Second Quarterly Report

for

STUDY OF NICKEL-CADMIUM CELLS

(17 August 1965 - 17 November 1965)

Contract No. NAS5-9586

Prepared by

Research and Development Center
General Electric Company
Schenectady, New York 12305

for

Goddard Space Flight Center
Greenbelt, Maryland

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SUMMARY

The work being performed under this contract consists of two phases: 1) a detailed study of the behavior of the positive nickel hydroxide electrode with respect to its charging characteristics, gassing behavior, and charge retention; and 2) a study of the sources and effects of impurities on the performance of nickel-cadmium cells. This program is an extension of the work on the characterization of nickel-cadmium cells conducted under a previous NASA contract (NAS5-3477). The overall goal of this work is the development of nickel-cadmium cells with more uniform capacity and operating characteristics, such as charge and discharge voltage, charge acceptance, pressure behavior during charging, and cycle life.

Electrodes for use in this program were received from the General Electric Company's Battery Business Section the last week of September. By the end of the second quarter, two hundred electrodes (100 positives and 100 negatives) had been processed through the initial six charge-discharge cycles characterization procedure. A computer program to correlate electrode capacity data was completed and the capacity data for the positive electrodes was correlated.

Evaluation of the two proposed methods for measuring the rate of oxygen evolution for the positive electrode study was completed. The Beckmann oxygen sensor showed a more rapid rate of response at low oxygen gassing rates (0 to 50 milliamperes) than the Niedrach-Alford gas diffusion electrode. Since the initial gas evolution behavior is most important for this study, it was decided to use the Beckmann sensor for these measurements.

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Section 1

INTRODUCTION

This report covers the work done during the second quarter of the contract, 17 August to 17 November 1965. The results of the work performed under a previous contract (NAS5-3477) on the characterization of nickel hydroxide and cadmium electrodes shows that, to a great extent, the variable or erratic behavior of the nickel-cadmium cell can be assigned to the behavior of the nickel hydroxide electrode. A second major contributing factor is the presence of impurities introduced into the cell either during its manufacture or formed as degradation products from cell components during the operation of the cell.

The objective of this program is to determine the relative importance of these two factors and the extent to which the variability in cell performance can be reduced. The experimental work includes detailed studies of individual positive electrodes and cyclic sealed cell performance tests.

During the second quarter, the initial characterization of the electrodes was started. A total of 200 electrodes (100 positives and 100 negatives) were completely charged and discharged for six cycles at a charge rate of 300 milliamperes (nominal C/4 rates based on the capacity of the positive plates). Complete potential versus time curves were recorded for each electrode during these cycles. The positive electrode capacity data for each electrode over the six cycles was averaged and curve-fitted by a least mean square procedure to note the slope of the capacity variation from cycle to cycle over the first six cycles. In addition, selected groups of electrodes were given repeated characterizations, each of six cycles duration, to note the variations in capacities with the number of times the electrodes were characterized.

No experimental work was done on the positive electrode studies or the impurities studies. Detailed plans for these studies were completed and reviewed with Mr. T. J. Hennigan, Goddard Space Flight Center, at a meeting held at the General Electric Research and Development Center, in Schenectady, New York, on November 23, 1965. Experimental work on the above studies will commence during the third quarter.

Section 2

PROGRAM SCOPE AND PLANS

A general discussion of the scope and plans for the program was given in the first quarterly report. The overall scope of the program is shown in Table 1.

Table 1

PROGRAM SCOPE

TASK 1 -- Study of the positive electrode behavior

- Voltage behavior during charge and discharge
- Capacity relationships
- Gassing behavior during charge, stand, and discharge
- Mechanical aspects of overcharge behavior

TASK 2 -- Study of the sources and effects of impurities in nickel-cadmium cells

- Manufacturing impurities
  - Electrolyte
  - Plate
  - Construction techniques
- Cell degradation products
  - Corrosion of components
  - Decomposition of organic materials used in the cell construction

Detailed plans for both tasks are discussed below.

POSITIVE ELECTRODE BEHAVIOR

The electrodes to be used in this task as well as in the impurity study are KO-15 plates cut down to a size of 1-3/4 inches by 3 inches. The characteristics of these plates are essentially the same as SAFT-VO plates used in the previous contract. The characteristics are tabulated in Section 4, "Discussion of Results," of this report.

Prior to use in these studies, the electrodes will have been characterized for at least six complete charge-discharge cycles at a rate of 300 milliamperes. From these tests the average capacity will be determined, as well as the capacity distribution for the electrodes from the lot. Electrodes for study will be selected on the basis of capacity from the low, high, and mean regions of the capacity distribution curve. The objective is to determine if the electrode capacity is a significant parameter in the behavior of the electrode in the test modes indicated below.

The other parameters with respect to electrode state are the effect of: storing electrodes in 31 percent potassium hydroxide at room temperature; and extensive cycling.

For each group of electrodes, it is planned to measure the electrode voltage versus a reference electrode, capacity, the start of oxygen evolution, and the rate of evolution during the charge portions of the cycle as well as on open circuit. The testing modes to be used are shown in Table 2.

Table 2

POSITIVE ELECTRODE BEHAVIOR TEST PLAN

Test Mode	Temperature (°C)	Charge and Discharge Rate	Open Circuit Stand Time (minutes)	Remarks
Cyclic Tests				
1. 25% Depth of Discharge	0 and 25	C/4 - c/4 C/4 - c/4	15 to 120	Periodic capacity measurement
2. 25 to 75% Depth of Discharge	25	C/4 - c/4	15 to 120	Periodic capacity measurement
3. 100% Depth of Discharge	25	C/4 - c/4	15 to 120	--
Open Circuit Decay Tests Starting State				
1. 75% charged	25	C/4 - 0	- -	Monitor voltage decay and oxygen evolution rate. Residual capacity measurement at fixed intervals of time.
2. 100% charged	0 and 25	C/4 - 0	- -	
3. 125% charged	25	C/4 - 0	- -	
4. 150% charged	25	C/4 - 0	- -	
5. 200% charged	25	C/4 - 0	- -	

The electrolyte in all cases will be 31 percent by weight potassium hydroxide. The test modes are designed to determine if loss of capacity varies with the cyclic mode and if it is related to loss of oxygen or charging efficiency as a function of the state of charge. Electrodes from each group will be run in duplicate initially. Additional samples will be run as needed depending on the results obtained.

IMPURITY STUDY

The impurities which will be investigated are listed in Table 3. Emphasis will be placed on those listed under the column labelled primary.

Table 3

IMPURITIES TO BE INVESTIGATED

Source	Primary	Secondary
Manufacturing		
Plate	NO_3^-, $CO_3^=$, Fe^{+++}_{++}, Cu, Ag	Cr, Al, Na,
Electrolyte	$SO_4^=$, Cl^- Li Organic Wetting Agents	$CO_3^=$, $SiO_4^=$, Na, Hg
Construction Materials	Kel F	--
Degradation in Operation		
Corrosion	Fe, Al_2O_3, Ag	--
Separators and Other Materials	Epoxy Carboxy-methyl cellulose Nylon Polypropylene Dynel	--

The testing will be done in two parts; a series of short term screening tests and longer term cyclic tests using nickel-cadmium cells. The screening tests will note the effect of the specific impurity, at a given concentration level in the electrolyte, on the capacity and gassing behavior of the positive electrode. In this case, the cyclic tests will be restricted to the 100 percent depth of discharge cycling mode and the open circuit tests from an initial state of 100 percent charged positive electrode.

In addition, the oxygen overvoltage as a function of current density will be measured for a fully charged positive electrode and on an unimpregnated piece of sinter structure. The corrosion current density or corrosion rate will be determined for the various impurities on the unimpregnated sinter structure. The technique to be used is known as the linear polarization technique and consists of measuring the change in potential versus applied current in the region of the rest potential. The effect of these impurities on the passive region of the polarization curve will also be determined. All of these tests will be made at room temperature.

In the case of the degradation products, it is proposed to expose the given item or component to an oxidizing atmosphere at elevated temperature in a solution of 31 percent potassium hydroxide. The conditions for this exposure will be 50 to 100 hours at 50 to 60°C. An aliquot of this electrolyte would be used in the short term tests described above. Identification of specific deleterious decomposition products will be attempted.

The impurities shown to have significant effects on the basis of the above tests will then be incorporated into complete nickel-cadmium cells to note the longer term effects under cycling conditions. The cycling tests will be done at 0 and 25°C using a 25 percent depth of discharge, and charge and discharge rates of C/4. The cells will periodically be removed from test for residual capacity measurements. Comparisons will be made with control cells containing the "normal" amount of impurities as manufactured.

Section 3

EXPERIMENTAL EQUIPMENT

CHARACTERIZATION EQUIPMENT

The parameters of the characterization process have been chosen to be six charge-discharge cycles at 300-milliampere charge, 300-milliampere discharge ($\sim$ C/4 rate). Intervals were: Rest 1.1 minutes, Charge 360 minutes, Rest 10 minutes, Discharge 360 minutes, Rest 10 minutes, and Reset. Total charge and discharge of 1800 milliampere-hours were found to be well in excess of all electrode capacities. The time of discharge has now been reduced to 300 minutes (1500 milliampere-hours) -- still in excess of most positive plates.

The characterization cycling equipment used on the previous NASA contract (NAS5-3477) has also been modified to facilitate more rapid data generation. The equipment was originally designed to cycle 10 positive and 10 negative electrodes simultaneously. The circuit was changed to accommodate 20 positive test electrodes as shown in Figure I-1 (Appendix I). The test electrodes are indicated by plus signs and counter electrodes by negative signs. R and R' denote reference electrodes in the "old positive" and the "old negative" cells, respectively.

The timer circuit (not shown) has been readjusted to "read" the voltages of the "old positive" and the "old negative" cells for 17 and 103 seconds, respectively, throughout the characterization test. This permits a readout and recording to be made of two positive electrodes on a single point Rustrak recorder. The two traces are readily distinguished as a dotted line superimposed on a background of a dashed line.

The net result of these changes is that the positive electrode characterization data can be generated twice as fast as previously without sacrifice in accuracy.

OXYGEN MONITORING EQUIPMENT

The two systems for monitoring the oxygen evolution described in the first quarterly report of this program were subjected to further testing. Both methods can be used to monitor oxygen generation rates with satisfactory response speed and accuracy in the range of 50 to 500 milliamperes gassing current. In this range, the alternate method, using a Niedrach-Alford gas diffusion electrode versus a charged cadmium electrode, was somewhat superior insofar as simplicity of setup and calibration was concerned. The proposed method, based on the use of a Beckmann gold oxygen sensing electrode versus a silver anode, was superior in the range of zero to 50 milliampere gassing current with respect to speed of response.

In the alternate method, the Niedrach-Alford electrode is below the hydrogen potential when the partial pressure of oxygen approaches zero. The hydrogen on the catalyst must first be consumed (nonelectrochemically) and the catalyst saturated (also nonelectrochemically) with oxygen at equilibrium with the partial pressure (small but finite) of the gas before a steady-state rate of electrochemical reduction of the oxygen being sensed is established. Tests showed that in the region of 0 to 50 milliamperes oxygen gassing current, the time to reach a steady-state value varied from a half to one hour for the Niedrach-Alford sensing electrode.

One approach to minimize the delay time caused by the hydrogen is to electrically bias the gas electrode to a potential above the hydrogen potential. With no oxygen present, the current flowing through the measuring circuit will be zero. The only delay in response to the first oxygen generated in the test cell should be caused by the initial absorption of oxygen by the catalyst surface. Minimizing the time delay to reach a steady state from this factor would require the reduction of catalyst not in contact with the electrolyte phase. This would require some additional electrode development work which is outside the scope of the present contract. For these reasons, the Beckmann sensor will be used for the oxygen evolution measurements.

Section 4

DISCUSSION OF RESULTS

A lot of 1000 positive and 1000 negative electrodes were obtained from the General Electric Company's Battery Business Section in Gainesville, Florida for use in this program. A complete history of the plates was included with the shipment for use in this program. The electrodes had been assembled into cellpacks, each containing 10 positive and 10 negative electrodes and then put through a series of charge-discharge cycles and inversions to electrochemically clean the electrodes. The capacity developed for both the positive and the negative electrodes in the course of this treatment is tabulated in Appendix I of this report. The capacity values are the average for the group of the 10 positive and the 10 negative electrodes in each cell. The plate material characteristics for each lot of negative plates and the positive plate blend are also listed in the appendix. The values listed are averages for each lot or blend.

The electrodes are KO-15 stock trimmed to a size of 1-3/4 inches by 3 inches. The same size was used in the previous NASA contract (NAS5-3477).

A computer program was designed to tabulate all characterized plates according to the following rules:

1. Gross capacity average over six cycles
2. Slope of a calculated line passing through each capacity step.

For grouping convenience, only electrodes having capacities of 900 to 1500 milliampere-hours gross capacity in steps of 50 milliampere-hours were tabulated. Similarly, the slopes which varied from -30 to +30 were tabulated in steps of five.

Table I-1 (Appendix I) is illustrative of the listing developed by the computer program. These electrodes were arranged only in order of increasing gross capacity and slope -- graphitic steps were not considered. The standard deviation and intercept were also calculated but not used by the process.

Electrodes sorted out by this method will be considered to be similar in later tests. For instance, electrodes 9, 10, and 52 having similar low capacities and low slopes will be considered to be quite distinct from electrodes 29, 44, and 62 which have high capacities and high slopes.

This program is now being expanded to further subdivide the groups of electrodes according to graphitic capacities and slopes. All data will be preserved on individual data cards for each electrode.

DISTRIBUTION OF ELECTRODE CAPACITIES

The capacity distribution for the first 100 positive electrodes characterized in this program is shown in Figure 1. The range of capacities fell between 1000 and 1300 milliampere-hours with approximately half in the range of 1100 to 1200 milliampere-hours.

For comparison, the capacity distribution of a series of KO-15-type (Battery Business Section, General Electric Company, Gainesville, Florida) and VO-type (Saft, France) electrodes characterized under the previous contract, is shown in Figure 2. The total number of electrodes characterized previously was 20 and 22, respectively -- in Figure 2 the ordinate has been normalized to indicate the distribution for a sample of 100 electrodes.

The KO-15-type plates had previously shown a narrower distribution of capacity ranges, but it may have been due to the much smaller number of electrodes processed. The VO-type plates showed a spread more like that of the present group with about the same average capacity.

EFFECT OF STORAGE ON AVERAGE CAPACITIES

The Electrode Number, Average Discharge Capacity, Standard Deviation, Slope, and Intercept for the first 100 electrodes characterized, taken in groups of 10, are listed in Tables 4 through 13. The groups of 10 electrodes are electrodes removed from a given cellpack in the electrochemical testing at the Company's Gainesville, Florida plant. The average of each electrode characterization capacity for each group of 10 electrodes is included (General Electric Research and Development Center, Schenectady, New York, Average) for contrast with similar capacity information mentioned in Section 4 (Gainesville Average), together with the lot and cellpack number.

The first 10 electrodes were put through the characterization procedure four times to determine the effect of wet storage on the electrode capacity. The results of these successive characterizations are shown in Table 4.

In the first run, the electrodes were initially dry and cycled six times at 250 milliamperes, charge and discharge ($\sim$ C/5 rate). All other cycling was done at 300 milliamperes, charge and discharge ($\sim$ C/4 rate). In these, as in other similar runs with other electrodes, there was a tendency to develop additional capacity between characterization runs (electrodes were stored in 31 percent potassium hydroxide after the first run). The slope of six successive cycles in general tended to increase from negative to positive values. There was no consistent trend in the degree of scatter (Standard Deviation) of successive runs either in particular electrodes or in the group taken as a whole. The four runs were started on 5 October 1965, 8 October 1965, 19 October 1965, and 1 November 1965 -- each run took approximately 3-1/4 days. The initial average for the 10 electrodes was very similar to the Gainesville information.

Similar data on electrodes 11 through 20 is shown in Table 5. The average capacities in the two runs tended to increase as did the slopes. In general, the standard deviation was somewhat less on the second run. The electrodes were first run on 12 October 1965 immediately after immersion in a 31 percent potassium hydroxide electrolyte. The second run was started on 5 November 1965 after 3-1/2 weeks total immersion time. Here again, the Schenectady Average capacity compared well with that given by Gainesville.

Two cellpacks of electrodes were split into packages of five each. These were then recombined into two new groups of 10 to test the effect of prior wetting on electrode performance. Electrodes 51-55 and 66-70 were immersed and immediately characterized on 29 October 1965. They were then stored in 31 percent potassium hydroxide and recharacterized on 29 November 1965. The data is summarized in Table 9. In both packages of five electrodes, the average capacity determined by the General Electric Research and Development Center is higher than the Gainesville figures. In all electrodes, the standard deviation was reduced in the second run while the slopes displayed the usual tendency to increase. In contrast to previous experience, however, the recharacterized capacities were smaller than the original values.

The unused portions of these two groups were stored in potassium hydroxide from 29 October 1965, but the electrodes were first characterized on 8 November 1965. Except for the initial soaking period, these should have behaved similarly to the first set described above. The characterization data from these electrodes (56-65) is tabulated in Table 10. The slopes are all near zero or more positive -- apparently due to the prior storage in potassium hydroxide. The average capacities are not significantly different from the complementary packages initial characterization listed in Table 9. The standard deviation does appear to be reduced, however, by the storage period and is similar in degree to that displayed by the complementary electrodes on recharacterization.

The other tables not specifically mentioned above are included for completeness. Summarizing briefly, all electrode groups showed the same or greater capacity than the corresponding Gainesville data. Most of the electrodes showed a negative slope on the first characterization which became more positive in successive cycles. This is interpreted to be the result of a gradual wetting of the electrode by electrolyte with time. This effect may also account for a decrease in data scatter after prolonged immersion.

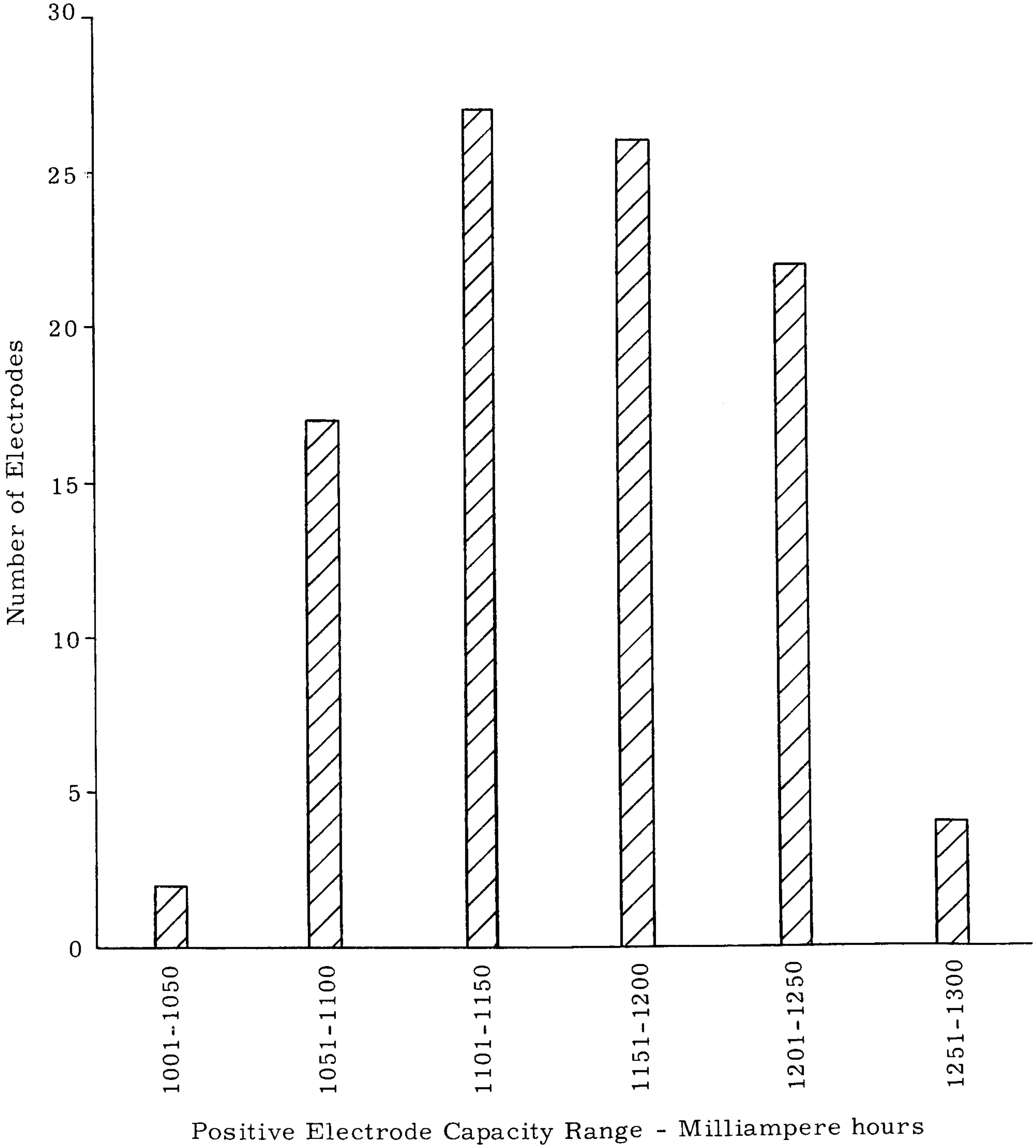


Figure 1. Positive Electrode Capacity Distribution

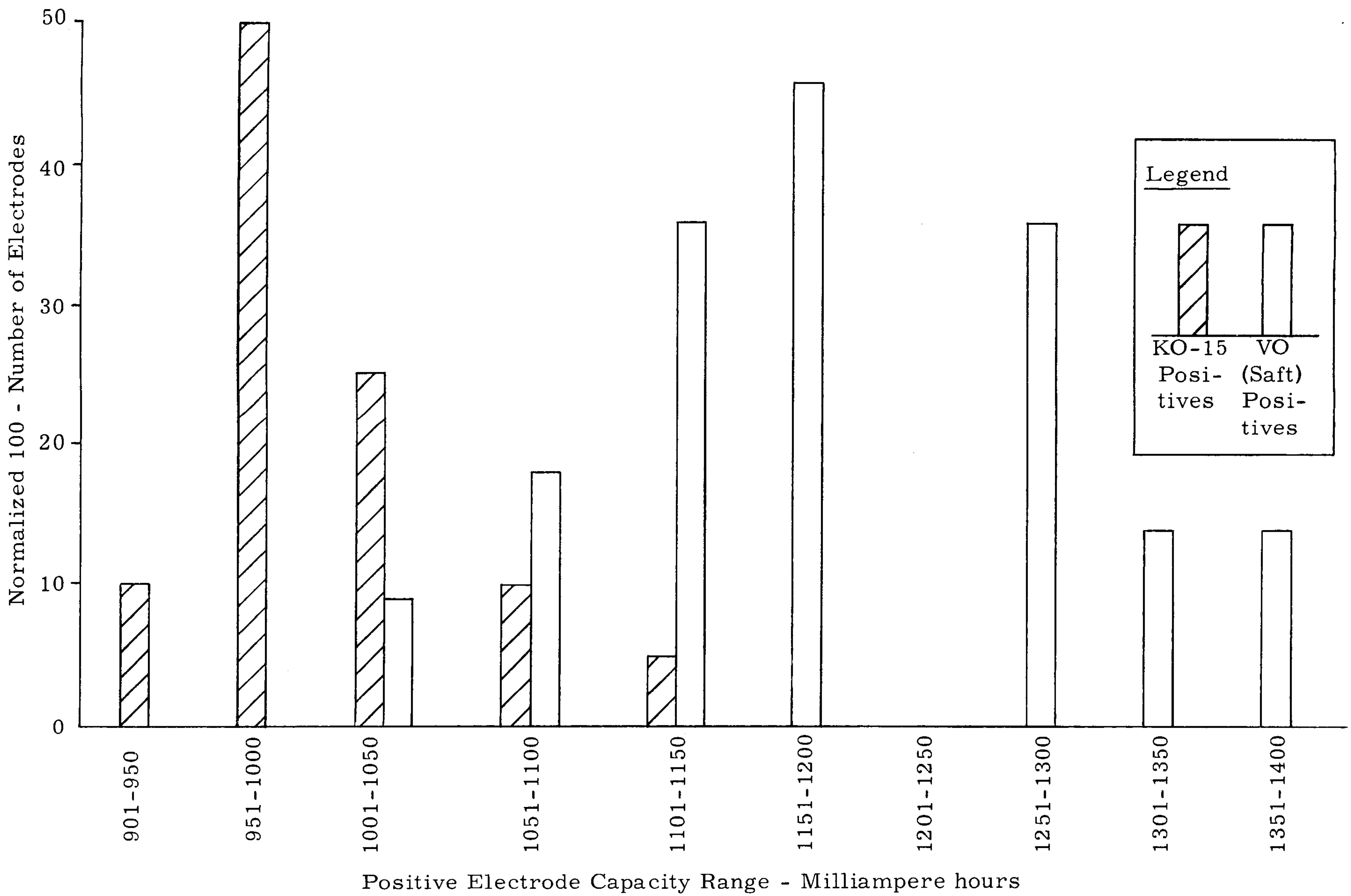


Figure 2. Positive Electrode Capacity Distribution - Previous NASA Contract NAS5-3477

Table 4

CHARACTERIZATION DATA SUMMARY - ELECTRODES 1-10

Electrode Number	Average Discharge Capacity (Mahrs)	Standard Deviation	Slope (Mahrs/cycle)	Intercept (Mahrs)
1	1208	5.86	-26.25	1286*
	1350	8.49	3.0	1338**
	1332	4.24	3.0	1323***
	1388	7.46	12.43	1344****
2	1175	9.84	-8.75	1201
	1268	30.0	-15.0	1320
	1233	3.68	7.5	1211
	1293	13.84	13.29	1246
3	1120	14.90	-11.65	1154
	1180	11.18	0.0	1180
	1185	22.85	12.0	1149
	1263	12.87	11.57	1222
4	1145	3.06	8.75	1171
	1230	12.68	8.57	1200
	1245	0.0	0.0	1245
	1305	9.26	8.57	1275
5	1115	9.19	-11.25	1149
	1190	8.94	12.0	1148
	1221	7.04	-1.5	1226
	1298	7.46	12.43	1254
6	1145	3.06	-16.25	1194
	1223	11.89	4.71	1206
	1233	3.68	7.50	1211
	1305	12.76	11.14	1266
7	1165	10.0	-7.5	1188
	1223	6.38	5.57	1203
	1245	8.49	3.0	1236
	1303	16.52	9.86	1268
8	1173	8.66	15.00	1218
	1243	15.58	2.14	1235
	1248	3.68	7.5	1226
	1333	11.08	9.86	1298
9	1080	5.86	-13.75	1121
	1158	9.75	9.0	1126
	1197	4.24	3.0	1188
	1288	12.10	10.71	1250
10	1053	3.54	-10.00	1083
	1112	9.75	9.0	1011
	1149	3.68	4.5	1136
	1233	15.52	11.57	1192

Gainesville average = 1105 Mahrs
Schenectady average = 1138 Mahrs
Lot 2 Cell 22

* 1st Run
** 2nd Run
*** 3rd Run
**** 4th Run

Table 5

CHARACTERIZATION DATA SUMMARY - ELECTRODES 11 - 20

Electrode Number	Average Discharge Capacity (Mahrs)	Standard Deviation	Slope (Mahrs/cycle)	Intercept (Mahrs)
11	1221	11.23	-12.0	1257*
	1236	7.04	1.5	1232**
12	1200	17.87	-4.5	1213.5
	1239	12.0	0.0	1239
13	1230	7.04	-10.5	1261.5
	1245	8.49	-3.0	1254
14	1215	14.07	-9.0	1242
	1239	10.17	4.5	1260
15	1254	8.49	-9.0	1281
	1275	4.24	6.0	1257
16	1164	8.49	-9.0	1191
	1233	10.39	12.0	1197
17	1221	8.49	-6.0	1239
	1275	8.49	12.0	1239
18	1236	7.04	-1.5	1241
	1317	10.39	12.0	1281
19	1113	44.70	-27.0	1194
	1185	4.24	21.0	1122
20	1116	8.49	-6.0	1134
	1221	3.68	10.5	1190

Gainesville average = 1183 Mahrs
Schenectady average = 1197 Mahrs
Lot 2 Cell 34

* 1st Run
** 2nd Run

Table 6

CHARACTERIZATION DATA SUMMARY - ELECTRODES 21 - 30

Electrode Number	Average Discharge Capacity (Mahrs)	Standard Deviation	Slope (Mahrs/cycle)	Intercept (Mahrs)
21	1198	13.28	-1.29	1202
22	1055	7.07	0	1055
23	1108	13.28	-1.29	1112
24	1058	10.86	2.14	1050
25	1090	6.44	-1.71	1096
26	1105	14.88	4.29	1090
27	1175	14.14	0	1175
28	1105	9.52	3.43	1093
29	1238	6.55	2.14	1230
30	1118	6.38	5.57	1098

Gainesville average = 1042 Mahrs
Schenectady average = 1125 Mahrs
Lot 2 Cell 36

Table 7

CHARACTERIZATION DATA SUMMARY - ELECTRODES 31 - 40

Electrode Number	Average Discharge Capacity (Mahrs)	Standard Deviation	Slope (Mahrs/cycle)	Intercept (Mahrs)
31	1230	4.24	-9.0	1257
32	1191	6.0	-12.0	1227
33	1110	12.55	7.5	1088
34	1104	7.04	-13.5	1144.5
35	1125	4.24	-9.0	1152
36	1131	3.67	-10.5	1163
37	1098	3.68	-7.5	1121
38	1149	16.84	-4.5	1163
39	1227	28.78	-12.0	1263
40	1080	8.49	3.0	1071

Gainesville average = 1081 Mahrs
Schenectady average = 1145 Mahrs
Lot 3 Cell 2

Table 8

CHARACTERIZATION DATA SUMMARY - ELECTRODES 41 - 50

Electrode Capacity	Average Discharge Capacity (Mahrs)	Standard Deviation	Slope (Mahrs/cycle)	Intercept (Mahrs)
41	1209	5.78	-2.64	1217
42	1170	9.33	-1.01	1173
43	1119	6.93	1.49	1114
44	1236	3.82	3.65	1224
45	1203	3.74	9.93	1171
46	1194	9.23	10.54	1160
47	1233	17.37	-1.22	1237
48	1203	4.61	-2.23	1210
49	1182	33.04	8.31	1155
50	1227	11.14	-0.81	1230

Gainesville average = 1149 Mahrs
Schenectady average = 1197 Mahrs
Lot 3 Cell 19

Table 9

CHARACTERIZATION DATA SUMMARY - ELECTRODES 51-55, 66-70

Electrode Number	Average Discharge Capacity (Mahrs)	Standard Deviation	Slope (Mahrs/cycle)	Intercept (Mahrs)
51	1218	25.70	-23.57	1300 *
	1153	11.08	9.86	1118 **
52	1168	32.22	-8.14	1196
	1143	10.28	17.57	1081
53	1158	19.05	-8.14	1186
	1105	11.08	5.14	1087
54	1115	14.88	-4.29	1130
	1073	7.46	17.57	1011
55	1103	19.69	-3.86	1116
	1057.5	7.46	17.57	996

Gainesville average = 1037 Mahrs
Schenectady average = 1152 Mahrs
Lot 3 Cell 25

Electrode Number	Average Discharge Capacity (Mahrs)	Standard Deviation	Slope (Mahrs/cycle)	Intercept (Mahrs)
66	1203	22.60	-6.43	1225
	1155	7.46	14.57	1104
67	1218	23.93	-9.86	1252
	1180	4.23	12.86	1135
68	1120	13.28	-7.71	1147
	1180	4.23	12.86	1135
69	1311	13.91	-34.5	1449
	1215	8.54	5.14	1197
70	1178	24.01	-7.29	1203
	1140	10.95	6.0	1119

Gainesville average = 1134 Mahrs
Schenectady average = 1223 Mahrs
Lot 4 Cell 19

* 1st Run
** 2nd Run

Table 10

CHARACTERIZATION DATA SUMMARY - ELECTRODES 56 - 65

Electrode Number	Average Discharge Capacity (Mahrs)	Standard Deviation	Slope (Mahrs/cycle)	Intercept (Mahrs)
56	1150	10.67	13.71	1102
57	1138	6.92	14.14	1088
58	1255	11.08	0.86	1252
59	1133	6.38	-5.57	1152
60	1090	8.45	-4.29	1105

Gainesville average = 1037 Mahrs
Schenectady average = 1152 Mahrs
Lot 3 Cell 25

Electrode Number	Average Discharge Capacity (Mahrs)	Standard Deviation	Slope (Mahrs/cycle)	Intercept (Mahrs)
61	1190	10.79	-1.71	1196
62	1230	14.71	1.71	1224
63	1185	13.09	-4.29	1200
64	1295	7.07	0.0	1295
65	1298	6.55	-2.14	1305

Gainesville average = 1134 Mahrs
Schenectady average = 1223 Mahrs
Lot 4 Cell 19

Table 11

CHARACTERIZATION DATA SUMMARY - ELECTRODES 71 - 80

Electrode Number	Average Discharge Capacity (Mahrs)	Standard Deviation	Slope (Mahrs/cycle)	Intercept (Mahrs)
71	No Data for No. 71			
72	1095	25.61	2.57	1086
73	1198	5.54	0.43	1196
74	1240	7.93	-6.86	1264
75	1195	12.10	-4.29	1210
76	1118	13.42	-3.00	1128
77	1158	4.23	-2.14	1165
78	1090	7.07	0.	1090
79	1248	10.07	-1.29	1252
80	1220	11.08	-0.86	1223

Gainesville average = 1164 Mahrs
Schenectady average = 1174 Mahrs
Lot 4 Cell 10

Table 12

CHARACTERIZATION DATA SUMMARY - ELECTRODES 81 -90

Electrode Number	Average Discharge Capacity (Mahrs)	Standard Deviation	Slope (Mahrs/cycle)	Intercept (Mahrs)
81	1150	4.47	-6.0	1171
82	1063	16.52	-14.14	1112
83	1158	5.61	-1.50	1164
84	1050	7.17	-7.71	1077
85	1083	4.23	-2.14	1090
86	1098	10.07	1.29	1093
87	1173	7.79	-6.43	1195
88	1168	3.96	-5.57	1187
89	1145	6.44	-10.29	1181
90	1193	3.59	-8.14	1221

Gainesville average = 1091 Mahrs
Schenectady average = 1128 Mahrs
Lot 4 Cell 21

Table 13

CHARACTERIZATION DATA SUMMARY - ELECTRODES 91 - 100

Electrode Number	Average Discharge Capacity (Mahrs)	Standard Deviation	Slope (Mahrs/cycle)	Intercept (Mahrs)
91	1120	3.96	-9.43	1153
92	1055	20.56	5.14	1037
93	1065	6.38	-9.43	1098
94	1078	9.64	-2.14	1085
95	1160	8.45	-4.29	1175
96	1133	6.38	-5.57	1152
97	1153	7.93	3.86	1139
98	1033	9.64	-2.14	1040
99	1200	6.71	-6.0	1221
100	1070	10.79	+1.71	1064

Gainesville average = 1073 Mahrs
Schenectady average = 1107 Mahrs
Lot 5 Cell 6

Section 5

PROGRAM FOR NEXT QUARTER

Additional positive electrodes will be characterized to confirm the capacity distribution obtained with first 100 electrodes and to provide a sufficient number of electrodes with similar capacity characteristics for use in the positive electrode studies. Experimental work on the positive electrode behavior and impurity studies will be started.

Section 6

NEW TECHNOLOGY

There were no developments during this reporting period that come under the "New Technology" clause of this contract.

APPENDIX I

Table I-2

PLATE MATERIAL HISTORY

NEGATIVE PLATE

Post and Spiral	2114-2	2120-6		2166-3
Lot No.	2	3		5
Hydrate per dm^2	16.84	17.64	17.84	14.93
Thickness Dry Coated	0.904	0.866	0.848	0.886
Weight, Dry Coated per $\frac{1}{2}$ dm^2	8.44	8.47	8.39	7.54
Weight, Impregnated per $\frac{1}{2}$ dm^2	16.86	17.29	17.31	17.51
Capacity by Electrochemical Testing, Amperehour/dm^2	5.16	5.30	5.17	4.00
Sinter Furnace	1	1	3	1
Date	11/22	11/23	12/28	12/4
Time	1820	0620	0200	22:30
Spiral Date	11/23	11/25	12/28	12/7/64
Electrochemical Cleaning Date	11/28	11/29	1/4	12/15/64

ALL POSITIVE PLATE Blend No. 525

Hydrates	16.47 per $\frac{1}{2}$ dm^2
Impregnated Weight	26.72 per dm^2
Thickness	0.895 millimeter
Capacity	3.65 amperehour/dm^2
Cycles	8
Weight, Dry Coated, per $\frac{1}{2}$ dm^2	9.71

Table I-3

ELECTROCHEMICAL TEST DATA

Post and Spiral: Positive Blend 525, Negative 2114-2 Lot No. 2

Cell Number	Amperehour* Negative Capacity	Amperehour* Positive Capacity
1	17.73	11.25
2	17.15	11.25
3	16.22	11.54
4	15.84	11.30
5	15.28	11.05
6	17.53	11.39
7	16.75	10.71
8	17.43	10.91
9	16.90	10.76
10	17.11	10.86
11	17.19	11.49
12	16.73	10.91
13	17.27	11.30
14	17.45	11.44
15	16.79	10.76
16	16.62	11.54
17	17.86	11.44
18	17.29	10.86
19	17.15	11.15
20	16.98	11.05

*Charged at 1.21 Amperes
Discharged at 2.91 Amperes
Capacity on second forward discharge cycle to 1.0 volt

Table I-4

ELECTROCHEMICAL TEST DATA

Post and Spiral: Positive Blend 525, Negative 2120-6 Lot No. 3

Cell Number	Amperehour* Negative Capacity	Amperehour* Positive Capacity
1	15.71	10.91
2	15.55	10.81
3	15.47	10.66
4	-----	-----
5	15.76	10.76
6	16.20	10.86
7	16.59	10.47
8	17.22	10.86
9	15.54	10.86
10	15.54	11.00
11	16.22	10.71
12	14.74	11.49
13	16.80	10.76
14	17.61	10.42
15	16.24	10.71
16	14.95	10.42
17	14.94	10.91
18	16.13	10.76
19	16.09	11.49
20	16.25	11.10
21	16.54	10.81
22	15.68	10.71
23	15.92	11.00
24	15.67	10.71
25	15.99	10.37
26	16.84	10.81
27	-----	-----
28	15.62	11.15
29	15.57	10.56
30	15.54	10.66
31	15.32	11.00

*Charged at 1.21 Amperes
Discharged at 2.91 Amperes
Capacity on second forward discharge cycle to 1.0 volt

Table I-5

ELECTROCHEMICAL TEST DATA

Post and Spiral: Positive Blend 525, Negative 2223-5 Lot No. 4

Cell Number	Amperehour* Negative Capacity	Amperehour* Positive Capacity
1	16.11	11.20
2	16.34	11.54
3	16.48	11.34
4	16.44	11.34
5	16.74	10.96
6	16.81	11.20
7	16.87	11.34
8	16.38	11.39
9	17.01	11.39
10	16.61	11.64
11	16.46	11.20
12	16.57	11.39
13	16.83	11.64
14	16.62	11.05
15	16.73	11.39
16	16.34	11.49
17	17.21	10.91
18	17.06	11.34
19	16.58	11.34
20	16.67	11.44
21	16.57	10.91
22	17.25	11.64

*Charged at 1.21 Amperes
Discharged at 2.91 Amperes
Capacity on second forward discharge cycle to 1.0 volt

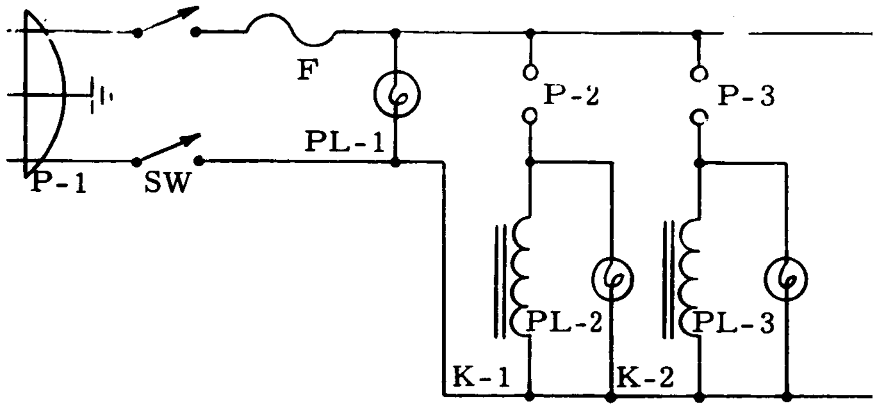
Table I-6

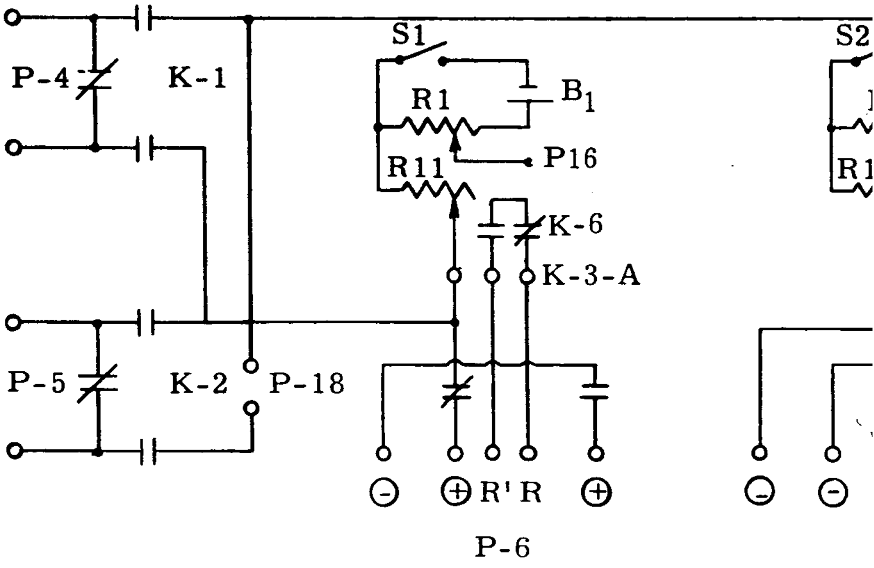
ELECTROCHEMICAL TEST DATA

Post and Spiral: Positive Blend 525, Negative 2166-3 Lot No. 5

Cell Number	Amperehour* Negative Capacity	Amperehour* Positive Capacity
1	18.20	11.30
2	18.20	11.09
3	18.17	10.57
4	17.87	10.42
5	17.38	10.57
6	18.09	10.73
7	18.20	11.23
8	18.35	11.23
9	18.24	8.73
10	18.19	11.39

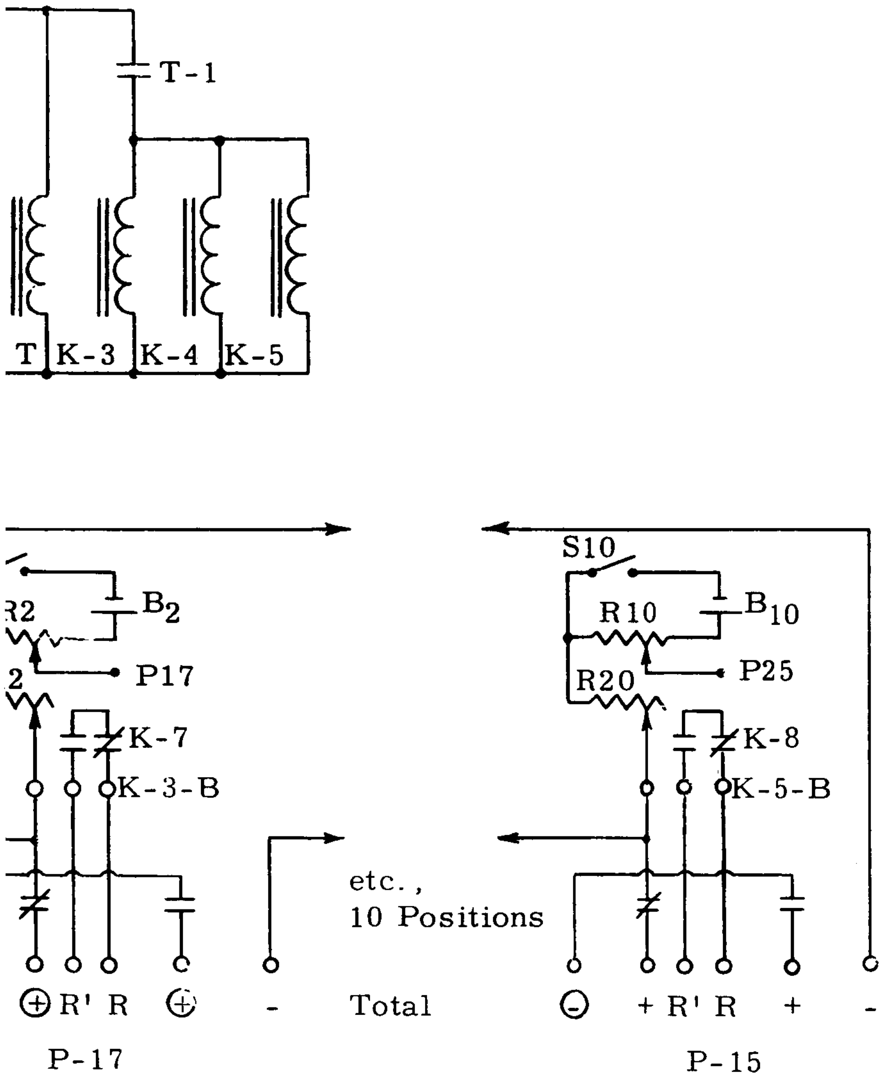
*Charged at 1.21 Amperes
Discharged at 2.91 Amperes
Capacity on second forward discharge cycle to 1.0 volt





Note: RL changed with variation in load

C/10	500	12.5 Watts	Ohmite 0117
C/2	100	25.0 Watts	Ohmite 0151
C	50	50.0 Watts	Ohmite 0318



P-1
P-2
P-3
P-4
P-5
P-6 - P-15
P-16 - P-17
P-18
SW
F
PL-1
PL-2
PL-3
T
RL
K-1 & K-2
K-3 & K-4
K-5
K-6 & K-7
K-8
S-1 - S-10
B-1 - B-10
R-1 - R-10
R-11 - R-20

Figure I-1. Mod

PARTS LISTS

ʟine Cord, CA-CB Controller
Control, Charge, Pin Jacks, Yellow
Control, Discharge, Pin Jacks, Red
nput Charge, CCS, Terminal
nput Discharge, CCS Terminal
Pin Jacks, Cell Input Red +, Green +, White R, Blue -, Black -
Pin Jacks Recorder, Red +, Black -
Pin Jacks, Green and Red for RL
Switch, Toggle SPDT
Fuse, 3A
Pilot, Master, Green
Pilot, Charge, Yellow
Pilot, Discharge, Red
Timer, CM, 2 Minutes
Load Resistance (see drawing)
Mercury Relay, 3PST 2NO, 1NC, Ebert EM7, 110 VAC Coil
Leach 329-7 4PDT, 110 VAC Coil
Leach 337 2 PDT, 110 VAC Coil
Leach 329-7 4PDT, 110 VAC Coil
Leach 337-7 2PDT, 110 VAC Coil
Switch SPST Toggle "Bias"
Battery Mercury O Cell
50, 000 Ohms, 2 Watts
3 Megawatts

ified Nickel-Cadmium Characterization Cycle Control

3

Table I-1

CAPACITY DATA FOR CHARACTERIZED ELECTRODES

Electrode Number	Average Discharge Capacity (Mahrs)	Standard Deviation	Slope (Mahrs/cycle)	Intercept (Mahrs)
84	1050	7.17	-7.71	1077
98	1033	9.64	-2.14	1040
9	1080	5.86	-13.75	1121
10	1053	3.54	-10	1083
82	1063	16.52	-14.14	1112
37	1098	3.68	-7.5	1121
93	1065	6.38	-9.43	1098
22	1055	7.07	0	1202
25	1090	6.44	-1.71	1096
60	1090	8.45	-4.29	1105
78	1090	7.07	0	1090
85	1083	4.23	-2.14	1090
94	1078	9.64	-2.14	1085
24	1058	10.86	2.14	1050
40	1080	8.49	3	1071
72	1095	25.61	2.57	1086
86	1098	10.07	1.29	1093
100	1070	10.79	1.71	1064
92	1055	20.56	5.14	1037

19	1113	44.7	-27	1194
6	1145	3.06	-16.25	1194
3	1120	14.9	-11.25	1154
5	1115	9.19	-11.25	1149
34	1104	7.04	-13.5	1145
36	1131	3.67	-10.5	1163
89	1145	6.44	-10.29	1181
4	1145	3.06	-8.75	1171
20	1116	8.49	-6	1134
35	1125	4.24	-9	1152
59	1133	6.38	-5.57	1152
68	1120	13.28	-7.71	1147
81	1150	4.47	-6	1171
91	1120	3.96	-9.43	1153
96	1133	6.38	-5.57	1152
23	1108	13.28	-1.29	1112
38	1149	16.84	-4.5	1163
54	1115	14.88	-4.29	1130
55	1103	19.69	-3.86	1116
76	1118	13.42	-3	1128
26	1105	14.14	4.29	1090
28	1105	9.52	3.43	1093
43	1119	6.93	1.49	1114
30	1118	6.38	5.57	1098
33	1110	12.55	7.5	1088
56	1150	10.07	13.71	1102
57	1138	6.92	14.14	1088
8	1173	8.66	-15	1218
32	1191	6	-12	1227
2	1175	9.84	-8.75	1201
7	1165	10	-7.5	1188
16	1164	8.49	-9	1191
52	1168	32.22	-8.14	1196
53	1158	19.05	-8.14	1186
70	1178	24.01	-7.29	1203
87	1173	7.79	-6.43	1195
88	1168	3.96	-5.57	1187
90	1193	3.59	-8.14	1221
99	1200	6.71	-6	1221
12	1200	17.87	-4.5	1214
21	1198	13.28	-1.29	1202
27	1175	14.14	0	1175
42	1170	9.33	-1.01	1173

63	1185	13.09	-4.29	1200
75	1195	12.1	-4.29	1210
77	1158	4.23	-2.14	1165
83	1158	5.61	-1.5	1164
95	1160	8.45	-4.29	1175
73	1198	5.52	.43	1196
97	1153	7.93	3.86	1139
49	1182	33.04	8.31	1155
46	1194	9.23	10.54	1160
1	1208	5.86	-26.25	1286
51	1218	25.7	-23.57	1300
11	1221	11.23	-12	1257
13	1230	7.04	-10.5	1262
39	1227	28.78	-12	1263
14	1215	14.07	-9	1242
17	1221	8.49	-6	1239
31	1230	4.24	-9	1257
66	1203	22.6	-6.43	1225
67	1218	23.93	-9.86	1252
74	1240	7.93	-6.86	1264
18	1236	7.04	-1.5	1241
41	1209	5.78	-2.64	1217
47	1233	17.37	-1.22	1237
48	1203	4.61	-2.23	1210
50	1227	11.14	-.81	1230
79	1248	10.07	-1.29	1252
80	1220	11.08	-.86	1223
29	1238	6.55	2.14	1230
44	1236	3.82	3.65	1224
62	1230	14.71	1.71	1224
45	1203	3.74	9.93	1171
15	1254	8.49	-9	1281
64	1295	7.07	0	1295
65	1298	6.55	-2.14	1305
58	1255	11.08	.86	1252