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ANNUAL REPORT

TO

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

FOR

CHARACTERIZATION OF PHYSIO-CHEMICAL PROPERTIES OF POLYMERIC AND ELECTROCHEMICAL MATERIALS FOR AEROSPACE FLIGHT

NSG - 5009

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ABSTRACT

Electrochemical cells, or batteries contribute an important factor to the functioning of satellites and in many of the experiments in them. Battery failure can cause failure of the satellite's mission.

The " second plateau" and cadmium migration are two problems of particular interest since these are major causes of cell degradation. Sealed nickel - cadmium cells having undergone large number of cycles were discharged using Hg/HgO reference electrode . The negative electrode exhibited the second plateau. SEM of negative plates of such cells show clusters of large crystals of cadmium hydroxide. These large crystals on the negative plates disappear after continuous overcharging in flooded cells.

Atomic Absorption Spectroscopy and standard wet chemical methods are being used to determine the cell materials viz: nickel, cadmium, cobalt, potassium and carbonate. The anodes and cathodes are analyzed after careful examination and the condition of the separator material is evaluated.

SECOND PLATEAU

INTRODUCTION

Nickel-Cadmium cells are extensively used in satellite power systems. These cells undergo a large number of charge-discharge cycles. The changes in the battery voltage or capacity directly affect the power requirements and control unit function of the satellite power systems. It has been found very often that nickel-cadmium cells after a year's use show a voltage degradation during discharge. Such cells suffering with voltage degradation increase the load on the batteries and will sometimes result in loss of capacity. The voltage degradation during the discharge is commonly referred to as the second plateau or stepped discharge curve.

Different views have been expressed as to which electrode is contributing and about the mechanisms causing such voltage degradation. One of the mechanisms (Reference 1) suggested is that the recrystallization of cadmium hydroxide at the surface of the cathode during cycling insulates the lower layers of active cadmium, as a result the discharge occurs at a very low rate. as been reported (Reference 2) that an alloy Ni_5Cd_{21} formed in the negative electrode of nickel-cadmium cells subjected to contiuous charging at elevated temperatures is the cause of voltage degradation. Russian workers (Reference 3) reported that under certain conditions, e.g., if the battery is stored in the charged state or cycled with incomplete discharge, some of the cadmium forms the intermetallic compound Ni_5Cd_{21} with nickel, and is discharged at a potential on the positive side of the usual potential by 0.1V. Recently, Barnard et al (Reference 4) have reported that the secondary discharge plateau is associated with the inefficient reduction of sintered plate NiOOH electrodes. They point out that the potential of the lower plateau is highly dependent on discharge rate and also to some extent on the charge regime applied to the eletrode. Zimmerman and Janecki (Reference 5) also report that the voltage losses result from changes in the nickel electrode potential with cycling.

Gerald Halpert (Reference 6) presented the results of cycling 26.5 AH sealed nickel-cadmium cells. Sealed cells were cycled on a near earth orbit regime at 10°C amd to a voltage limit. Cells showed voltage degradation after about 6400 cycles. Pack 26H which was discharged with 25% DOD showed a more significant voltage degradation than pack 26G cells with 20% DOD. Graph A shows the second plateau behaviour of cells from pack 26H.

EXPERIMENTAL METHODS

1. Preparation of Hg/HgO Reference Electrode:

   a) Small amounts of mercury and mercuric oxide (red variety) were ground well with 2 to 3 drops of 31% KOH.

   b) The above mixture was put into a piece of teflon tubing of 50mm diameter which had a tiny hole at the bottom that is plugged with separator material.

   c) A few ml of pure mercury was put over the layer of Hg/HgO.

   d) A platinum or nickel wire was stuck in the mercury pool taking care to prevent the wire from touching the Hg/HgO interface.

Such a Hg/HgO electrode served as a stable reference electrode and was used to monitor the potentials versus the negative and positive electrode of the nickel-cadmium cells.

2. Cells Used for the Study:

History of the cells used is given in Table 1.

3. Identification of the Electrode causing the Second Plateau:

A 20 AH cell from pack 12 F was chosen for investigation. The cell had undergone 24958 cycles on a near earth orbit basis at Crane at 16 A of charge and discharge. The temperature was at 10°C and 40% DOD.

The following steps were carried out using the above mentioned sealed cell:

   a) The fully charged cell was discharged to 50% and the Hg/HgO reference electrode was carefully introduced by drilling a hole on the top of the cell and sealing the hole all around with putty. Care was taken to prevent the cell from exposure to air by keeping it in a polyethylene bag filled the nitrogen.

   b) The cell was recharged at the same charge regime to the specified voltage limit of 1.458 V and discharged at 10 A rate to 0.5 volt.

   c) During the discharge, the reference versus negative and reference versus positive electrode potentials were monitored and recorded using a two-channel recorder. The cell voltage was also recorded separately. The results obtained from the discharge of the cell from pack 12 F is shown in Figure 1.

   d) The discharged cell was once again cycled 10 times overnight and was discharged at 10 A while still monitoring the the potentials of the negative and the positive versus the Hg/HgO reference. As expected, the cell now did not exhibit the second plateau due to earlier reconditioning effect.

Similar experiments were conducted using 3 12AH cells one each from pack 3H, 3J, and 3D and another 20AH cell from pack 1 K. These cells were discharged at Crane, Indiana using the reference electrode technique described earlier. In all the cases, the results show that it is the negative electrode versus reference which exhibit the second plateau.

The help of Mr. Jim Harkness, Steve Hall, and S. Hammersely in carrying out the tests at NWSC, Crane, Indiana, is appreciated.

4. Experiments with Flooded Cells:

After discharging the cells using reference electrode these were brought from Crane to Goddard. Flooded cells were assembled in plexiglass cell cases using the negative and positive plates taken out from a cell that showed the second plateau. Each flooded cell consisted of two negatives and one positive separated by pellon. These flooded cells were charged to different voltage limits. Different charge rates as given in Table 2 were employed to charge the cells. The plateau reappeared in those cases marked with an asterisk and the voltage limit was 1.434 volt per cell.

RESULTS AND DISCUSSION

The results of the present investigation indicate that the negative electrode is responsible for the second plateau in nickel-cadmium cells. The negative and positive plates from such cells were used to assemble flooded cells in the laboratory. These were charged at different rates for different durations to a voltage limit and discharged. The second plateau could be induced again in some cases (see Table 2). The discharge profile of one such case is shown in Figure 2. In two cases, however, the reference versus positive potential showed a slight hump, a sample of which is shown in Figure 5. Comparing the positive versus reference electrode discharge profile to the negative versus reference electrode (Hg/HgO) profile in Figures 1 and 3, it can be seen that the magnitude of the second plateau on the negative electrode is larger (300 mv). In agreement with a number of workers, a shift in the second plateau with cycling is demonstrated in Figure 4.

The half-cell reaction at the cadmium electrode is well known:

$$Cd + OH^- \underset{\text{Charge}}{\overset{\text{Discharge}}{\rightleftharpoons}} Cd\ (OH)_2 + 2e^- \qquad (1)$$

The $Cd(OH)_2$ is also known to form through dissolution precipitation mechanism: (Reference 7)

$$Cd + 3(OH)^- \rightleftharpoons Cd(OH)_3^- + 2e^-$$
$$Cd(OH)_3^- \rightleftharpoons Cd(OH)_2 + OH^- \qquad (2)$$

Reactions (1) and (2) precipitate cadmium hydroxide and migrate to the surface of the electrode, towards the separator and positive electrode. In the inital stages of cycling, the cadmium hydroxide is present as thin film masking some areas of active cadmium. As the cycling progresses, these films provide convenient sites for crystal growth and thus mask the active cadmium surface with large crystals of cadmium hydroxide. The SEMs of negative plates of cells that showed second plateau show very large crystals of cadmium hydroxide and the positives do not have any crystal growth. Ford (Reference 8) demonstrated that the nickel-cadmium cells that had electrolyte starvation suffered both in voltage and capacity. The cells examined by him were Gulton 6 AH cells cycled at 20 C, 25% DOD with a voltage limit of 1.417 and C to D ratio of approximately 115. By simply increasing the electrolyte content the capacity degradation of such cells was overcome but the double plateau effect still existed. Increase of electrolyte seem to dissolve smaller crystals but there is still a bulk of large crystals masking the active surface of the electrode. The experiments in the present work have shown that continuous charging of negative electrodes with large crystal growth in flooded condition almost elminates the crystals. SEMs of negative plates after gasing by overcharging in excess electrolyte showed no trace of large crystals. This is in agreement with the results of Fritzwill and Hess (Reference 9) who pointed out that prolonged reduction leads to the dissolution of crystals of $Cd(OH)_2$.

The tear-down analysis of cycled cells has shown that the cadmium migration is quite heavy in the areas under compression and quite often the separator sticks strongly to the eletrode surface. This may be explained by assuming that in sealed cells the electrolyte is squeezed out from areas where there is more compression and these electrolyte starved areas seem to be good nucleation sites for crystal growth. The crystal size grows as the cycling continues and finally result in loss of voltage and/or capacity. When no effort is made to restore the voltage and capacity by reconditioning, a situation may arise when the cadmium dendrites will pass through the weak separator and lead to what is popularly called soft or hard shorts which will cause cell failure. It appears, if one can prevent cadmium migration and supress crystal growth the voltage degradation i.e., second plateau behaviour is taken care of.

From the Navigation Technology Satellite-2 (NTS-2) nickel-hydrogen battery performance. F.E. Betz, J.D. Dunlop and J.F. Stockel (Reference 10) have reported that the battery voltage level improves with continued cycling as the discharge duration increases. The increase in voltage was related to the positive electrode i.e., the nickel electrode. Stockel in an updated paper (Reference 11) reported that nickel-hydrogens have not shown any voltage or capacity degradation during 3.5 years in orbit and eight eclipse seasons.

CONCLUSIONS

1. The second plateau is exhibited mainly by the negative electrode.
2. Formation of large crystals of $Cd(OH)_2$ on the negative electrode during cycling is responsible for voltage degradation.
3. Continuous gasing of the negative electrode in flooded cells leads to the dissoultion of large crystals of cadmium hydroxide.

FUTURE PLANS

It will be interesting to establish conditions that will minimize cadmium migration. It is planned to investigate the possibility of using some sort of coating, electroplating, or additives that may achieve this purpose. Also plans are underway to look into the effect of varying the compression on the plate stack.

CADMIUM MIGRATION

INTRODUCTION

Although much has been learned about the Ni-Cd cell since its development, there is still much that is unknown. Most of the research and development has been qualitative and empirical. It was aimed at increasing cell performace, capacity and life, without concern about the basic electrode and side reactions. This is because the fundamental processes of the sealed Ni-Cd system are complex and not yet adequately understood. Although some of the problems have been solved, there is still some doubt as to the nature of the charge/discharge reactions in the positive and negative electrodes, the mechanism of oxygen recombination, distribution of electrolyte and the morphology of the active material with aging. Depending on how a cell is constructed and stored, and the frequency or use, there are certain factors which seem to limit the performance and life of the cell. These would include: negative fading, cadmium migration, positive plate expansion and deterioration, loss of electrolyte and separator dryout, undesirable pressure buildup, carbonate contamination, leaks and shorts.

The object of this study is to examine one of the degradation mechanisms in the Ni-Cd cell during certain applications, that is the migration of cadmium from the negative electrode into or toward the separator area. It is difficult to point to any one factor as the cause of cadmium migration. There are, however, circumstances or conditions in which it seems to be enhanced. These include the extent and nature of the cycle regimes, the temperature, the extent of carbonate contamination, and the nature and condition of the separator.

Cadmium migration has been known to be one major factor causing nickel-cadmium cell degradation. As demands for long life and more reliable space batteries increase,solving the degradative problems becomes of greater urgency.

We are conducting a series of experiments to investigate the causes of cadmium migration as a function of charge mode, discharge mode, rate of charge or discharge and temperature.

Current investigation is aimed at identifying the part of the cycle during which most cadmium migration occurs. The effect of charge rate and temperature are also being investigated.

EXPERIMENTS ON CADMIUM MIGRATION

These investigations involve use of flooded cells. Cells are made up in the laboratory and consist of one negative and one positive plates, a nylon or screen separator, a plastic case and 31% KOH as the electrolyte

a) Plates with separator in between them to prevent physical contact are installed in the cell case and flooded with a known volume of KOH. The cell case is then covered with adhesive tape and putty to seal it. A new cell is set up for each run.

b) Continuous charge or discharge is carried out. The parameters being investigated include current density, temperature and time.

c) Each set of plates and separator is examined physically and analyzed chemically for Cd. before use.

d) After the test is completed, the cell is disassembled. The plates and separator are washed in closed plastic containers with deionized water, dryed in the oven at 40 C, weighed and then analyzed for Cd by A.A. Cd migration from the negative plate through the separator to the positive plate is observed to different extents depending on test conditions. The cell case is not soluble in KOH and does not contain any Cd. During the experiment, the aliquots of the electrolyte are are checked for Cd. A constant temperature water bath is used to control the temperature during the test.

The results of these experiments are given in Tables 3 through 12.

CONCLUSIONS:

The preliminary results of the experiments on cadmium migration show:

a) The positive plate gained cadmium as a result of increase of charge time and rate of charge.

b) Low rate of charging and long duration of charging also seem to promote cadmium migration. Separator materials in such cases were found to contain appreciable amounts of cadmium.

c) Cadmium seem to migrate more during discharging towards the separator and finally reach the positive.

d) Increase of temperature enhances the rate of cadmium migration.

ANALYSIS OF NICKEL-CADMIUM CELLS

A number of sealed nickel-cadmium cells have been opened and examined. The cell material i.e., the positive electrode, the negative electrode and the electrolyte were analysed according to " Procedure for analysis of Nickel-cadmium Cell Materials " by Halpert G. and Vasanth Kunigahalli, GSFC Publication X-711-74-279, Revision A.

The agreement of the results obtained by A.A. Spectroscope analyses with those obtained by standard analyses have previously been confirmed.

For analysis of each sample a calibration curve is derived from standard solutions. The given samples are diluted and the concentration of metal and the aliquot is calculated from the calibration curve. This multiplied by the dilution factor givesthe concentration of the metal in the original sample.

The varian Model 1200 A.A. spectrophotometer in use at Bowie State College gives absoption readings. A computer regression analysis program is used to give the slope and intercept of the best straight line for the standardization points. The computer program then fits the absorption readout of the unknown to the curve and gives the concentration of the metal in ppm.

The results of the analyses of some cells and electrode samples at different levels of charge are given in tables 13 through 19.

GRAPH A

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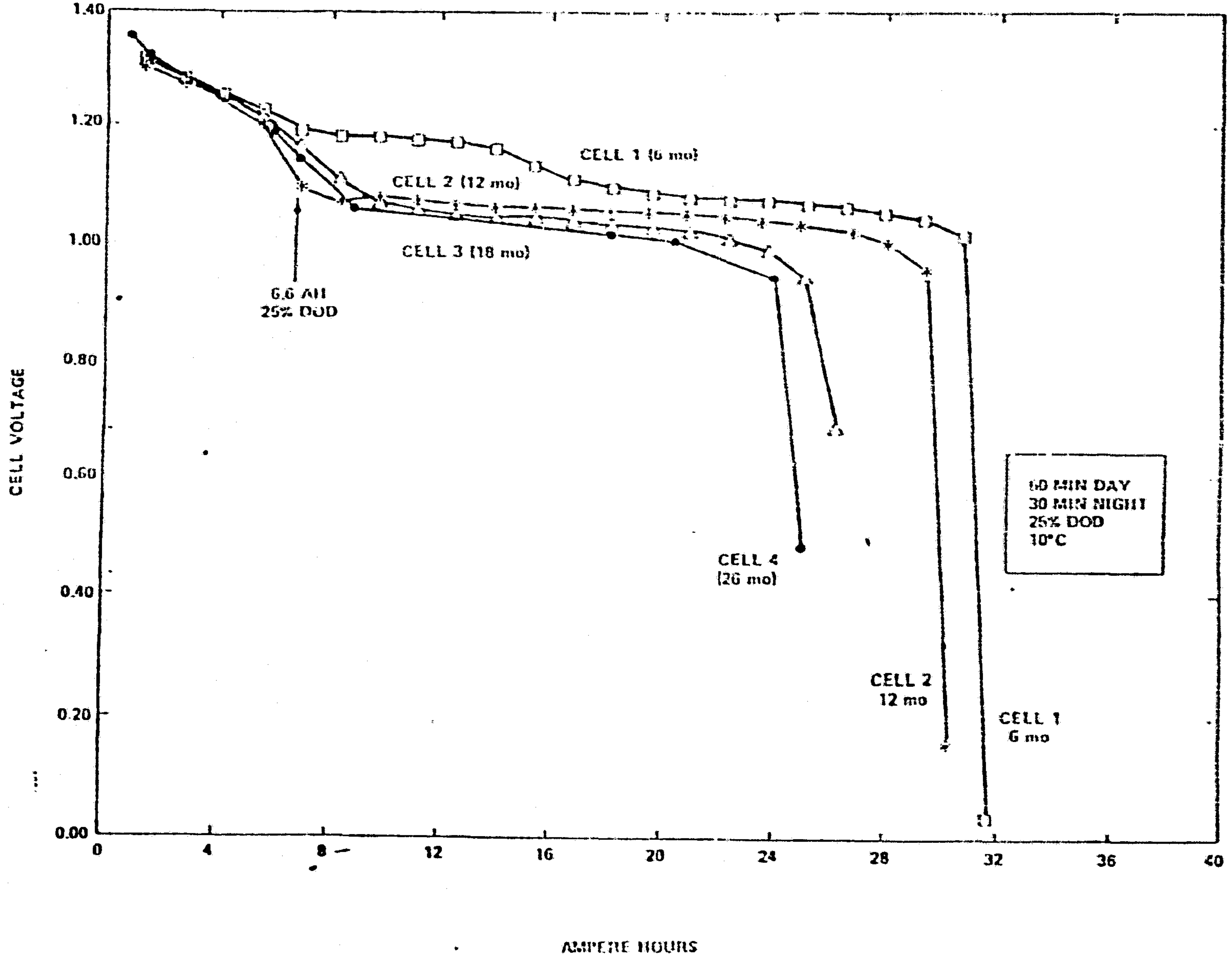
DISCHARGE



Six-Month Capacity Test for Pack 26H

FIGURE 1

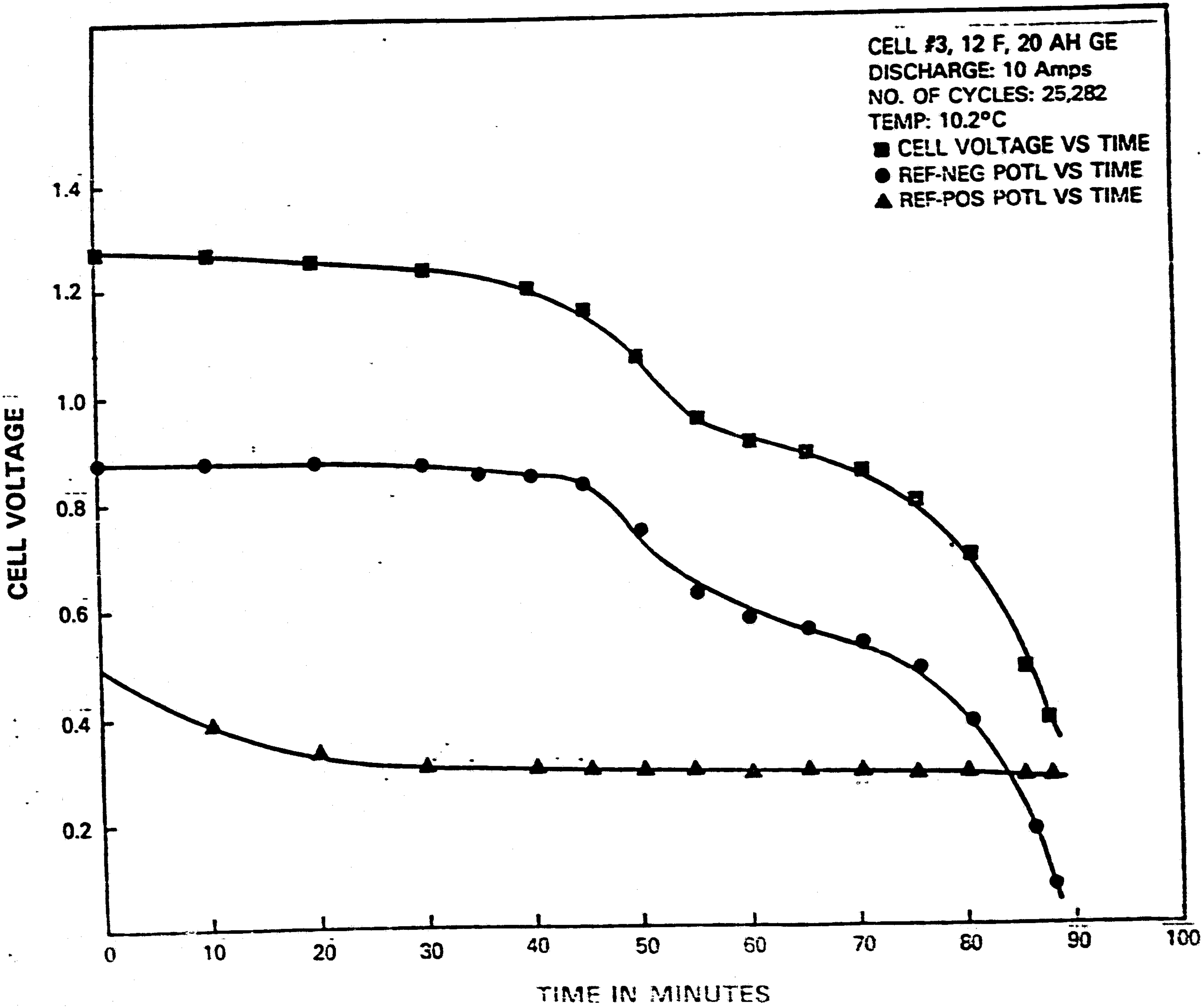


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FIGURE 2

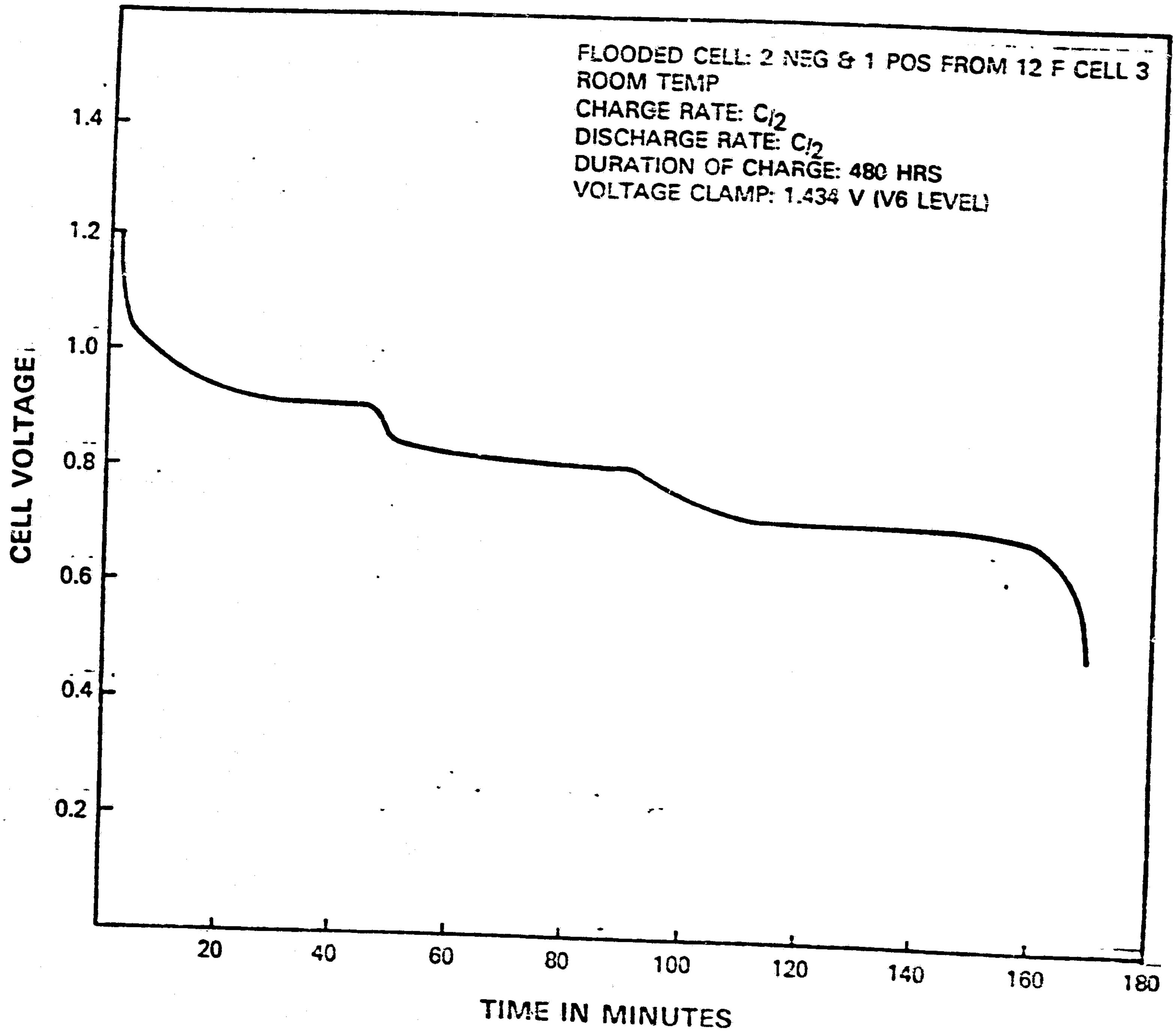
FLOODED CELL: 2 NEG & 1 POS FROM 12 F CELL 3
ROOM TEMP
CHARGE RATE: C/2
DISCHARGE RATE: C/2
DURATION OF CHARGE: 480 HRS
VOLTAGE CLAMP: 1.434 V (V6 LEVEL)
CELL VOLTAGE
1.4
1.2
1.0
0.8
0.6
0.4
0.2
20
40
60
80
100
120
140
160
180
TIME IN MINUTES

FIGURE 3

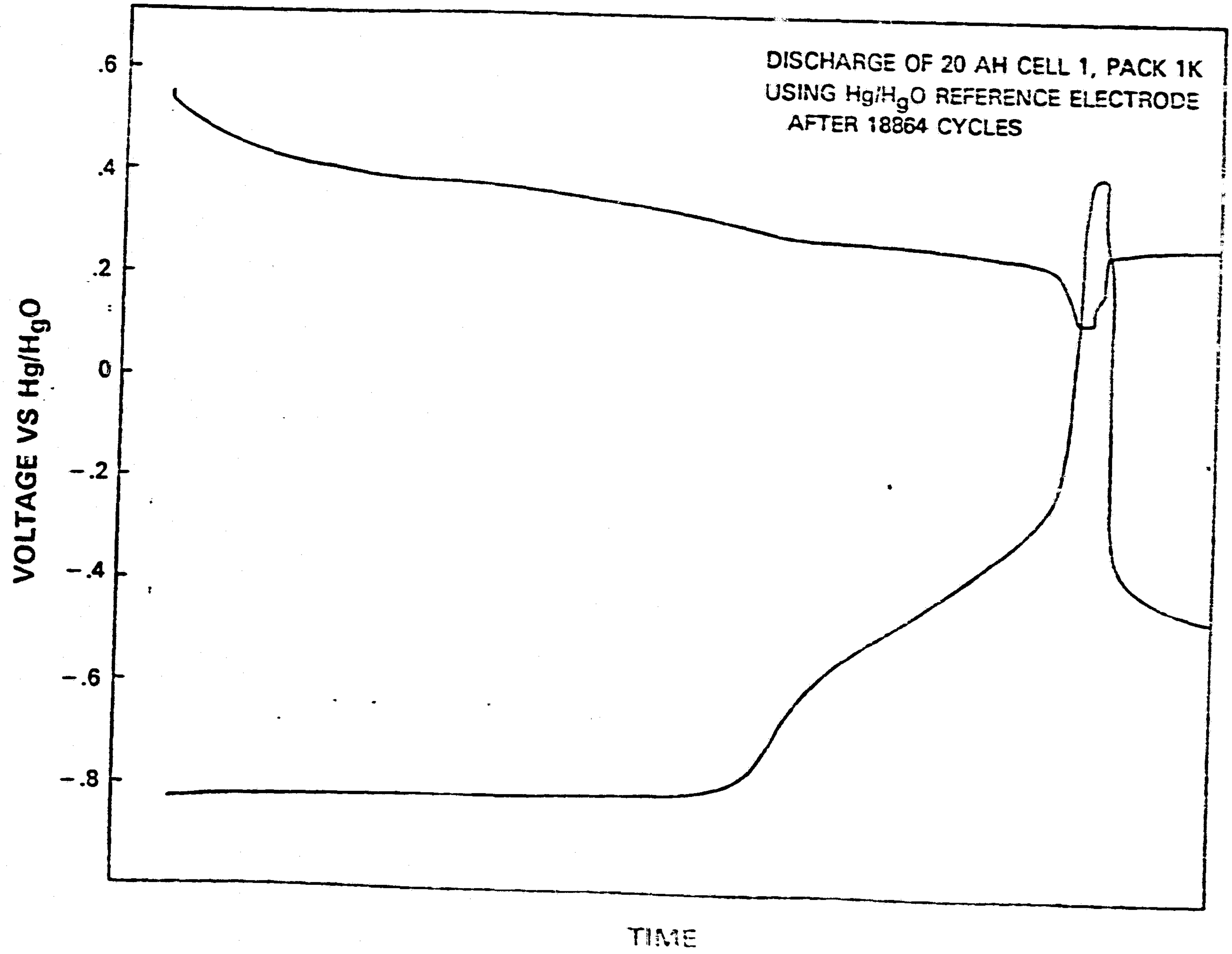
DISCHARGE OF 20 AH CELL 1, PACK 1K
USING Hg/H_gO REFERENCE ELECTRODE
AFTER 18864 CYCLES

FIGURE 4

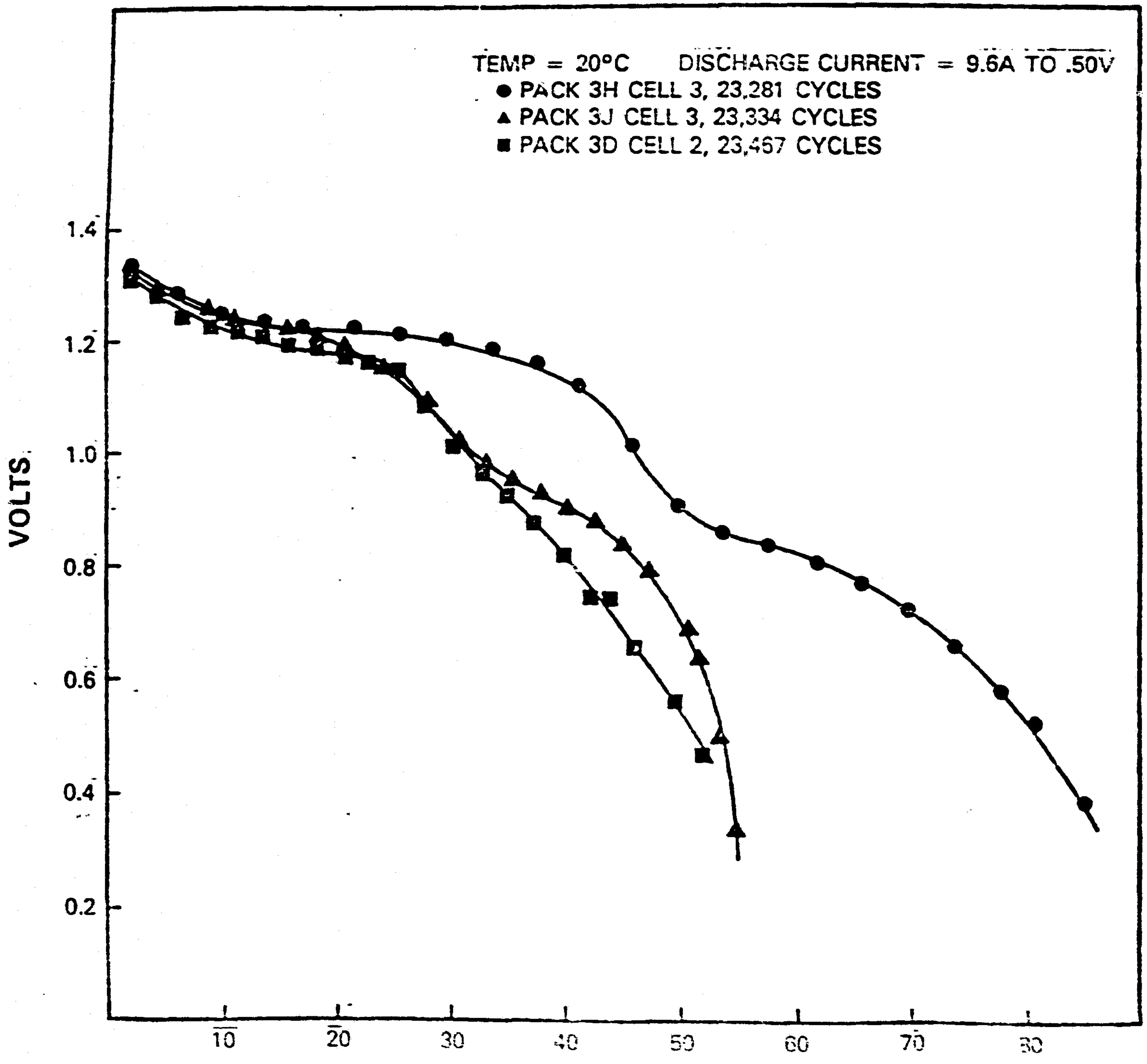

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FIGURE 5

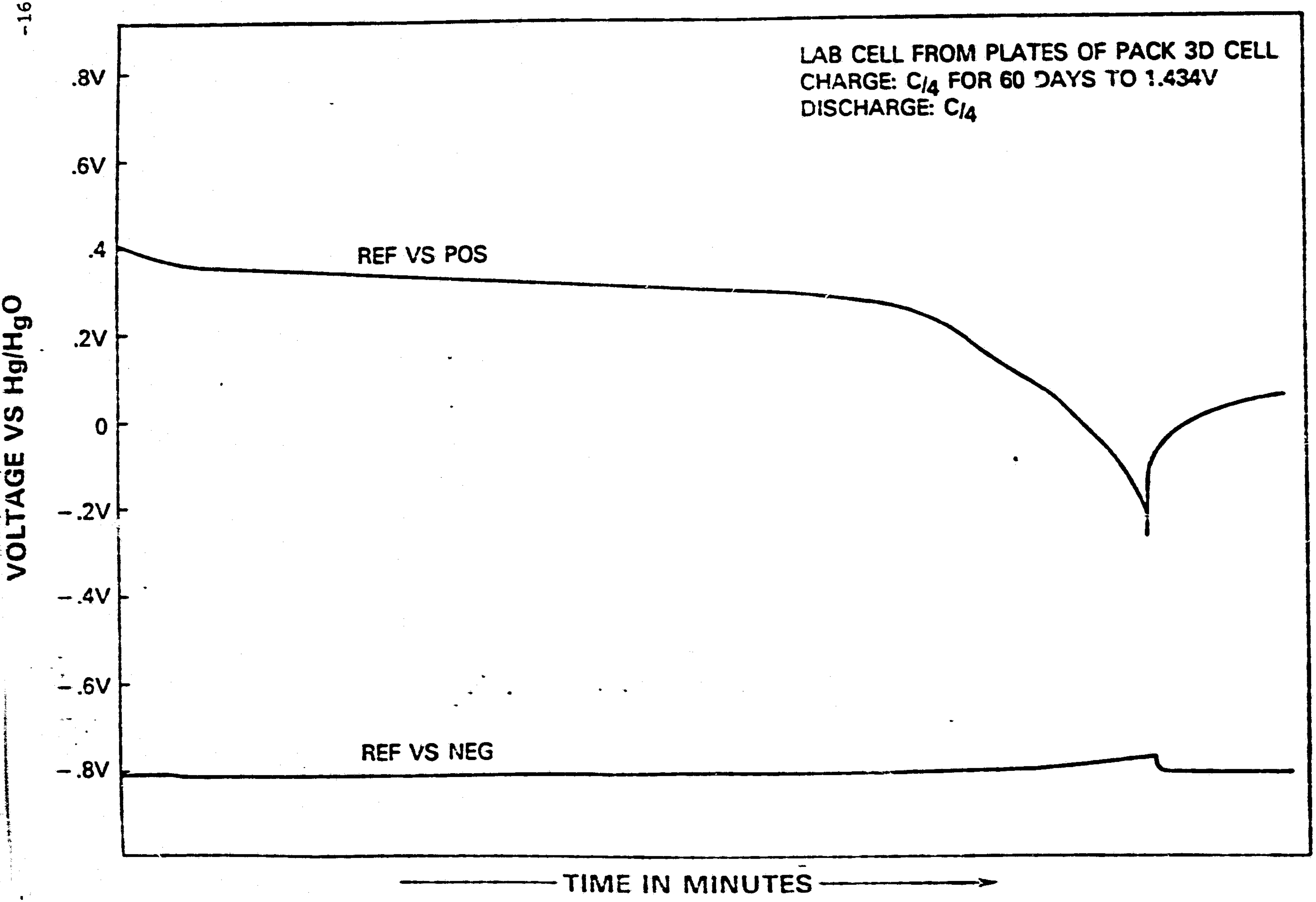
LAB CELL FROM PLATES OF PACK 3D CELL
CHARGE: C/4 FOR 60 DAYS TO 1.434V
DISCHARGE: C/4
REF VS POS
REF VS NEG
.8V
.6V
.4
.2V
0
−.2V
−.4V
−.6V
−.8V
VOLTAGE VS Hg/HgO
TIME IN MINUTES

TABLE 1

CELL HISTORY AND OPERATING PARAMETERS

PACK #	12F	1K	3H	3J	3D
CELL #	3	1	3	3	2
NOMINAL CAP (AH)	20	20	12	12	12
VOL. OF KOH (ml)	85	85	41.5	39	40
POS. LOADING (g/dm^3)	1704	1704	2113	2130	2095
NEG. LOADING (g/dm^3)	1865	1865	2180	2542	2180
SPECIAL TREATMENT	NEG TEFLNTD	PELLON 2503	NO PQ TREAT	OLD PROC. NO PQ	CONTROL GROUP
ORBIT PERIOD (HR)	1.5	1.5	1.5	1.5	1.5
TEMP (°C)	10	20	20	20	20
CHARGE RATE (A)	16	16	9.6	9.6	9.6
NO. OF CYCLES	24,958	18,864	23,281	23,334	23,467
DOD (%)	40	40	40	40	40
VOLT. LIMIT (V)	1.457	1.434	1.453	1.453	1.453-1.473
AH-OUT TO 0.5 V (AH)	14.50	10.86	8.19	8.80	8.35
POS. THICKNESS (IN)	0.027	0.027	0.027	0.032	0.027
NEG. THICKNESS (IN)	0.0315	0.0315	0.031	0.026	0.031

TABLE 2

CONDITIONS OF CHARGE/DISCHARGE FOR FLOODED CELLS

DISCHARGE RATE: C/2 ROOM TEMP

VOLT LIMIT	NASA LEVEL #	CHARGE RATE	# HRS CHARGED
1.475	V8	C/2	288
1.455	V7	C	288
1.434*	V6	C/2	480
1.434*	V6	C/2	672
1.434	V6	C	714
1.434*	V6	C	912
1.434*	V6	C	1248
1.414	V5	C/2	176
1.414	V5	C/2	288
1.414	V5	C/2	720

*SECOND PLATEAU APPEARED IN THESE CASES.

NOTES ON TABLES 3, 4, 5

1. Cell #4 was on open circuit for 168 hours before charging, 6 hours on charge, 65 hours open circuit; 7 hours charge, 188 hours open circuit.

   Cells 6A, 3B, and 4B were on open circuit 117 hours before and 91 hours after charging.
   Cells 2A and 7 were on open circuit 70 hours before and 140 hours after charging.
   Cell 5 was on open circuit for 843 hours before charging and 140 hours after charging.

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TABLE 3

CHANGE IN CONC. OF Cd IN POSTIVE PLATE-CHARGE MODE

CELL #	CHARGE RATE	CHARGE TIME (HRS)	Cd INITIAL (mg/PPM)	Cd FINAL (mg/PPM)	SEPARATOR	TEMPERA
2A	c/8	96	1.4/5.2	4/11.4	Nylon	Room
3B	c/5	52	0.9/3.4	5.5/18.0	Nylon	40°C
4	c/3	13	0.6/5.5	2.7/25.1	Nylon	Room
4B	c/8	52	1.4/4.4	5.8/14.5	Nylon	Room
5	c/8	96	1.0/3.7	7.5/30.3	Screen	Room
6A	c/5	52	.9/3.3	7/17.4	Nylon	Room
7	c/8	96	.9/4.1	5/17/6	Nylon	Room

TABLE 4

CHANGE IN CONCENTRATION OF Cd IN ELECTROLYTE - CHARGE MODE

CELL #	CHARGE RATE	CHARGE TIME (HRS)	Cd INITIAL (PPM/Mg)	Cd FINAL (PPM/Mg)	SEPARATOR MATERIAL	TEMPERATURE
2A	c/8	96	5.5/1.3	13.3/33	Screen	Room
2B	c/5	52	13.7/3.4	9.6/2.4	Screen	40°C
3B	c/5	52	12.6/3.1	11.8/3.0	Nylon	40°C
4	c/3	13	9.5/2.4	1.7/0.4	Nylon	Room
4B	c/5	52	8.3/2.0	9.6/2.4	Screen	Room
5	c/8	96	9/2.3	13.0/3.3	Nylon	Room
6A	c/5	52	8.3/2.0	10.0/2.25	Nylon	Room
7	c/8	96	5.0/1.3	12.7/3.2	Nylon	Room

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TABLE 5

CHANGE IN CONCENTRATION OF Cd IN SEPARATOR - CHARGE MODE

CELL #	CHARGE RATE	CHARGE TIME (HRS)	Cd INITIAL (PPM/M)	Cd FINAL (PPM/Mg)	SEPARATOR MATERIAL	TEMPERATURE
4	c/3	13	0.58/5.5	2.65/25.1	Nylon	Room
7	c/8	96	0.9/4.1	5.0/17.6	Nylon	Room
5	c/8	96	0.95/3.7	7.5/30.3	Nylon	Room
2A	c/8	96	1.43/5.2	4.0/11.4	Screen	Room
1A	c/5	52	0.93/3.3	7.0/17.4	Nylon	Room
4B	c/5	52	1.43/4.4	5.8/14.5	Screen	Room
3B	c/5	52	0.90/3.3	5.5/18.0	Nylon	40 °C
2B	c/5	52	1.33/4.8	5.0/16.1	Screen	40 °C

NOTES ON TABLES 6, 7, 8

1. Cell #3 was on open circuit 280 hours, on discharge 7 hours, on open circuit 17 hours, on discharge 7 hours and on open circuit 140 hours.

   Cells 3A, 4A, and 6 were on open circuit 93 hours before discharging and 214 hours after discharging.

   Cells 1C, 4C were on open circuit 141 hours before discharging and 142 hours after discharging.
2. Initial Cd concentration of these electrode and was determined on electrode material before the cell was assembled. Final Cd concentration was determined on cathode when the cell was taken apart at the end of the experiment.
3. Initial concentration of the Cd in the electroylte was determined immediately before charging.

   Final Cd concentration was determined after sitting on open circuit for 24 hours. Cell #4 for 13 hours.

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TABLE 6

CHANGE IN CONCENTRATION OF Cd IN POS PLATE DISCHARGE MODE

CELL #	DISCHARGE RATE	DISCHARGE TIME (HRS)	CD INITIAL (PPM/Mg)	CD FINAL (PPM/Mg)	SEPARATOR MATERIAL	TEMPERATURE
1C	c/5	52	1.0/3.9	16.3/36.4	Nylon	Room
[illegible]	c/3	14	0.4/3.8	3.15/27.7	Nylon	Room
[illegible]A	c/8	99	1.1/4.2	18.0/44.4	Nylon	Room
4A	c/8	99	0.9/4.4	24.3/82.3	Screen	Room
4C	c/5	52	1.1/3.6	11.3/26.1	Screen	Room
[illegible]	c/8	99	0.8/3.8	8.7/20.1	Nylon	Room

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TABLE 7

CHANGE IN CONCENTRATION OF Cd IN ELECTROLYTE-DISCHARGE MODE

CELL #	DISCHARGE RATE	DISCHARGE TIME (HRS)	Cd INITIAL (PPM/Mg)	Cd FINAL (PPM/Mg)	SEPARATOR MATERIAL	TEMPERATU
1C	c/5	52	7.5/1.9	5.5/1.4	Nylon	Room
3	c/3	14	8.3/2.1	5.5/1.4	Nylon	Room
[illegible]A	c/8	99	6.3/1.6	5.8/1.5	Nylon	Room
4A	c/8	99	5/1.3	6.0/1.5	Screen	Room
4C	c/5	52	8.3/2.1	5.5/1.4	Screen	Room
[illegible]	c/8	99	5.0/1.3	9.5/2.4	Nylon	Room

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TABLE 8

CHANGE IN CONCENTRATION OF Cd IN SEPARATOR-DISCHARGE MODE

CELL #	DISCHARGE RATE	DISCHARGE TIME (HRS)	Cd INITIAL (PPM/Mg)	Cd FINAL (PPM/Mg)	SEPARATOR MATERIAL	TEMPERATU
3	c/3	14	0.086	0.093	Nylon	Room
6	c/8	99	0.097	0.44	Nylon	Room
7A	c/8	99	0.094	0.474	Nylon	Room
1C	c/5	52	0.100	1.22	Nylon	Room

[illegible]

CHANGE IN CONCENTRATION OF Cd IN POSITIVE PLATE - CHARGE MODE

Cell #	Discharge rate	Discharge time (hours)	Cd initial (before charge) (Mg)	Cd final (after charge) (Mg)	Temperature °C
10	c/3	24	0.40	0.72	25
20	c/5	24	0.40	1.10	40
40	c/10	48	0.31	1.44	25
50	c/10	24	0.70	0.65	10
60	c/3	48	0.77	1.34	40
70	c/3	72	0.52	0.94	10
150	c/5	48	0.59	1.17	10
170	c/10	72	0.73	3.7	40
180	c/5	72	0.79	1.98	25

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TABLE 10

CHANGE IN CONCENTRATION OF Cd IN POSITIVE PLATE - DISCHARGE MODE

Cell #	Discharge rate	Discharge time (hours)	Cd initial (before discharge) (Mg)	Cd final (after dischage) (Mg)	Temperature °C
30	c/5	24	0.57	9.30	40
90	c/3	24	0.58	1.24	10
100	c/5	48	0.60	3.54	10
110	c/3	48	0.71	21.0	40
120	c/5	72	0.66	16.0	25
130	c/10	48	0.71	8.02	25
140	c/3	72	0.66	8.50	10
160	c/3	24	0.59	7.37	25
190	c/10	72	0.60	9.01	40

TABLE 11

CHARGE IN THE CONCENTRATION OF Cd IN ELECTROLYTE - DISCHARGE MODE

Cell #	Charge rate	Charge time (hour)	Close to Cd initial (Mg)	Positive Plate Cd final (Mg)	Close to Cd initial (Mg)	Negative Plate Cd final (Mg)	Temperature °C
80	c/5	24	.25	.31	0.66	0.82	40
90	c/10	24	.120	.22	0.55	0.36	10
100	c/5	48	.38	.17	0.80	0.36	10
110	c/3	48	.55	.32	1.09	0.81	40
120	c/5	72	.24	.14	1.49	0.32	25
130	c/10	48	.27	.32	1.39	0.66	25
140	c/3	72	.21	.12	0.84	0.29	10
160	c/3	24	.49	.81	0.66	.62	25
190	c/10	72	.31	.35	1.51	0.70	40

TABLE 12

CHARGE IN CONCENTRATION OF Cd IN ELECTROLYTE - CHARGE MODE

Cell #	Charge rate	Charge time (hour)	Close to Positive Plate		Close to Negative Plate		Temperature °C
			Cd initial (Mg)	Cd final (Mg)	Cd initial (Mg)	Cd final (Mg)	
10	c/3	24	0.06	0.00	.15	0	25
20	c/5	24	0.07	0.09	.09	.06	40
40	c/10	48	0.130	0.06	.16	.04	25
50	c/10	24	0.11	0.08	.21	.10	10
60	c/3	48	0.24		.35	.03	40
70	c/3	72	.08	.03	.15	.03	10
150	c/5	48	.05	.08	.09	.07	10
170	c/10	72	.09	0.17	.20	.03	40
180	c/5	72	.09	0.10	.10	.08	25

TABLE 13

GE 12AH SN05

Group 8

NEGATIVE PLATES

Plate Composition (by wt):	100% Charged	100% discharged	Plate #
1. $Cd(OH)_2$	6.11	5.54	
2. Cadmium metal	0.87	0.74	
3. $Ni(OH)_2$	.558	.534	
4. Ni in plaque	2.73	3.38	
5. Substrate	2.98	2.68	
6. Nickel Tab	0.12	0.12	
7. Total Wt	13.36	12.99	
8. Actual wt	13.460	12.46	
9. % Deviation	1.575	3.29	
10. Dimensions: Length in cm	7.62	7.62	
Width in cm	6.95	6.95	
Thickness cm	0.08	0.08	
11. Solid volume, cc	4.24	4.24	
12. Nickel, g/cc	0.64	0.79	
13. % Porosity (includes substrate)	84.86	83.94	
14. Effective substrate thickness	.0024	.0024	
15. Effective Porosity (excludes Substrate)	92.81	91.12	
16. Volume of voids, cc	393.51	386.35	
17. Cadmium AM/cc voids	0.017	0.016	
18. Total AM/cc voids	0.027	0.025	
19. % $Ni(OH)_2$ in Active Material	5.30	5.46	
20. Others			

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*AM stands for active material

TABLE 14

R-G 123

NEGATIVE PLATES

Plate Composition (by wt):		100% charged Plate #	100% discharged Plate #	Plate #
1. $Cd(OH)_2$		1.80	5.14	
2. Cadmium metal		3.50	2.29	
3. $Ni(OH)_2$		0.41	0.43	
4. Ni in plaque		2.93	2.81	
5. Substrate		3.04	2.95	
6. Nickel Tab		0.12	0.12	
7. Total Wt		11.80	13.72	
8. Actual wt		12.66	12.66	
9. % Deviation		6.79	7.72	
10. Dimensions:	Length in cm	7.62	7.62	
	Width in cm	6.95	6.95	
	Thickness cm	0.08	0.08	
11. Solid volume, cc		4.24	4.24	
12. Nickel, g/cc		0.69	0.66	
13. % Porosity (includes substrate)		84.18	84.73	
14. Effective substrate thickness		0.0024	0.0024	
15. Effective Porosity (excludes Substrate)		92.25	92.58	
16. Volume of voids, cc		391.14	392.54	
17. Cadmium AM/cc voids		0.014	0.018	
18. Total AM/cc voids		0.025	0.025	
19. % $Ni(OH)_2$ in Active Material		4.26	4.42	
20. Others				

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*AM stands for active material

TABLE 15

GE 12AH SN01
Group 5 cell B

NEGATIVE PLATES

Plate Composition (by wt):		100% charged Plate #	100% discharged Plate #	Plate #
1. $Cd(OH)_2$		2.52	6.42	
2. Cadmium metal		3.55	0.09	
3. $Ni(OH)_2$		0.81	0.88	
4. Ni in plaque		4.57	4.25	
5. Substrate		2.85	2.69	
6. Nickel Tab		0.12	0.12	
7. Total Wt		14.42	14.45	
8. Actual wt		15.15	15.15	
9. % Deviation		4.82	4.62	
10. Dimensions:	Length in cm	7.62	7.62	
	Width in cm	6.95	6.95	
	Thickness cm	0.08	0.08	
11. Solid volume, cc		4.24	4.24	
12. Nickel, g/cc		1.08	1.00	
13. % Porosity (includes substrate)		80.33	81.4	
14. Effective substrate thickness		0.0024	0.0024	
15. Effective Porosity (excludes Substrate)		87.86	88.76	
16. Volume of voids, cc		372.53	376.36	
17. Cadmium AM/cc voids		0.017	0.017	
18. Total AM/cc voids		0.033	0.033	
19. % $Ni(OH)_2$ in Active Material		6.59	7.06	
20. Others				

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*AM stands for active material

TABLE 16
GE 12AH SN/023

(Uncycled Face Down) *

NEGATIVE PLATES

Plate Composition (by wt):		Plate # 3	Plate # 9	Plate # 13
1. $Cd(OH)_2$		7.9678	7.5247	8.0502
2. Cadmium metal		.1764	.2060	.2029
3. $Ni(OH)_2$		.5689	.5547	.6556
4. Ni in plaque		4.0911	4.4240	4.4787
5. Substrate		2.8597	2.8801	3.0162
6. Nickel Tab		0.12	0.12	0.12
7. Total Wt		15.7239	15.6495	16.4636
8. Actual wt		16.98132	16.9769	16.8699
9. % Deviation		7.36	7.77	2.44
10. Dimensions:	Length in cm	7.62	7.62	7.62
	Width in cm	6.95	6.95	6.95
	Thickness cm	0.0863	0.0816	0.08128
11. Solid volume, cc		4.57	4.64	4.30
12. Nickel, g/cc		0.89	0.95	1.04
13. % Porosity (includes substrate)		82.91	82.32	80.43
14. Effective substrate thickness		0.0024	0.0024	0.0024
15. Effective Porosity (excludes Substrate)		90.00	89.32	88.31
16. Volume of voids, cc		411.30	414.42	379.73
17. Cadmium AM/cc voids		0.019	0.019	0.021
18. Total AM/cc voids		0.034	0.034	0.036
19. % $Ni(OH)_2$ in Active Material		4.03	3.97	4.74
20. Others				

*This cell was kept with terminals facing down from 6/6/79 to 11/20/83.

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*AM stands for active material

TABLE 17

GE 12AH SN018

NEGATIVE PLATES (Uncycled, face up*)

Plate Composition (by wt):		Plate # 3	Plate #9	Plate #
1. $Cd(OH)_2$		7.59	7.54	
2. Cadmium metal		0.07	0.20	
3. $Ni(OH)_2$		0.55	0.60	
4. Ni in plaque		4.43	4.30	
5. Substrate		2.84	2.88	
6. Nickel Tab		0.12	0.12	
7. Total Wt		15.60	15.64	
8. Actual wt		16.75	16.98	
9. % Deviation		6.86	7.8	
10. Dimensions:	Length in cm	7.62	7.62	
	Width in cm	6.95	6.95	
	Thickness cm	0.084	0.086	
11. Solid volume, cc		4.44	4.60	
12. Nickel, g/cc		0.99	0.94	
13. % Porosity (includes substrate)		81.65	82.46	
14. Effective substrate thickness		0.0024	0.0024	
15. Effective Porosity (excludes Substrate)		88.87	89.44	
16. Volume of voids, cc		394.58	411.42	
17. Cadmium AM/cc voids		.019	.019	
18. Total AM/cc voids		0.035	0.034	
19. % $Ni(OH)_2$ in Active Material		3.9	4.2	
20. Others				

* This cell was kept with terminals facing up from 6/6/79 to 11/20/84.

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*AM stands for active material

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TABLE 18
GE 12AH SN 023
(Uncycled, face down*)

POSITIVE PLATES

Plate Composition (By wt):	Plate # 2	Plate # 8	Plate # 12
1. NiOOH – charged	0.38	0.00	0.00
2. $Ni(OH)_2$ – discharged	7.99	7.40	8.73
3. $Co(OH)_2$	0.28	0.27	0.29
4. $Cd(OH)_2$	0.18	0.17	0.19
5. Ni in plaque	1.79	2.01	1.72
6. Substrate	2.79	2.83	2.97
7. Nickel Tab	0.12	0.12	0.12
8. Total wt	13.53	12.79	14.02
9. Actual wt	13.81	13.58	13.82
10. % Deviation	2.89	6.41	0.50
11. Dimensions: Length in in.	7.62	7.62	7.62
Width in in.	6.95	6.95	6.95
Thickness in in.	0.0795	0.0782	0.0784
12. Solid volume, cc	4.21	4.14	4.15
13. Nickel g/cc	0.43	0.49	0.41
14. % Porosity (includes substrate)	87.77	86.86	87.30
15. Effective Substrate thickness	0.0024	0.0024	0.0024
16. Effective porosity (Excludes substrate)	95.17	94.49	95.40
17. Volume of Voids, cc	400.66	391.19	395.91
18. Nickel AM/cc voids	0.021	0.019	0.022
19. Total AM/cc voids	0.027	0.027	0.027
20. % $Co(OH)_2$ in Active Material	2.54	2.51	2.68
21. % $Cd(OH)_2$ in Active Material	1.63	1.58	1.75
22. Others			

* This cell was kept with terminals facing down from 6/6/79 to 11/20/83.

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TABLE 19
GE 12AH

S/N01 Group 5 Cell A

NEGATIVE PLATES

Plate Composition (by wt):		100% Charged Plate #	100% discharged Plate #	Plate #
1. $Cd(OH)_2$		2.30	5.81	
2. Cadmium metal		4.13	0.85	
3. $Ni(OH)_2$		0.69	0.03	
4. Ni in plaque		4.20	4.30	
5. Substrate		2.70	2.57	
6. Nickel Tab		0.06	0.06	
7. Total Wt		14.08	14.01	
8. Actual wt		15.23	15.23	
9. % Deviation		7.51	8.01	
10. Dimensions:	Length in cm	7.62	7.62	
	Width in cm	~~6.95~~	~~6.95~~	
	Thickness cm	0.08	0.08	
11. Solid volume, cc		4.24	4.24	
12. Nickel, g/cc		0.99	1.02	
13. % Porosity (includes substrate)		81.71	81.63	
14. Effective substrate thickness		0.0024	0.0024	
15. Effective Porosity (excludes Substrate)		88.88	88.53	
16. Volume of voids, cc		376.85	375.37	
17. Cadmium AM/cc voids		0.017	0.017	
18. Total AM/cc voids		0.033	0.034	
19. % $Ni(OH)_2$ in Active Material		5.50	2.84	
20. Others				

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*AM stands for active material

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