Hennigan, Code 716.2), Greenbelt, Maryland 20771
7	National Aeronautics and Space Administration (Mr. Ernst M. Cohn, Code RNW), Washington, D. C. 20546
8	National Aeronautics and Space Administration (Mr. A. M. Greg Andrus, Code SAC), Washington, D. C. 20546
9-11	National Aeronautics and Space Administration, Scientific and Technical Information Division (Winnie M. Morgan, Code US), Washington, D. C. 20546
12	National Aeronautics and Space Administration, Office of Technology Utilization, Washington, D. C. 20546
13	National Aeronautics and Space Administration, Goddard Space Flight Center (Mr. Joseph Sherfey, Code 735), Greenbelt, Maryland 20771
14	National Aeronautics and Space Administration, Goddard Space Flight Center (Mr. Gerald Halpert, Code 735), Greenbelt, Maryland 20771
15	National Aeronautics and Space Administration, Langley Research Center (Mr. John L. Patterson, MS-472), Hampton, Virginia 23365
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