NASA CR-72719
TIS REPORT NO. GE-SSO-70SD249

FINAL REPORT

TESTING OF SILVER CADMIUM CELLS

by

M.D. Read
GENERAL ELECTRIC COMPANY
SPACE SYSTEMS ORGANIZATION
Valley Forge Space Center
Philadelphia, Pa. 19101

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

May 1, 1970

Contract NAS 3-13223

Lewis Research Center
Cleveland, Ohio
William J. Nagle, Project Manager
Direct Energy Conversion Section

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Requests for copies of this report should be referred to

National Aeroanutics and Space Administration
Scientific and Technical Information Facility
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FOREWORD

The work described here was done at the Valley Forge Space Center, General Electric Company, under NASA Contract NAS 3-13223 with Mr. William J. Nagel, Direct Energy Conversion Section, NASA Lewis Research Center, as Project Manager.

Mr. H. Zettick of the General Electric Company was responsible for building the test equipment and conducting the tests.

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ABSTRACT

A test program was carried out to determine the life cycling capability of silver cadmium cells constructed with a new type of inorganic separator.

Cells were cycled in packs of 5 at ambient temperatures of 100°C (373°K) and 25°C (298°K) on stand and on 24 hour, 8 hour, and 1½ hour cycle test at various depths of discharge. Testing was continued until all cells failed and each cell was disassembled for failure analysis. The analyses revealed that the most probable cause of failure for these cells was silver migration and separator permeability.

SUMMARY

A test program was carried out to determine the life cycle capability of secondary silver cadmium cells constructed with a new type of inorganic separator material.

The testing included conditioning followed by charge-discharge cycling of one group of new cells, and open circuited stand or cycling of a second group of cells previously on test. Cells were cycled in packs of 5 at ambient temperatures of 100°C. (373°K.) and 25°C.(298°K.) at depths of discharge of 20%, 40%, and 75% and cycle periods of 1 1/2, 8 and 24 hours respectively. Testing was continued until all cells in the pack had failed, where failure is defined as inability to deliver a minimum of 0.6 volts at the end of a discharge cycle. Each failed cell was disassembled and subjected to a failure analysis.

The cells cycling at 100°C.(373K.) had a maximum life of 20 days, while the cells cycling at 25°C.(298°K.) had a maximum life of 200 days. Other factors which affected the cycle life of the cells included electrolyte concentration (45% KOH gave longer life than 40%, or 30% KOH) and cycle period (24 hour cycle packs had the longest life). The new cells, although they had a greater capacity, in general tended to have a poorer cycle life than the old cells when cycling from the previous test program was included.

The failure analysis, which consisted of physical measurements and visual inspection, revealed that the most probable cause of failure of all cells was silver migration and inorganic separator permeability.

INTRODUCTION

The silver cadmium secondary cell is generally life limited by the deterioration of the conventional separators used to date, caused by the concurrent attack of strong alkali electrolyte and soluble silver oxides. It was decided to assemble and test cells manufactured with a non-oxidizable inorganic separator to determine if this would alleviate the problem.

A previous test program to investigate assembly and preliminary testing of this type of cell was carried out under Contract NAS 3-10925 for NASA/Lewis. A complete report of this work is contained in MacDonnel Douglas, Report No. NASA CR-72587.

Forty-six cells remaining from this test program were among the seventy-six cells received for testing by the General Electric Company. A summary of their test history is contained in Table I. At the conclusion of the previous test, cells were allowed to stand open circuited for 5 hours following a charge period, and then given a capacity discharge. The second column refers to the OCV at 5 hours, and the third column the capacity on that discharge. The rest of the table is self explanatory.

The remaining 30 cells submitted for testing to GE are referred to as new cells and were fabricated by MacDonnell Douglas under the

TABLE I

OLD SILVER CADMIUM CELLS

CELL NO.	OCV 5 HR STAND	CAPACITY A.H.	CYCLE HRS.	TEMP °C	DOD %	PREVIOUS CYCLES
(30% KOH)						
CL34-1	1.38	3.7	24	25	75	214
CL34-2	1.38	2.7	24	25	75	214
(40% KOH)						
CL38-2	1.42	4.8	8	25	75	428
CL38-4	1.39	4.9	8	25	75	428
CL38-5	1.42	4.9	8	25	75	428
CL40-1	1.38	4.1	1.5	25	40	2098
CL40-2	1.38	3.7	1.5	25	40	2098
CL40-3	1.38	4.7	1.5	25	40	2098
CL40-4	1.38	4.7	1.5	25	40	1827
CL40-5	1.39	3.7	1.5	25	40	2098
CL42-1	1.38	3.6	1.5	25	20	2098
CL42-2	1.38	3.8	1.5	25	20	2098
CL42-3	1.38	3.0	1.5	25	20	2098
CL42-4	1.38	2.7	1.5	25	20	1938
CL42-5	1.39	2.7	1.5	25	20	2098
CL44-1	1.38	3.5	1.5	25	40	2098
CL44-2	1.35	3.7	1.5	25	40	2050
CL44-3	1.37	3.6	1.5	25	40	2098
CL44-4	1.35	1.7	1.5	25	40	2098
CL44-5	1.26	3.6	1.5	25	40	2098
CL46-1	1.42	40	1.5	25	20	1760
CL46-2	1.37	3.6	1.5	25	20	2016
CL46-3	1.38	2.8	1.5	25	20	1100
CL46-4	1.36	3.2	1.5	25	20	2016
CL46-5	1.38	3.1	1.5	25	20	2016
(45% KOH)						
CL48-1	1.41	4.9	1.5	25	40	3095
CL48-2	1.38	5.1	1.5	25	40	3095
CL48-3	1.39	5.1	1.5	25	40	3095
CL48-4	1.41	5.1	1.5	25	40	3095
CL48-5	1.41	5.1	1.5	25	40	3095

TABLE I (continued)

OLD SILVER CADMIUM CELLS

CELL NO.	ORIGINAL CAP. A.H.	DAYS ON STAND @ 25°C	FINAL OCV	RESIDUAL CAP. A.H.	CAP. LOSS, %
(30% KOH)					
CL30-1	3.4	71	1.39	2.8	18
CL30-2	3.6	71	1.38	3.2	11
CL30-3	3.6	71	1.36	2.6	28
CL30-4	3.3	71	1.15	2.4	27
CL30-5	3.5	73	1.11	2.2	37
CL30-6	3.4	71	1.11	2.0	41
CL30-7	3.4	71	1.38	2.6	34
CL30-8	3.5	60	1.11	1.9	46
CL30-9	3.2	60	1.11	1.8	44
CL30-10	3.4	71	1.11	1.5	56
(40% KOH)					
CL49-1	3.9	108	1.39	3.2	18
CL49-2	4.5	108	1.40	3.0	33
CL49-3	4.5	146	1.38	2.55	44
CL49-4	3.9	146	1.39	2.65	32
(45% KOH)					
CL49-5	4.6	160	1.35	2.60	43.5
CL49-6	4.5	160	1.34	2.65	41

previously mentioned contract, but not cycled. They were given five capacity discharges in order to form the plates and the results of cycles 1 and 5 are reported in Table II. The "new" cells differed from the "old" cells primarily in the negative plate construction, and the number of plates. Old cells contained 5 positive and 6 negatives, the negatives being cadmium impregnated sintered nickel plaques. New cells contained 4 positives and 5 negatives, the negative being cadmium oxide paste on an expanded silver mesh grid. The old cells contained about 12.5 grams of silver on the positive electrodes while the new cells contained about 21.2 grams.

The purpose of this test program was to determine the effect of various operating parameters on cell cycle life, such as cycle period, depth of discharge, and temperature; and the effect of various construction variables on cycle life, such as electrolyte concentration, plate construction, and especially the effectiveness of the inorganic separator. It was desired to test those cells to destruction which had survived the previous test program, as well as the new cells, and to test to failure all cells in a pack so that a better statistical analysis could be performed on the results of the life tests.

The test program followed the task format noted in the statement of work, Exhibit A of NASA/Lewis Contract No. NAS 3-13223.

TABLE II

OUTPUTS OF NEW SILVER-CADMIUM CELLS (40% KOH)
(Discharge At 1 A to 0.6 V)

CELL NO. Charge at 0.3 A to	CYCLE 1 1.70 V	CYCLE 5 1.80 V or 7 Ah input
1	5.50 Ah	6.90 Ah
2	5.22 Ah	7.00 Ah
3	5.37 Ah	6.90 Ah
4	5.15 Ah	6.90 Ah
5	5.75 Ah	6.90 Ah
6	5.29 Ah	6.80 Ah
7	5.52 Ah	6.95 Ah
8	5.52 Ah	6.95 Ah
9	5.19 Ah	6.80 Ah
10	5.75 Ah	6.90 Ah
11	5.75 Ah	6.90 Ah
12	5.65 Ah	6.90 Ah
13	5.52 Ah	7.00 Ah
14	5.74 Ah	6.95 Ah
15	5.62 Ah	6.90 Ah
16	5.75 Ah	6.85 Ah
17	5.75 Ah	6.95 Ah
18	5.82 Ah	7.00 Ah
19	5.90 Ah	6.95 Ah
20	5.85 Ah	7.05 Ah
21	5.70 Ah	7.00 Ah
22	5.60 Ah	7.00 Ah
23	5.93 Ah	7.00 Ah
24	5.80 Ah	7.00 Ah
25	5.60 Ah	6.95 Ah
26	5.80 Ah	7.05 Ah
27	5.25 Ah	6.75 Ah
28	5.60 Ah	6.85 Ah
29	5.68 Ah	6.90 Ah
30	5.65 Ah	6.85 Ah
AVERAGE	5.60 Ah	6.92 Ah

DESCRIPTION OF TEST CELLS

The seventy-six silver cadmium cells submitted for testing may be divided into two groups. Forty-six cells, surviving from a previous test program are referred to as "old" cells and 30 cells previously untested are referred to as "new" cells. Construction details of these two groups of cells are contained in Table III.

The cells were unpacked, physically inspected, and weighed to the nearest 0.1 gram. This information was useful for comparative purposes during the failure analysis performed at the end of the test.

The cells were assembled in Polysulphone plastic cases and contained a 40PSIG pressure relief valve as well as nut and bolt type negative and positive terminals.

The following cells showed signs of carbonate formation at the terminals indicating electrolyte leakage:

New Cells: #20 and #27

Old Cells: CL30 - 1/3/4/6/7/8/9/10, CL42 - 1

In additon, new cell #26 had a crack in the case.

TABLE III

CELL CHARACTERISTICS

	OLD CELLS	NEW CELLS
Postive Plates		
No.	5	4
Dimension	1.6" x 1.6" x .013"	1.75" x 1.6" x .024"
Silver	2.5 gm, ea.	5.3 gm, ea.
Interseparator	1 layer Pellon 2506K	1 layer Pellon 2506K
Negative Plates		
No.	6	5
Dimension	1.93" x 1.95" x .022"	1.90" x 2.10" x .070"
Type	Cd Impreg. Sintered Nickel Plaque	94% Cd O on Silver grid
Interseparator	2 layers Pellon 2506K	1 layer KT paper
Separator		
Type	Inorganic Rigid 3420-09	Inorganic Rigid 3420-09
Thickness	.025 in.	.025 in.
Electrolyte	30%, 40% or 45% KOH	40% KOH, 26.5 cc
Case and Cover	Polysolfone P-1700	Polysolfone P-1700
Cell Dimension	3"h x 2.28"w x 1.04"t (7.6cm. x 5.8cm. x 2.6cm)	3"h x 2.28"w x 1.04"t (7.6cm. x 5.8cm. x 2.6cm)
Weight (approx., filled)	245 gm.	260 gm.
Nominal Capacity	3.5 AH	5.0 AH

TEST APPARATUS

The test apparatus consisted of two major assemblies - the data acquisition system and the test panels.

The data acquisition system, Hewlett-Packard Model 2101C, was utilized to automatically measure and record data from the test program. The system included a digital clock which could be programmed to turn on the data system at prescribed intervals; a cross bar scanner, capable of accepting 200 3-wire data inputs and scanning through a given range on command from the clock; a high precision integrating digital voltmeter; and a high speed printer. In addition to printing the time with each data print-out the system was modified to include a date identification.

Component Model numbers are noted below:

H.P. 2911A/B, Guarded Cross Bar Scanner

H.P. 2401C-M31, Digital Voltmeter

H.P. H006-5050A, Digital Recorder

H.P. 2411A, Guarded Data Amplifier

H.P. 2509A-M1, Digital Clock

Each of the test panels, one for each cell pack, contained two major sub-assemblies -- the cycling control and the charge/discharge control. Tests were timed to reach critical periods, such as the end of the discharge and the end of charge periods, in coordination with data scanning as determined by the data acquisition system operating on a one hour schedule. Time and coordination of event was obtained by integrating the cycle timing with the digital clock. Readings could then be taken automatically within a few seconds of the end of charge or discharge on every cycle. The data was transcribed, by hand, from the tape to a data book for permanent record. The charge/discharge control panels operated independently for each test from two central power supplies. Each panel was designed to allow the pack to charge at the specified maximum current level until the perscribed voltage level was reached (equivalent to 1.60 volts per cell at 25°C.(298°K.) and 1.52 volts per cell at 100°C.(373°K.)). At this point a cross-over occured and the voltage limit mode was controlling with the charge current tapering as required. Because of the desire to test each cell to failure and the inability to regulate at less than 7 volts it was necessary to modify the circuit in order to maintain a pack voltage charge limit when failed cells were removed from test. This was accomplished by placing two 20 amp IN250B silicon diodes in series with the pack for every cell removed. This provided a voltage of about 1.42 volts, relatively unaffected by the changes in charge current, and thereby allowed the voltage limit to function down to the last cell in the pack. A single diode, placed in parallel with, but in reverse direction to, the other diodes allowed the discharge portion of the cycle to be carried out. The cells were discharged at the specified constant current rate with the use of a power supply.

Figure 1 is a photograph showing the data acquisition systems and test rack.

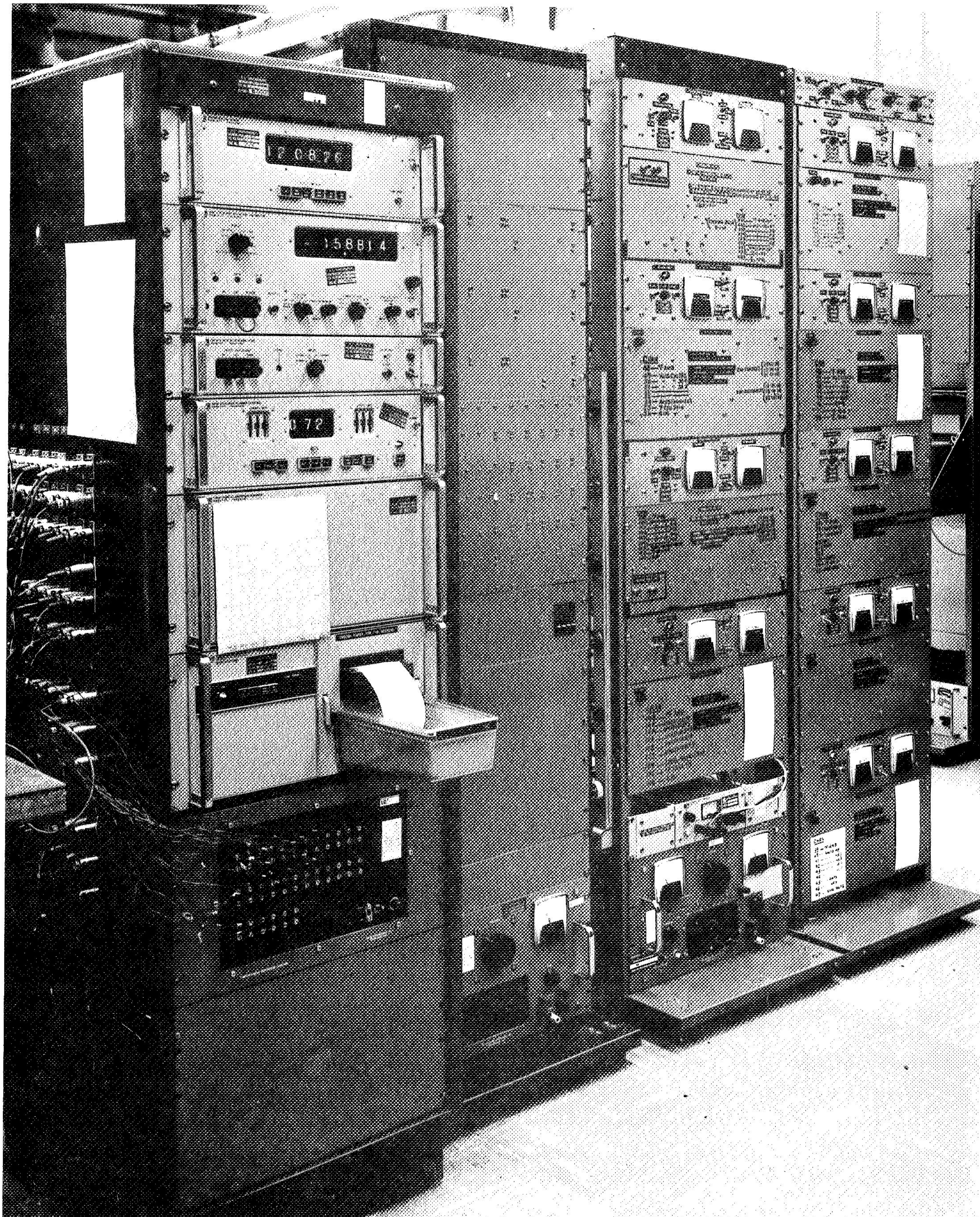


FIGURE 1

TEST PROCEDURE

All cells were inspected and weighed when received. Following the incoming inspection the cells were assembled into packs and placed on test. Figure 2 is a photograph showing some of the cell packs on test. Testing was divided into four tasks.

Task 1 - Testing of New Cells

Task 1 was concerned with the testing of 30 new and uncycled cells. The cells were assembled into 5 cell packs, with thermocouples in each pack. The cells were then given two conditioning cycles, consisting of charging at a rate of 0.35 amp to a pack voltage limit of 8.00 volts (1.60 volts per cell) for 23 hours, followed by discharging at a 2.0 ampere rate to 0.6 volts per cell. The cells were then charged, as noted above and put on automatic charge/discharge cycling as shown in Table IV. When cell voltage at the end of a discharge period fell below 0.6 volts, the cell was considered as having failed and it was removed from the test. Diodes were inserted in the circuit in place of the failed cell and voltages were readjusted to the required levels.

A failure analysis was performed on every cell consisting of an external physical and visual inspection and then a complete disassembly and visual inspection of all cell components. Results of all failure analyses were recorded.

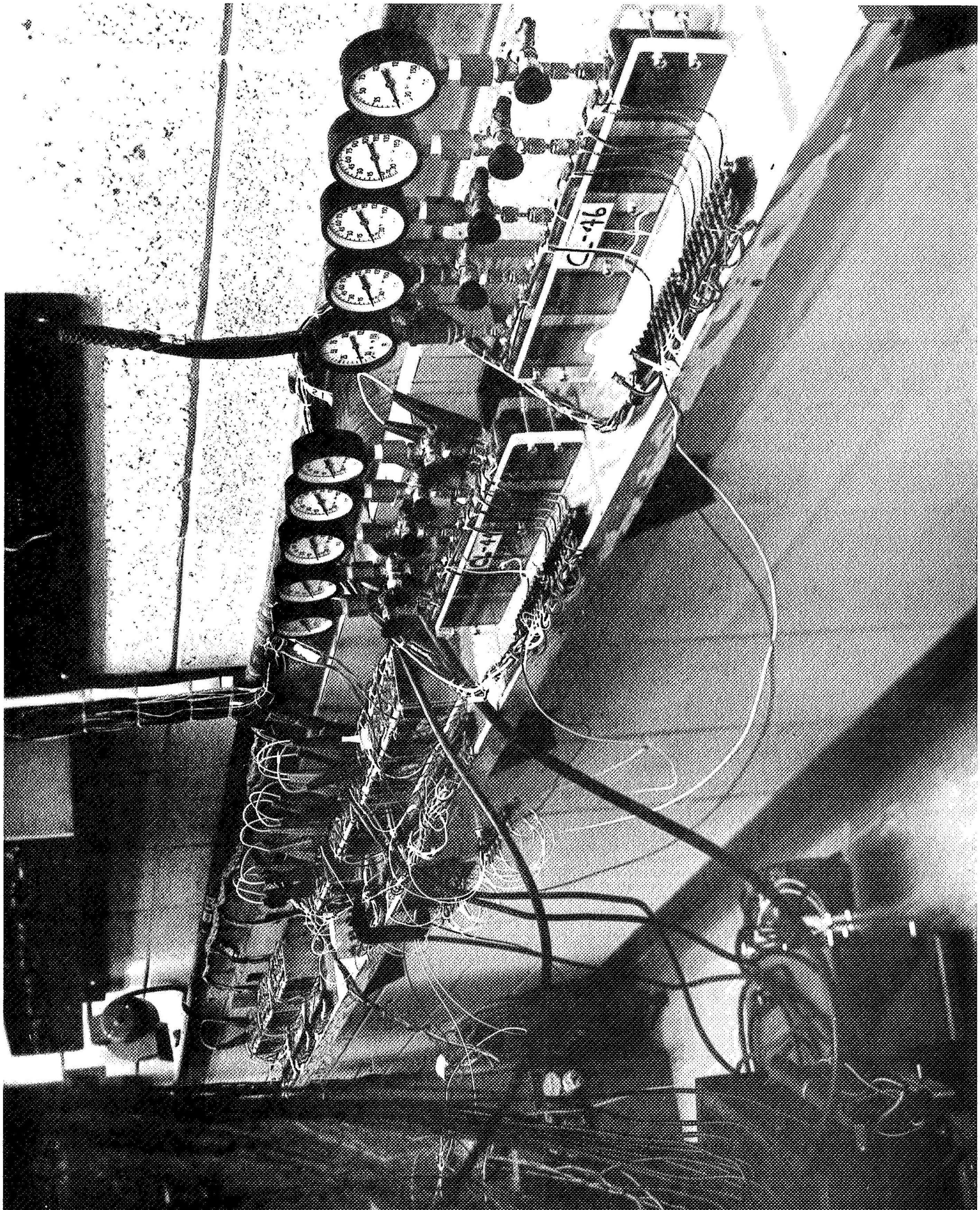


FIGURE 2

TABLE IV

CELL CYCLING REGIME

PACK NO.	TEMP.	CHARGE			DISCHARGE	
	°C	I, ma.	t, hrs.	V, max. (per cell)	I, ma.	t, hrs.
NEW						
1-5	25	200	22.8	1.60	3125	1.2
6-10	100	200	22.8	1.52	3125	1.2
11-16	25	315	7	1.60	2000	1.0
17-20	100	315	7	1.52	2000	1.0
21-25	25	1100	1	1.60	2000	0.5
26-30	100	1100	1	1.52	2000	0.5
OLD						
CL-34	25	150	22.8	1.60	2200	1.2
CL-38	25	450	7	1.60	2600	1.0
CL-40	25	1600	1	1.60	2800	0.5
CL-42	25	800	1	1.60	1400	0.5
CL-44	25	1600	1	1.60	2800	0.5
CL-46	25	800	1	1.60	1400	0.5
CL-48	25	1600	1	1.60	2800	0.5

Data was recorded automatically 24 hours a day at specified intervals by the data acquisition system and transcribed manually into books for a permanent record.

Task 2 - Conditioning Old Cells

Task 2 was concerned with conditioning 46 cells which had previously been on test. The cells were assembled into packs for testing, with thermocouples, each pack containing 5 cells except for CL-30 (10 cells), CL-34 (2 cells), CL-38 (3 cells), and CL-49 (6 cells). The conditioning consited of two cycles, charging at 0.25 amperes to a voltage limit equivalent to 1.60 volts per cell for 23 hours, followed by discharging at a 1.0 ampere rate to 0.6 volts per cell.

Task 3 - Wet Stand Test

Task 3 was concerned with wet stand tests on 16 cells, packs CL-30 and CL-49. The cells were given an initial charge at 0.25 amperes for 23 hours, with a voltage limit equivalent to 1.60 volts per cell and placed on open circuited stand at room ambient. It was planned to discharge two different cells from each pack at two month intervals and compare the capacity with that obtained from the conditioning cycles.

Task 4 - Cycle Testing of Old Cells

Task 4 was concerned with cycle testing of 7 packs of old cells (30 cells) at room ambient conditions. Prior to the start of cycling the cells were charged at a rate of 0.25 amperes for 23 hours, with a voltage limit equivalent to 1.60 volts per cell. The cells were then put on automatic cycling as indicated in Table IV. Data was recorded automatically as described in Task 2, and transcribed manually into books. As cells failed they were removed from the pack and a failure analysis was performed as noted in Task 1.

A sample of gas was to be withdrawn from the cells of packs CL-44 and CL-46 each month and analyzed for hydrgen, oxygen, and nitrogen using a gas chromatograph.

TEST RESULTS

Test results will be reported on a Task basis as defined in the TEST PROCEDURE section.

Task 1 - Testing of 30 New Cells

Each of the 6 new cell packs received two conditioning cycles consisting of a 23 hour charge, discharging at 2.0 amps to an end voltage of 3.0 volts (0.6 volts/cell, average). The capacities obtained on each cycle are noted in Table V. Maximum allowable variation between capacities on 1st and 2nd discharges was 0.8 ampere hours. The cells were then recharged and placed on automatic cycle according to the schedule of Table IV. The cells on the 1 1/2 hours cycle discharged to a 20% depth of discharge, the cells on the 8 hour cycle discharged to a 40% D.O.D. and the cells on a 24 hour cycle discharged to a 75% D.O.D. Average end of discharge voltage for cells during cycling are shown in Figure 3 for 25°C. (298°K.) and Figure 4 for 100°C. (373°K.). Also shown are the points at which cell failures occurred.

One of the problems contributing to failure of batteries during cycle tests is cell to cell voltage divergence during charge, especially when a voltage limit charge mode is used. When one cell's voltage begins to increase the charge current will begin to decrease before other cells have reached a full charge voltage, because of the need to maintain the specified average or pack

TABLE V

CAPACITY OF NEW CELLS ON CONDITIONING CYCLES

PACK NO.	CYCLE NO. 1 AMP. HRS.	CYCLE NO. 2 AMP. HRS.
1-5	6.69	6.60
6-10	6.27	6.50
11-15	6.59	7.40*
16-20	6.15	6.66
21-25	6.50	6.92
25-30	6.50	6.52

* Voltage limit failed on charge allowing pack voltage to increase to 1.78 volts/cell average.

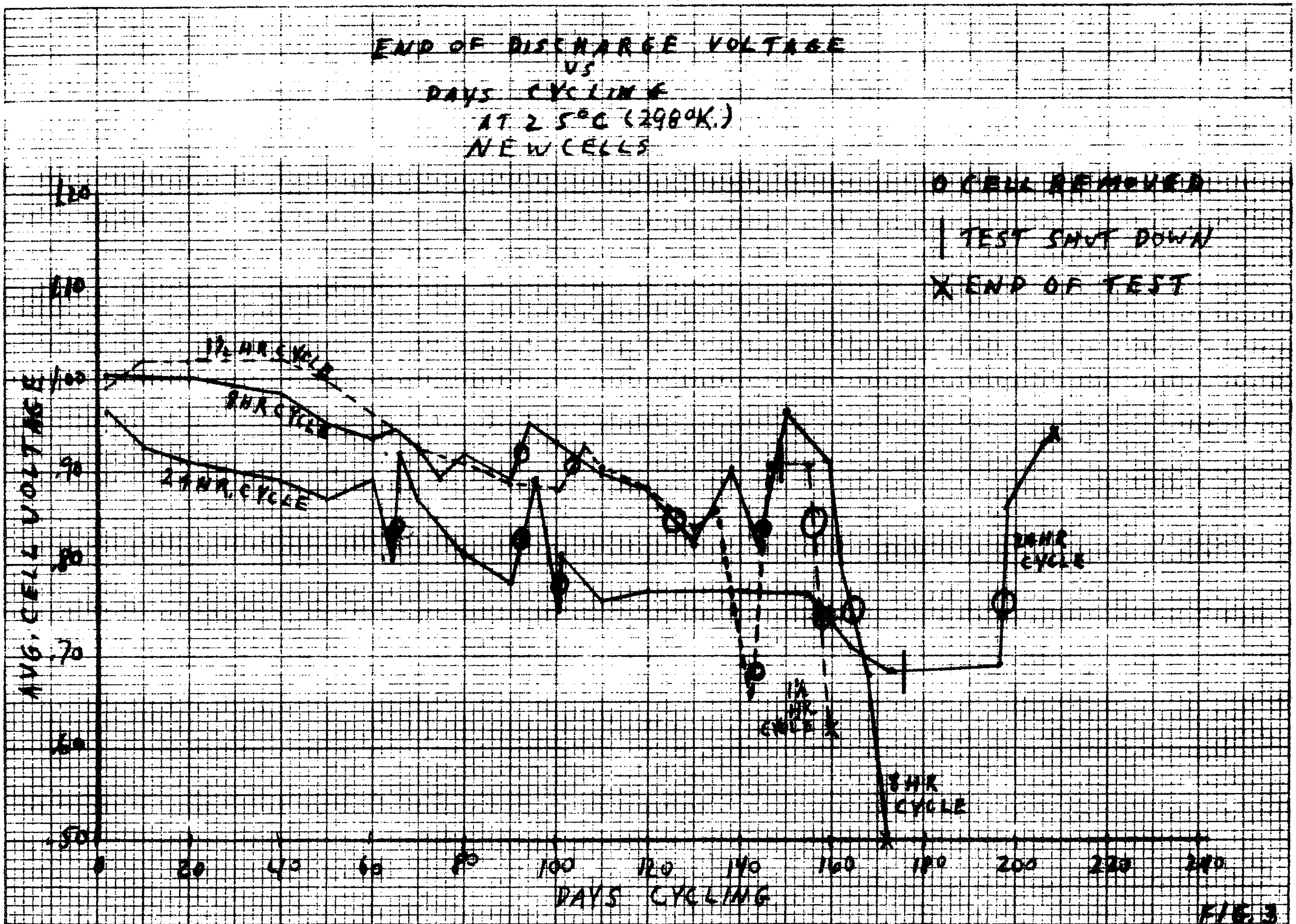

END OF DISCHARGE VOLTAGE
VS
DAYS CYCLING
AT 25°C (298°K.)
NEW CELLS
O CELL REMOVED
| TEST SHUT DOWN
X END OF TEST
1½ HR CYCLE
8 HR CYCLE
24 HR CYCLE
1½ HR CYCLE
8 HR CYCLE
AVG. CELL VOLTAGE
DAYS CYCLING

FIG. 3

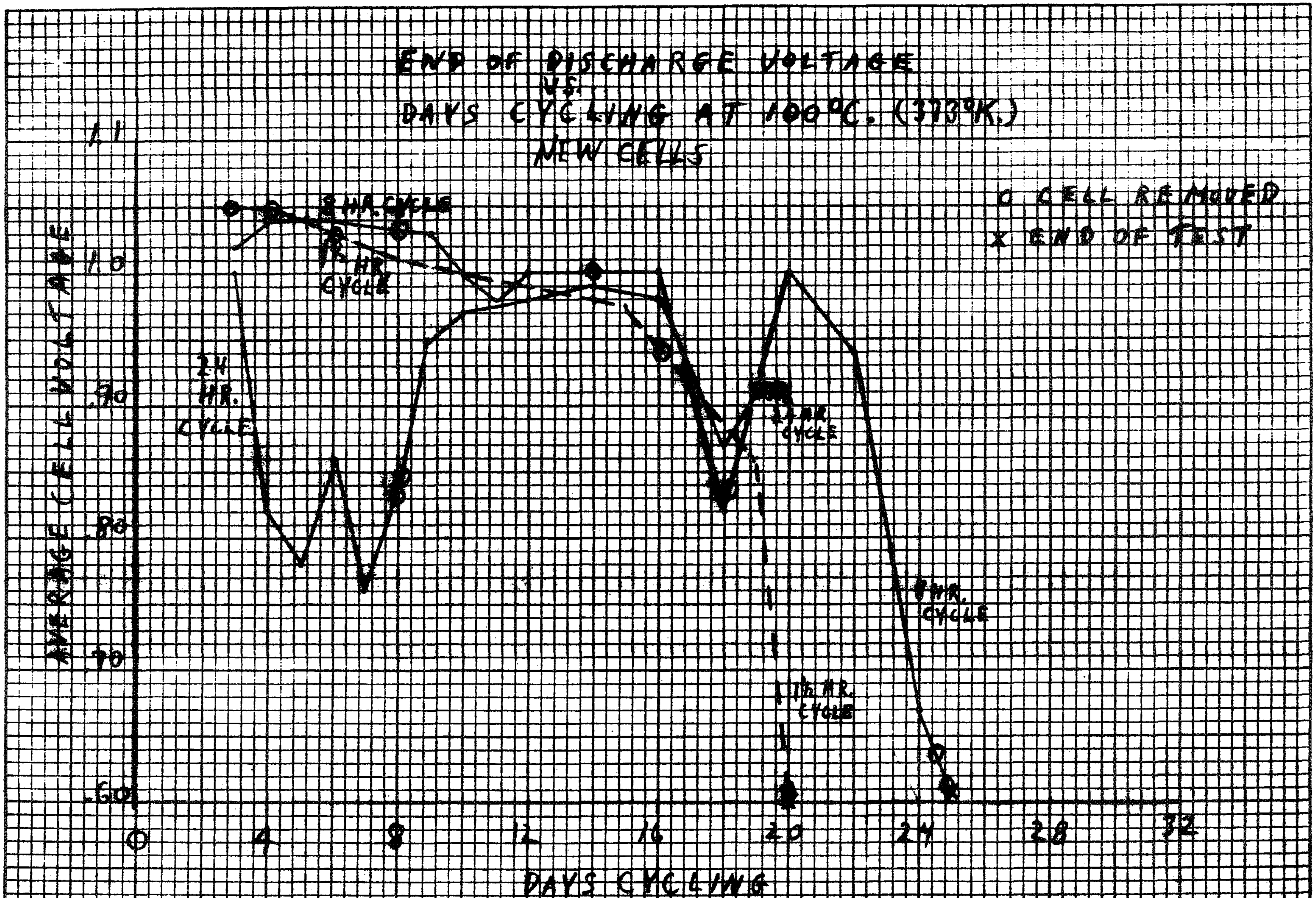

END OF DISCHARGE VOLTAGE
VS.
DAYS CYCLING AT 100°C. (373°K.)
NEW CELLS
O CELL REMOVED
X END OF TEST
8 HR. CYCLE
1½ HR. CYCLE
24 HR. CYCLE
1½ HR. CYCLE
8 HR. CYCLE
1½ HR. CYCLE
AVERAGE CELL VOLTAGE
1.1
1.0
.90
.80
.70
.60
0
4
8
12
16
20
24
28
32
DAYS CYCLING

FIG. 4

voltage. An illustration of this condition for an extreme case is shown in Figure 5, for the pack operating at 100°C. on a 90 minute cycle. Maximum individual cell voltage at times was above 2.2 volts while minimum voltage on other cells in the pack was below 1.2 volts. Consequently the cells with the higher voltage gassed excessively and the cells exhibiting low charge voltages generally failed early because of poor charge acceptance.

All packs were tested until every cell in the pack had failed, cells being removed from test when the end of discharge voltage dropped below the specified level of 0.6 volts. Table VI shows failure data including the end of charge and end of discharge voltage on the last cycle, as well as the number of cycles completed.

A failure analysis was performed on each cell as failure occured (except for Cell #4 which was returned to NASA/Lewis) and results were reported on the form shown in Figures 6A and 6B.

The physical external analysis showed that some leakage of electrolyte had occured with all cells at the terminals or pressure relief valve, but that leakage was much more extensive at 100°C (373°K.) than at 25°C. (298°K.). The weight of electrolyte lost was usually less than 1 gram for the cells operating at 25°C. (298°K.), but was from 2 to 10 grams for cells cycling at 100°C. (373°K.).

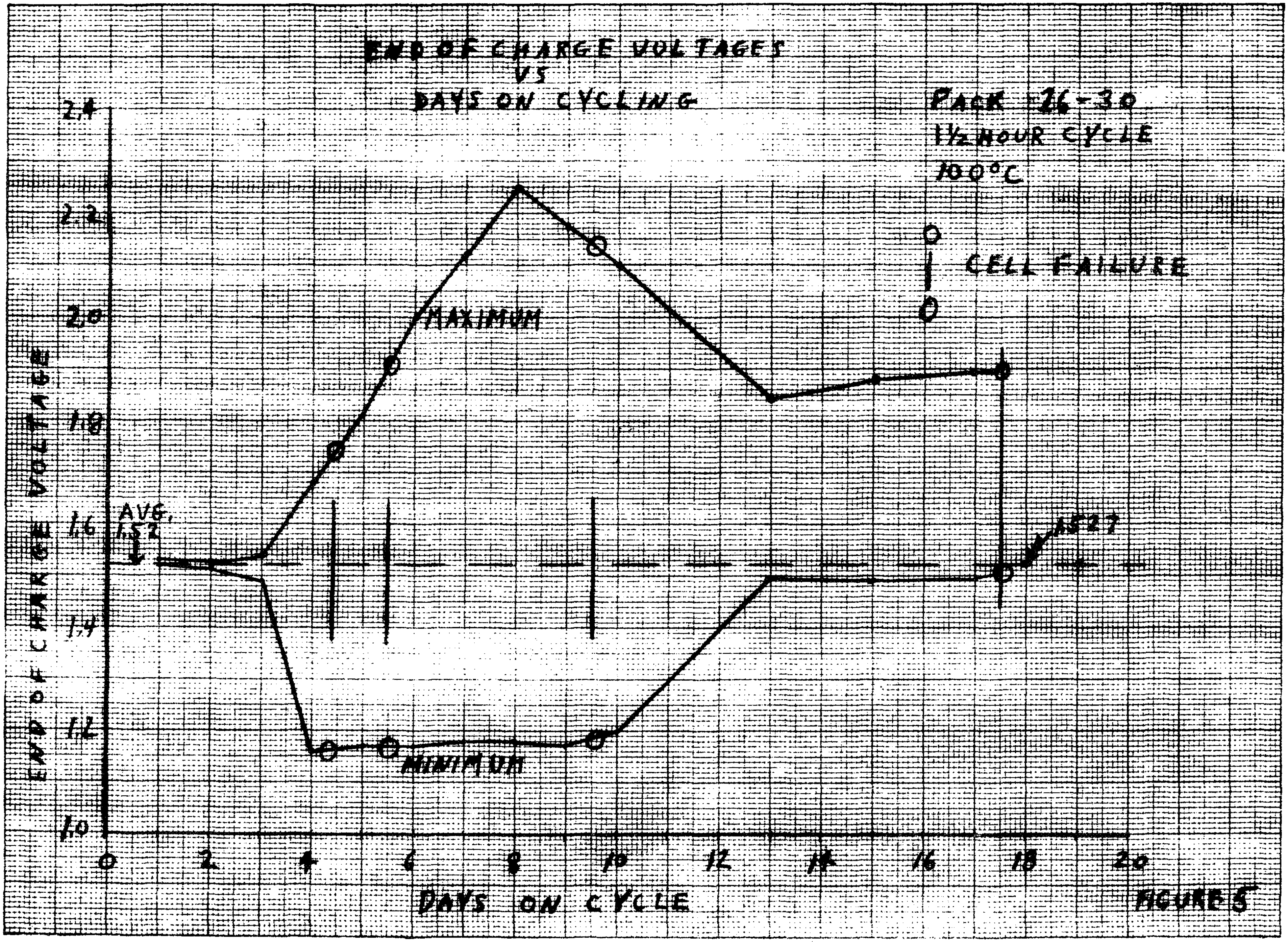

END OF CHARGE VOLTAGES
VS
DAYS ON CYCLING
PACK #26-30
1½ HOUR CYCLE
100°C
CELL FAILURE
MAXIMUM
MINIMUM
AVG. 1.52
1.527
END OF CHARGE VOLTAGE
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0
2
4
6
8
10
12
14
16
18
20
DAYS ON CYCLE

FIGURE 5

TABLE VI

NEW CELL FAILURES

CELL NO.	CYCLE PERIOD HRS.	TEMP. °C (°K)	END OF CHARGE VOLTAGE	END OF DISCHARGE VOLTAGE	CYCLES TO FAILURES
1	24	25	1.555	+.576	102
2		(298)	1.507	+.581	64
3			1.511	+.584	94
4			1.817	+.940	207 *
5			1.507	+.514	195
6	24	100	1.580	-.555	20
7		(373)	1.170	-1.84	8
8			1.485	-0.58	8
9			1.494	+0.307	20
10			1.495	-.036	20
11	8	25	1.199	-.186	381
12		(298)	1.203	+.424	495
13			1.272	+.476	425
14			1.198	-.760	488
15			1.499	+.581	272
16	8	100	1.539	+.478	68
17		(373)	1.430	-.162	41
18			1.175	+.457	49
19			1.565	+.549	70
20			1.145	-.130	25
21	1½	25	1.232	+.446	2048
22		(298)	2.162	+.301	2017
23			1.317	+.403	2106
24			1.336	+.633	2128
25			1.440	+.549	1609
26	1½	100	1.158	+.582	56
27		(373)	1.498	+.590	246
28			1.750	+.515	297
29			1.162	-.259	58
30			1.166	-.327	99

* Cell returned to NASA/Lewis for failure analysis

FAILURE ANALYSIS REPORT

SILVER CADMIUM TEST PROGRAM

NASA Contract No. NAS 3-13223

Date: Report No. 7K2 -

Cell Identification

Lot No.________ Cell No.________ G.E. Test No.______

Test Conditions

Cycle Period________hrs. Temp________°C

Charge_____hrs.,______amps. Discharge_____hrs.,______amps.

Failure Conditions

Cycles to failure_________________Date___________

Cause of failure_______________________

End of discharge voltage, last cycle______________

External Inspection

a. Leakage_____________
b. OCV 1 hr. after test___________
c. Initial weight_________________gms
   Final weight__________________gms
   Weight change_________________gms
d. Phenoplphthalein test____________
e. Case inspection___________________

Internal Inspection

a. Active material in case___________
b. Pack wetness: free KoH _____; moist______; dry_____
c. Migrated active material__________________
d. Terminals__________________
   Plate tabs_________________
e. No. of plates: positive____________; negatives_______.

FIGURE 6B

f-g. Separator Inspection

Plate No. (+)	(-)	Type	Condition
(from top, (+) terminal on left)			

h. Plate Inspection

Plate No. (+)	(-)	Condition
from top, (+) terminal on left)		

Remarks

signed ______________________

The failure analysis of the cells at 100°C. (373°K.) showed that the inorganic separator, while still intact had lost a considerable amount of strength and was quite brittle compared to new uncycled separators. Although no obvious internal shorts were discovered, a visual observation of the disassembled cells showed evidence of silver migration in the separator materials and sometimes on the negative plate itself. At the higher temperature, especially after several days of operation, it was difficult to find more than a trace of the organic interseparators. In many cases a considerable amount of active material migration was observed at both the positive and negative plate tabs, as well as build up of material at the terminals underneath the potting. This could very well have caused a shorting condition, resulting in low capacity during the discharge portion of cycling.

The cells tested at 25°C. (298°K.) did not show evidence of inorganic separator deterioration, but they show a considerable amount of silver migration to the separators. It appeared as though the same failure processes occured at the lower temperature as at the higher, but to a lesser extent.

A photograph of a disassembled cell, #20, is shown in Figure 7. At the top of the picture are the case and cover assembly, showing some of the active material removed from the positive terminal. The 5

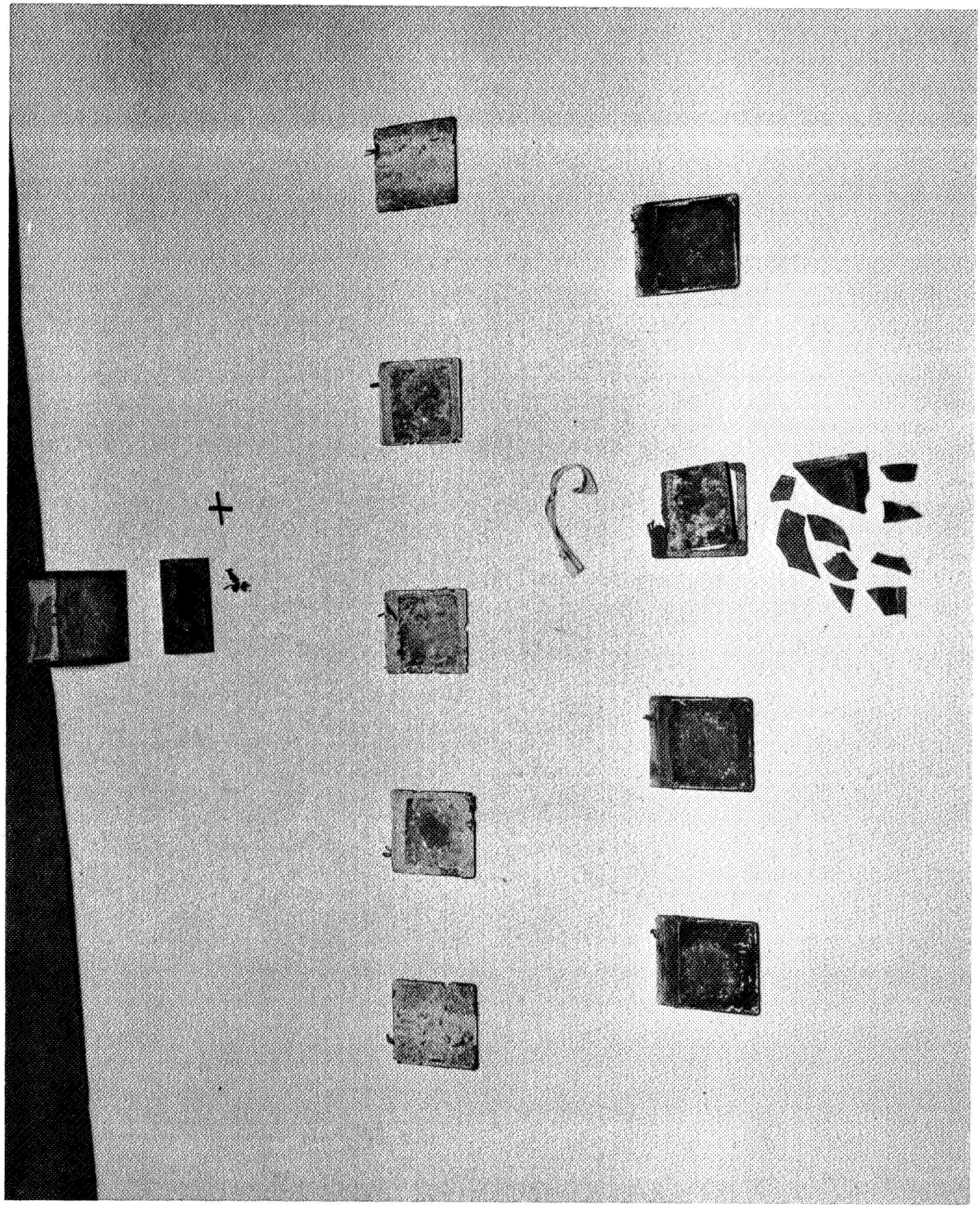


FIGURE 7

negative and 4 positive plates are shown next. The negative plates are covered by the fiberous interseparator, while the positive plate is encased in the inorganic separator. One inorganic separator was removed in pieces (bottom of picture) and the tape from the top of the plate is also shown.

Task 2 - Conditioning of 46 Old Cells

The cells previously on test were reconditioned, according to TEST PROCEDURES, Task 2, prior to being placed on cycle testing. Reconditioning consisted of two charge/discharge cycles carried out at room ambient. No more than 0.5 ampere hours difference was to be observed between the 1st and 2nd cycle capacities for the cells to be considered as satisfactorily reconditioned. The results of the reconditioning cycles are noted in Table VII. It may be noted from the above data that 3 cells, CL-30-8, CL-40-5 and CL-44-5, had very low capacities and were considered as having failed prior to the start of cycling.

Task 3 - Wet Stand Tests

Cells CL-30, 1 through 10 and CL-49, 1 through 6, were given a charge and placed on open circuited stand at room ambient. Voltages on each cell were checked daily and are noted in Table VIII. As may be seen from the above data none of the cells lasted longer than 7 days. Therefore the capacity discharges, planned at two month intervals, were not carried out.

TABLE VII

CONDITIONING OLD CELLS

PACK NO.	CELL NO.	CYCLE 1 End Charge Volt 23 hr. @ .25 amp.	CYCLE 1 Disch. Cap. AN @ 1.0 Amp.	CYCLE 2 End Charge Volt 23 hr. @ .25 amp.	CYCLE 2 Disch. Cap. AH @ 1.0 Amp.
CL-30	1	1.578	2.37	1.562	1.82
	2	1.622	2.70	1.553	1.59
	3	1.536	1.51	1.618	1.90
	4	1.538	1.88	1.584	2.15
	5	1.644	2.53	1.642	1.97
	6	1.589	2.27	1.606	1.90
	7	1.595	2.40 *	1.560	1.90
	8	.933	<.10	out	--
	9	1.577	2.27	1.548	1.64
	10	1.580	1.95	1.606	1.97
CL-49	1	1.524	1.51	1.614	2.92
	2	1.625	2.43	1.615	2.79
	3	1.674	2.81	1.618	3.05
	4	1.598	2.36	1.611	3.12
	5	1.627	2.53	1.563	2.77
	6	1.615	2.81	1.591	3.04
CL-34	1	1.617	3.63	1.632	3.43
	3	1.538	3.17	1.591	3.75
CL-38	2	1.629	4.22	1.636	3.85
	4	1.626	4.22	1.522	3.20
	5	1.587	3.90	1.615	3.73
CL-40	1	1.804	4.30	1.822	4.14
	2	1.516	1.94	1.564	3.28
	3	1.974	3.70	1.909	3.64
	4	1.524	1.90	1.200	1.56
	5	1.141	<.33	1.105	<.10
CL-42	1	1.775	3.66	1.835	3.69
	2	1.682	3.70	1.772	3.64
	3	1.651	3.34	1.722	3.25
	4	1.094	1.00	1.123	1.09
	5	1.676	3.02	1.564	2.82
CL-48	1	1.615	3.66	1.616	3.53
	2	1.590	3.68	1.555	3.82
	3	1.620	3.22	1.638	3.32
	4	1.576	3.39	1.528	3.46
	5	1.607	3.32	1.623	3.37
CL-44	1	1.162	.95	1.160	.67
	2	1.172	1.23	1.168	.70
	3	1.686	3.87	1.786	3.92
	4	1.683	4.30	1.780	4.05
	5	1.146	.19	1.130	< .10
CL-46	1	1.675	3.75	1.611	3.59
	2	1.573	1.50 *	1.579	3.59
	3	1.828	2.84	1.795	3.12
	4	1.167	1.50	1.121	1.03
	5	1.749	3.44	1.774	3.60

* Cell shorted out by mistake

TABLE VIII

STAND TEST CELL VOLTAGES

OCV

CELL NO.	1 DAY	2 DAYS	3 DAYS	4 DAYS	5 DAYS	6 DAYS	7 DAYS
CL-30-1	1.081	1.036	.016	.007			
CL-30-2	1.078	1.083	1.07	.038			
CL-30-3	1.082	1.071	.019	.008			
CL-30-4	1.075	.014	.006	.004			
CL-30-5	1.083	1.079	.095	.036			
CL-30-6	1.081	1.026	.018	.008			
CL-30-7	1.076	.016	.004	.002			
CL-30-8	--	--	--	--			
CL-30-9	.762	.011	.004	.003			
CL-30-10	1.086	.151	.017	.008			
CL-49-1	1.126	1.096	1.095	1.084	.020	.009	.004
CL-49-2	1.093	1.092	.079	.011	.004	.002	.001
CL-49-3	1.315	1.096	1.097	1.097	1.094	1.090	.078
CL-49-4	1.320	1.096	1.096	1.095	1.092	.069	.013
CL-49-5	1.088	0.154	.011	.004	.001	.008	.001
CL-49-6	1.349	1.229	1.094	1.093	1.089	1.081	.029

In order to eliminate the possibility that the cells had become discharged through the measuring circuitry, which was wired in permanently, cell # CL-30-4 was removed from the pack and retested. This cell was placed on the laboratory bench and given a standard charge of 23 hours at 0.25 amperes with a 1.60 volt limit. The open circuit voltage was then measured periodically, and the circuit was disconnected between readings. At one hour the OCV was 1.311 and after 27 hours the OCV was 0.096 volts, proving that the measurement circuitry was not the cause of decreased cell state of charge.

The cells from pack CL-30 were disassembled and a failure analysis performed on each. Cell No. 8 was found to have shorted at the top of the pack where negative material had migrated to the plate tab area. No other obvious signs of shorts were noted. It is assumed that the separators become conductive due to negative material migration, allowing the cells to self-discharge. Discoloration, indicating the presence of negative material, was observed on many separators.

Task 4 - Cycle Testing of Old Cells

Following reconditioning, the "old" cells not used for the stand tests were given a full charge and placed on automatic charge/discharge cycling, as noted in Table III. The cells on the 1 1/2 hour cycle discharged to a 20% or 40% depth of discharge, and the cells on the 8 hour and 24 hour cycles were discharged to a 75% D.O.D.. Cycle data on all "old" cells is shown in Table IX. The end of charge and end of discharge voltage are noted with the number of cycles completed. Also noted are the 8 cells returned to NASA Lewis for analysis. All other cells were disassembled and given a failure analysis as reported under TEST PROCEDURE, Task 1. Figure 8 shows the average end of discharge voltage for Pack No. CL-48.

The results of the failure analysis compare with the results obtained from the "new" cells cycling at 25°C.(298°K.). Weight losses were less than 1 gram in all cases and most cells showed some sign of electrolyte leakage either at the terminals or relief valve. Internal inspection showed the same degree of separator degradation and silver migration as was noted under Task 1 for cells cycling at 25°C.(298°K.). The inorganic separator appeared in good physical condition in all cases, but the organic separators were degraded in proportion to the time on test. Results were reported on the same form as reported under Task 1 (Figure 6A/B).

The gas analysis, proposed for the cells from packs Cl-44 and CL-46, was not performed since a measurable pressure build-up did not occur in any of the cells, and therefore it was not possible to withdraw a gas sample.

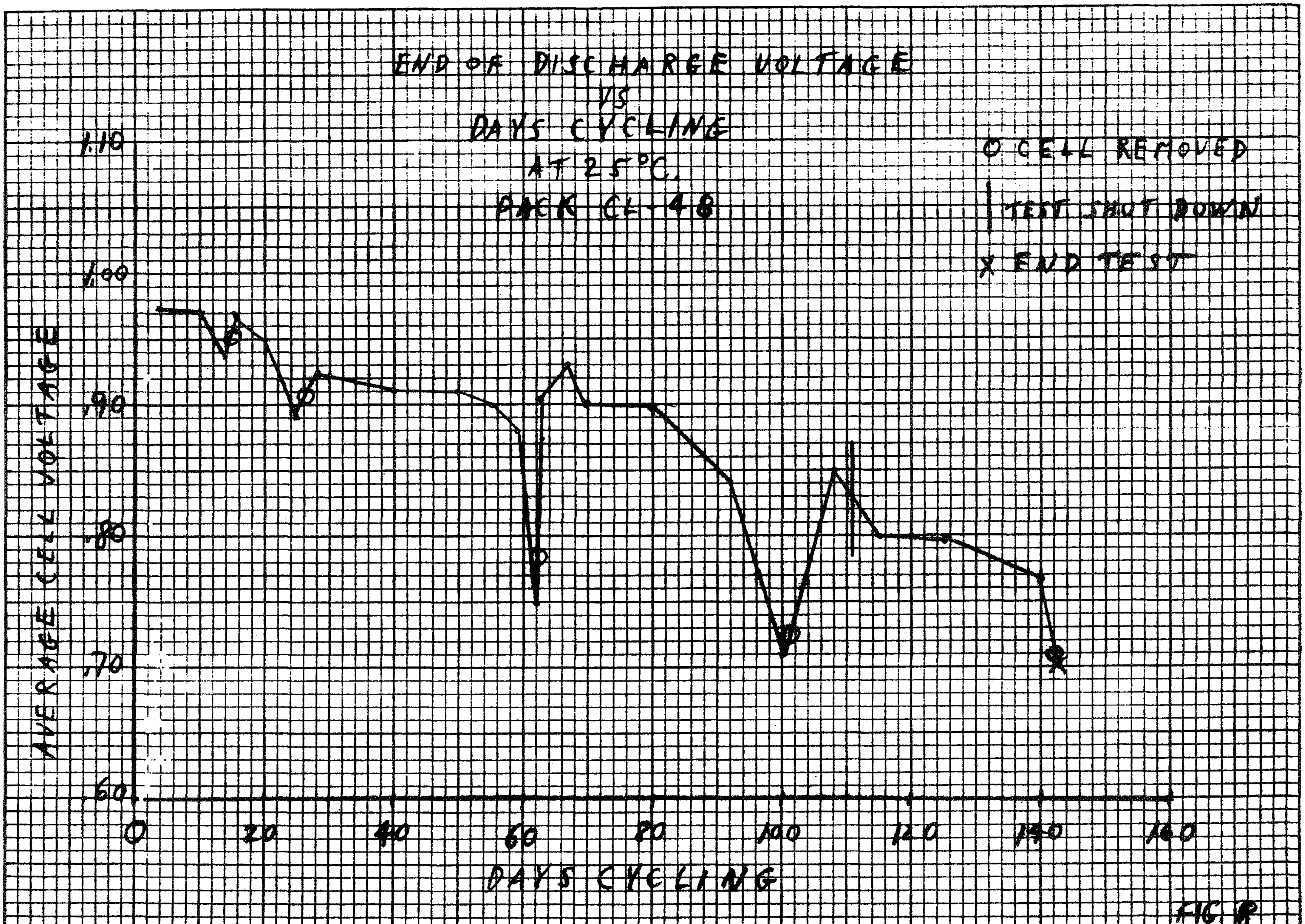
TABLE IX

OLD CELL CYCLE TEST FAILURES

TEMPERATURE 25°C. (298°K.)

CELL NO.	CYCLE PERIOD HRS.	END OF CHARGE VOLTS	END OF DISCHARGE VOLTS	CYCLES TO FAILURE	
CL-34-1	24	1.535	+.508	4	*
CL-34-2		1.552	+.497	35	*
CL-38-2	8	1.468	-.123	7	*
CL-38-4		1.453	+.416	9	*
CL-38-5		1.760	+.602	451	
CL-40-1	1½	1.517	+.583	103	*
CL-40-2		1.511	+.491	149	*
CL-40-3		1.531	+.454	990	
CL-40-4		1.202	-.284	4	*
CL-40-5		1.047	-.026	2	*
CL-42-1	1½	1.195	-.191	724	
CL-42-2		1.189	-.641	137	
CL-42-3		1.194	+.277	94	
CL-42-4		1.184	-.274	8	
CL-42-5		1.199	+.228	36	
CL-44-1	1½	1.095	-.227	3	
CL-44-2		1.518	+.554	67	
CL-44-3		1.520	+.363	225	
CL-44-4		1.367	+.516	349	
CL-44-5		1.130	-.637	2	
CL-46-1	1½	1.197	-.251	95	
CL-46-2		1.198	+.557	191	
CL-46-3		1.575	+.433	1233	
CL-46-4		1.195	+.186	11	
CL-46-5		1.193	+.584	199	
CL-48-1	1½	1.495	+.419	996	
CL-48-2		1.499	+.582	1617	
CL-48-3		1.491	-.762	417	
CL-48-4		1.605	+.704	2296	*
CL-48-5		1.266	-.056	233	

* Cells returned to NASA/Lewis



END OF DISCHARGE VOLTAGE
VS
DAYS CYCLING
AT 25°C.
PACK CL-48
O CELL REMOVED
| TEST SHUT DOWN
X END TEST
AVERAGE CELL VOLTAGE
1.10
1.00
.90
.80
.70
.60
0
20
40
60
80
100
120
140
160
DAYS CYCLING

FIG. [illegible]

SUMMARY OF RESULTS

All cells were tested to failure, as indicated by the inability of the cell to deliver in excess of 0.6 volts at the end of discharge. The exception to this was the last two cells remaining on the test program, "new" cell #4 and cell #CL-48-4. The testing was terminated while these cells still had end of discharge voltages in excess of 0.6 volts, since it was not believed that Continuing the testing beyond this point would add measurably to the value of test data.

A summary of the cycle life data is shown in Table X. The data is presented as related to test temperature, cycle period, depth of discharge, and electrolyte concentration. The number of cycles completed during previous testing and during tests at GE is shown for each cell as well as the total number of cycles completed, and pack average cycle life.

The 16 cells on wet stand showed very poor characteristics, no cell maintaining an open circuit voltage in excess of 0.1 volts after 7 days on stand at GE.

The results of the failure analysis showed that an average of less than 1 gm. of electrolyte was lost from each cell on test at 25°C. (298°K), but from 2 to 10 gm. was lost from each cell on test at 100°C. (373°K.). The teardown inspection showed that the cells

TABLE X

SUMMARY OF CYCLE TESTS

PACK/ CELL	KOH %	TEMP. °C (°K)	CYCLE HRS.	DOD %	CYCLES COMPLETED			
					PRE-VIOUS	GE TEST	TOTAL	PACK AVG.
1	40	25(298)	24	75		102		
2						64		
3						94		
4						207		
5						195		132
6	40	100(373)	24	75		20		
7						8		
8						8		
9						20		
10						20		15
11	40	25	8	40		381		
12						495		
13						425		
14						488		
15						272		412
16	40	100	8	40		68		
17						41		
18						49		
19						70		
20						25		51
21	40	25	1½	20		2048		
22						2017		
23						2106		
24						2128		
25						1609		1982
26	40	100	1½	20		56		
27						246		
28						297		
29						58		
30						99		151
CL-34-1	30	25	24	75	214	4	218	
CL-34-2					214	35	249	234
CL-38-2	40	25	8	75	428	7	435	
CL-38-4					428	9	437	
CL-38-5					428	451	879	584
CL-40-1	40	25	1	40	2098	103	2101	
CL-40-2					2098	149	2247	
CL-40-3					2098	90	2188	
CL-40-4					1827	4	1831	
CL-40-5					2098	2	2100	2093
CL-42-1	40	25	1½	20	2098	724	2822	
CL-42-2					2098	137	2235	
CL-42-3					2098	94	2188	
CL-42-4					1938	8	1831	
CL-42-5					2098	36	2134	2266

TABLE X (continued)

SUMMARY OF CYCLE TESTS

PACK/ CELL	KOH %	TEMP. °C (°K)	CYCLE HRS.	DOD %	CYCLES COMPLETED			
					PRE-VIOUS	GE TEST	TOTAL	PACK AVG.
CL-44-1	40	25	1½	40	2098	3	2102	
CL-44-2					2050	67	2117	
CL-44-3					2098	225	2323	
CL-44-4					2098	349	2447	
CL-44-5					2098	2	2030	2203
CL-46-1	40	25	1½	20	1760	95	1855	
CL-46-2					2016	191	2207	
CL-46-3					1100	1233	2333	
CL-46-4					2016	11	2027	
CL-46-5					2016	199	2215	2127
CL-48-1	45	25	1½	40	3095	996	4091	
CL-48-2					3095	1617	4712	
CL-48-3					3095	417	3512	
CL-48-4					3095	2296	5391	
CL-48-5					3095	233	3328	4206

cycling at 100°C. (373°K.) suffered severe separator degradation, the organic fiberous material almost completely disappearing, while the inorganic material became brittle. Evidence of silver migration was present, on the inorganic separator and negative plates, and some active material had migrated to the cell terminals. Inspection of the cells cycling at 25°C. (298°K.) also showed separator degradation and silver migration, but not as extensive as at the higher temperature. The cells on test the longest showed the most degradation and migration, as might be expected.

No conclusive evidence or reasons for failure could be determined from these tests, but the most probable cause of life limitation of this silver cadmium cell appears to be the permeability of the separator material to silver ions.