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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Memorandum 33-536

Development and Testing of a High Cycle Life 30 A-h Sealed AgO-Zn Battery

R. S. Bogner

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PASADENA, CALIFORNIA

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PREFACE

The work described in this report was performed by the Guidance and Control Division of the Jet Propulsion Laboratory.

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Portions of the data in this report were extracted from the ESB, Inc., Exide Missile and Electronics Division, Final Report, High Cycle Life Sealed Silver Oxide-Zink Cell Development, September 8, 1970, performed under JPL Contract No. 952472.

The Phase II battery testing was performed by the Naval Ammunition Depot Quality Evaluation Laboratory Department, Crane, Indiana, on JPL Work Request DPR WO-5150.

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ABSTRACT

A two-phase program was initiated to investigate design parameters and new technology to develop an improved AgO-Zn battery. The basic performance goal was 100 charge/discharge cycles (22 h/2 h) at 50% depth of discharge following a six-month period of charged stand at room temperature (25 ±4°C). Phase I, cell evaluation, involved testing 70 cells in five-cell groups. The major design variables were active material ratios, electrolyte concentrations, separator systems, and negative plate shape. Phase I testing showed that cycle life could be improved 10% to 20% by using greater ratios of zinc to silver oxide and higher electrolyte concentrations. Wedge-shaped negatives increased cycle life by nearly 100%. The FSC separator proved superior to RAI 2291 separators for cycle life; however, test results were complicated by the cell pack tightness, a variable not originally planned to be introduced into the test. Phase II battery evaluation, which was initiated before the Phase I results were known completely, involved evaluation of six designs as 19-cell batteries. Phase II testing was done at NAD Crane, Indiana. Only one battery exceeded 100 cycles following nine months charged stand. That battery, containing FSC separators, gave 204 cycles at 50% DOD before the first cell failed. Unfortunately, the wedge-shaped negative was not evaluated in Phase II. Phase II and Phase I failures were due to loss of negative plate capacity caused by negative plate erosion.

I. INTRODUCTION

Future planetary exploration missions contemplated by NASA/JPL impose increased stand-life and cycle-life requirements that cannot be reliably met by the sealed silver oxide-zinc battery designs used on past spacecraft.

The silver oxide-zinc system is desirable over other systems for space applications because of its high energy density, high rate capability, low magnetic properties, and relatively low capacity loss on stand. JPL is engaged in development programs to improve the stand-life and cycle-life capabilities of the system. The development program discussed herein was initiated primarily to attempt to meet the design requirements for a Mariner Mars spacecraft.

ESB, Inc., was selected as the contractor for the development effort. A two-phase program was initiated to evaluate various design features, to assess the capability of these designs as cells and batteries, and to meet the performance requirement consisting of a six-month open-circuit charged stand at room temperature followed by 100, 24-h cycles at 50% depth-of-discharge (DOD). Other requirements included:

(1) Recharge within 24 h.

(2) Operation in a space vacuum.

(3) Operation in the temperature range of 50 to 100°F.

(4) Meet the environmental requirements set forth in JPL Specification TS 500437 Rev. B (Mariner Mars 1971).

The Phase I effort of the program was to evaluate several design parameters and testing methods, in five- to ten-cell groups. The Phase II effort was to test the best designs from Phase I in 19-cell batteries. Phase II was initiated before Phase I was complete; however, initial performance data from Phase I cells assisted in the design of the Phase II cells.

II. PHASE I CELL DESIGNS

Initially, cell design considerations were to include, but not necessarily be limited to, the investigation and analysis of the following:

(1) Separator configuration on both positive and negative electrodes.

(2) A means of preventing growth of zinc over or out of its separator compartment.

(3) New types of separators.

(4) Cell characteristics as a function of electrode thickness during charge and discharge.

(5) Numbers of layers of separator material.

(6) Electrolyte concentration.

(7) Concentration of negative plate additives.

(8) Electrolyte quantity.

(9) Active material ratio.

(10) Maximum overcharge capability.

(11) Constant current versus constant potential charge methods.

(12) Methods of accelerated testing.

Because of funding limitations, it was not possible to include all of the variables listed and certain compromises were made.

The design variables investigated in the Phase I cells were:

(1) ZnO:Ag weight ratios, 1.4:1 and 1.2:1.

(2) KOH electrolyte concentration, 45% and 41%, both 90% saturated with ZnO.

(3) Negative plate shape, standard and wedge.

(4) Type of semipermeable membrane, RAI 2291, fibrous sausage casing (FSC), irradiated EM 476I (polypropylene), and EM 470 (Dynel).

(5) Type of absorber.

(6) Separator combination and electrode wrapped, i. e., negative vs positive wrap combination.

To evaluate these variables, ESB set up a test matrix on 70 cells consisting of seven basic designs. Each basic design group was divided into two five-cell groups, each also with a different design parameter. Table 1 lists the experimental design test matrix. The separator systems used in the cells consisted of combinations of two "absorbers" and two membranes as shown in Table 1. The "absorber" is a relatively inert material placed next to the positive electrode to help prevent oxidation of the membrane and to absorb electrolyte. The two types, both made by Kendall Mills, were Dynel (EM 470) and irradiated polypropylene (EM 476I). The semipermeable membranes were (FSC) fibrous sausage casing, made by the Visking Division of Union Carbide, and (RAI 2291) irradiated polyethylene grafted with methacrylic acid, made by RAI, Inc.

Table 1 also indicates which electrode was wrapped and how combinations of the separator membrane were positioned in the cell. For example, Design Group 3 had four layers of RAI 2291 on the positive electrode followed by two layers of FSC on the positive electrode; the absorber was dynel. Design Group 6 had three layers of RAI 2291 on the positive electrode and four layers of RAI 2291 on the negative electrode; the absorber was polypropylene. The electrolyte and ZnO:Ag weight ratio columns show the number of cells of each design group that contain the listed variable.

A nine-cell group of Mariner Mars 1969 cell designs was also tested for comparison with the new designs and is shown at the bottom of Table 1. The Mariner Mars 1969 cells contained one layer of polypropylene EM 476I and six layers of cellophane 193 PUDO around the positive electrode.

Initially, the pack tightness (or pressure) of all seven cell designs was to be the same based on a common set of design equations. The cell element (plate and separator stack) thickness was calculated based on the design thickness of the positive and negative plates and the measured wet thickness of the separator system used in each design. The wet thickness of each separator system was determined by measurement with a Randall-Stickney gauge after 120 h soak in 45% KOH. The resultant measurements are shown in Fig. 1. Pack tightness was calculated based on the wet thickness of the separator system at 1.64 N/cm^2. At this pressure it was thought that the major wrinkles in the separators would be smoothed out and still allow some free electrolyte to remain between the layers.

One cell of each design was fabricated early to verify the design tolerances. The element designs that contained two or more layers of FSC could be inserted into the cell jar easily. The element designs that did not contain FSC could not be inserted in the cell jar without damaging and compressing the cell element. The reason for this is that the FSC expands approximately 100% when wet while the RAI material expands 10% or less and generally contains many fine wrinkles. Since the separator systems were of different thicknesses, plastic shims were used to take up excess volume in the cell jar. The original pack pressures were reduced by decreasing shim thicknesses. Consequently, another design variable, pack tightness, was introduced somewhat randomly into the test. The final calculated pack pressures are listed in Table 1.

Design features common to all cells in both Phase I and II are listed in Table 2. The electrolyte was added to the cells under vacuum to remove air pockets. The cells were completely filled (flooded) and soaked for 72 h. After a formation charge, the cells were inverted to drain off the excess electrolyte. After draining, the cell fill holes were sealed. According to past design practice by ESB, the proper quantity of electrolyte is thus retained in the cell. However, this method of electrolyte adjustment is subject to question when using new types of separator material and needs further investigation. Table 3 lists the quantity of electrolyte retained in each cell, which was obtained by weighing the cells before and after draining.

III. PHASE I TESTING AND RESULTS

The cells were formation charged at 1.55 mA/cm^2 (1.53 A) for an input of 47 A-h (0.38 A-h/g of silver). The cells were discharged at 15 A to 1.25 V cutoff. The minimum discharge capacity was 0.313 A-h/g of silver for all designs except Group 5 which gave only 0.123 A-h/g of silver (15.1 A-h). For the second discharge of Design 5 cells, the discharge rate was reduced from 15 A to 8 A, but there was no appreciable increase in capacity. It was concluded that the Design 5 cell pack was too tight; however, it is also possible that there was not enough electrolyte in the cells.

The cell groups were given three to four additional cycles using two-step charge and discharge rates to attempt to obtain uniform performance from the cells. However, there was still considerable capacity variation among cells of the same design. The maximum variation was about 10 A-h. The reasons for the wide variations in a given design are not understood. Tables 4 through 10 give the detailed charge and discharge rates and the capacities of each cell and design group.

After approximately four months charged stand the cells were discharged, charged, and placed on a 24-h cycle regime at 50% depth of discharge (DOD). The cycle consisted of 2 h of discharge and a 22-h charge at a constant potential with a current limit of 1.5 A.

The cell groups were discharged through a resistance adjusted to give an average current of 7.50 A over 2 h (15 A-h). An Esterline-Angus 24-point recorder was used to record cell group current and cell group voltages. At 25- to 30-cycle intervals, each cell group was discharged until the first cell reached 1.30 V (100% DOD), to measure total capacity as a function of cycle life. When a cell in the group could not support the 50% DOD it was considered failed. The charge potential of 1.94 ±0.01 V/cell was used for the first 50 to 65 cycles (not all design groups were on the same cycle number) and was raised to 1.96 ±0.01 V thereafter because it appeared the cells were not accepting proper charge as noted by falling end-of-discharge voltage and rising end-of-charge current, primarily on Design Group 3. When the charge potential was increased, recovery was noted by the increase in end-of-discharge voltage. This was particularly evident on Design Group 3. There was no appreciable change in Design Group 2; however, Design

Group 7 started to develop leaks, apparently from high pressures, and this group was considered failed at 55 to 57 cycles. Figure 2 summaries the cycle life of the Phase I cells based on the first cell failure. With the exceptions of Designs 5 and 7 as noted above, the remaining design groups failed from loss of capacity due to negative electrode erosion. None of the cells failed by shorting through the separator system.

The eight-cell row assembly of Mariner Mars 1969 cells tested at the same time and cycled under the same routine failed at 32 cycles by shorting through the separator. The cells were also near failure due to negative electrode erosion because most of the active material was observed to be in the lower 25% of the plate grid.

Two design groups gave significantly better cycle results than the others. Design Group 1, with the wedge-shaped negative, gave 226 cycles compared with its control with standard negatives which gave 136 cycles. Design Group 2 cells gave 213 and 251 cycles for each of the 5 cell groups, suggesting that FSC is a much better separator. The results from groups 1 and 2 suggest that a significant improvement might be achieved by combining the wedge negative and the FSC separator.

The effect of electrolyte concentration is seen in Design Groups 2 and 3. The cell groups containing 45% KOH gave 10 to 20% higher cycle life than those with 41% KOH.

The increase in material ratio showed an improvement in cycle life of 10% to 20% as can be noted from the results obtained from Groups 4 and 6.

Since failures were due to loss of capacity and not shorts it is difficult to attribute this failure mode specifically to the separator system. It is felt that some other design factors or test factors not readily evident contributed to the results. Perhaps cell pack tightness played a role in the failure. The reasons for failure will be discussed further at the end of Phase II test results.

Impedance measurements were made on the cells with a model 502 Keithly milliohmmeter before formation, after formation, and after stand. The significance of the measurements at present is not completely understood, but the results were recorded for future reference. Generally, the impedances before formation ranged from about 40 to 60 mΩ and after formation were about 50% less. After the stand period the values increased about ten fold. No attempt has been made to correlate the impedance measurements with cell performance.

IV. PHASE II CELL DESIGNS

Due to schedule limitations, it became necessary to initiate Phase II of the program before Phase I cycling tests were completed. Consequently, one of the most promising designs, the wedge-shaped negative, was omitted from the Phase II effort.

The remaining six designs (Groups 2 through 7) were repeated in the Phase II effort with some modifications. The modifications were as follows:

(1) 43% KOH electrolyte saturated with ZnO was used in all cells.

(2) ZnO-to-Ag weight ratio was 1.5:1 in all cells.

(3) An additional layer of polypropylene (EM 476I) was added to Design Group 6 around the negative plate.

(4) Formation charge: 1.09 mA/cm^2 to 0.36 to 0.38 A-h/g of silver, or 2.1 V/cell.

Top off after seal at 1.09 mA/cm^2 to 0.38 to 0.42 A-h/g of silver, or 1.97 V/cell.

(5) Electrolyte was added to bring low cells up to the group mean value.

(6) Calculated pack pressures were reduced in Designs 4 and 5 by about 50%.

(7) Cell elements were designed to occupy full thickness of cell jar instead of using shims as in Phase I.

Table 11 summarizes the design group variables and shows the mean quantity of electrolyte in each group. Table 12 shows the quantity of electrolyte in each cell.

Since the cell elements were designed to occupy the full thickness of the cell jar, the design groups contained different numbers of plates. Plates were added to those designs that contained RAI 2291 separators because the thickness of this material is less than that of FSC, as noted previously in Phase I designs and shown in Fig. 1. The number of electrodes and their thicknesses are also recorded in Table 11.

V. PHASE II TESTING AND RESULTS

After the formation charge as noted above, the cells were discharged at a current density of 8.06 mA/cm^2 or approximately the C/4 rate (C is the rated capacity of the cell) to 1.30 V. This was followed by an additional charge/discharge cycle and recharge. The charge and discharge parameters and results of these three cycles are given in detail in Tables 13 through 19.

Following the third charge cycle, the cells were shipped to the Naval Ammunition Depot, Crane, Indiana, (NAD-Crane) for stand and cycle-life test. From the time the cells were first activated and during the test, they were in a room temperature environment estimated to be 25 ±4°C except during shipment from ESB to NAD Crane. After a stand period of approximately nine months, the cells were tested with a phenolphthalene solution for electrolyte leaks in preparation for cycling tests. No leaks were detected. Cells were monitored for leakage throughout the test, but leakage was not considered as criteria for the failure in these tests.

Before the cells were placed on cycle tests they were given two capacity check cycles at the C/4 discharge rate to 1.30 V per cell. The charge was in two steps as follows: 1.09 mA/cm^2 of positive plate area to 2.00 ±0.01 V/cell followed by a charge of 0.62 mA/cm^2 of positive plate area to 1.98 ±0.01 V/cell.

After the capacity check cycles, the cells were placed on an automatic cycle regime as six 19-cell batteries. The cycle regime was the same as used in Phase I tests: Discharge at C/4 rate for 2 h, recharge at a constant potential of 1.94 ±0.01 V/cell with a current limit of 1.50 A for 22 h. Individual battery and cell voltage measurements were recorded periodically on each cycle. Every 25 cycles the batteries were given a 100% discharge (until the first cell in the battery reached 1.30 V) to measure capacity degradation as a function of cycle life. If any cell in a battery dropped to 1.30 V during the 50% DOD cycles, the cell was removed from the battery and cycling was continued after adjusting the battery charge potential. The battery was considered to have failed when the first cell could not support the 50% DOD.

Figure 3 compares the capacities of each design before stand, after stand, and the second capacity check after stand. The spread in capacity and the average capacity are also shown in Fig. 3. It is seen that all design groups lost capacity during stand that was not recoverable on the second capacity check after stand. Design Group 3 produced the most consistent data and Group 4 gave the most inconsistent results with a capacity spread of over 20 A-h. Large spreads in capacity indicate there are uncontrolled factors in cell fabrication. The cycle data was analyzed to ascertain if the low capacity cell was the first cell to fail on cycling. The results are shown in Table 20 where the low cell of each capacity check cycle at 25-cycle intervals was recorded. The low cell was consistently low only in Design Group 5.

The results of the cycling test are summarized in Figs. 4, 5, and 6. Figure 4 shows the capacity available from each group as measured on the lowest cell at 25-cycle intervals. Only Design Group 2, containing four layers of FSC, passed the 100-cycle requirement. It gave 204 cycles before the first cell dropped below 50% of its rated capacity.

Design Groups 6 and 4, containing only the RAI separator material, failed first at 39 and 52 cycles, respectively. Design Groups 3, 5, and 7, containing combinations of RAI 2291 and FSC separators, failed at 84, 90, and 99 cycles. All failures were due to loss of capacity caused by the erosion of the negative active material.

A measure of the electrical performance of each battery is shown in Fig. 5, where the average cell potential at the end of 2 h of discharge on the cycling test is shown as a function of cycle. Design Group 2 with the FSC separator shows the best electrical performance. Design Groups 3, 5, and 6 with combinations of RAI 2291 and FSC separators are next, all with similar performance; Groups 4 and 6, containing only RAI 2291, again show the worst performance.

Figure 6 shows the rate of failure of the cells in each group. From this data it is seen that the failure rate is fairly uniform. Design Group 7 had an early failure. The autopsy and analysis of the failed cell revealed it was unusually dry and the failure was attributed to a manufacturing defect. Representative samples of failed cells from each Design Group were autopsied for failure analysis. It was observed that the negative plate material was concentrated on the lower portion of the plate grid and, in most instances, the edges of the lower portion of the plate were also devoid of active material. This type of failure is not strictly attributable to the separator system, or is not what might be termed a first-order failure caused by the separator. Shorting failures would be a first-order failure attributable to the separator system.

The data tends to lead one to the conclusion that the early failures of the design groups containing the RAI 2291 separator membrane were probably associated with the cell pack pressure. The pack pressure was less in Design Groups 4 and 6 than in the design group containing the FSC separator (Group 2) or in groups containing combinations of RAI 2291 and FSC (Groups 3, 5, and 7). The cycle results show the negative electrode to have eroded more rapidly and failed sooner in design groups with low pack pressures than in the design groups with high pack pressures. On the other hand, it is pointed out that the Design Group 5 cells in Phase I with pack pressures equal to the pressure of Design Group 2 with FSC separators failed to perform properly in that they delivered only about one-half their rated capacity.

From these results it is concluded that further testing and analysis are needed to elucidate the pertinent design factors affecting performance when using new types of separator membranes. A better knowledge of the effects and interactions of pack pressure (also better methods of measurement), electrolyte volume, and absorber are required. Since the RAI 2291 membrane and similar membranes absorb very little electrolyte and swell very little in comparison to cellulosic-type membranes it is possible that a thicker, more absorbent "absorber" might be beneficial. The nature of the movement or erosion of the negative material is also more complicated than indicated by the above discussion and is probably due to several effects. If the problem of negative plate erosion were solved, it would be a major advancement in the state-of-the-art in silver oxide-zinc battery technology.

The data do not indicate whether it is preferable to wrap the separator around the negative or positive electrode, nor do the data indicate if it is beneficial to use one absorber in preference to the other (EM 476I or EM 470). A more rigorous analysis of the data might show some subtle differences.

VI. CONCLUSIONS

Test results from six 19-cell batteries indicate that silver-zinc batteries can be designed to meet the requirements of spaceflight when such requirements call for high cycle life (more than 100 24-h cycles at 50% depth-of-discharge) after a period (at least 6 months) on charged open-circuit stand. Although the designs were not subjected to environmental tests nor were the performance parameters tested over an expected operational temperature range, the comparable results represent an improvement in cycle life over that of the Mariner Mars 1969 design by a factor of six.

The design parameters that effected an improvement in cycle life were:

(1) Increased electrolyte concentration.

(2) Increased negative-to-positive material ratio.

(3) Wedge-shaped negative plates.

(4) Fibrous sausage casing separators.

The wedge-shaped negative plate design was evaluated in cells with only the RAI 2291 separators. The wedge-shaped negative should be evaluated with the FSC separator. From the results obtained with the wedge negatives in conjunction with RAI separators (100% improvement), it is estimated the combination of wedge negative plates and FSC separators should produce a battery capable of 300 cycles.

From this work it could not be determined if it is better to wrap the separator membrane around the negative or positive plate. Of the two absorbers tested (EM 476I and EM 470), there was no indication that one was better than the other.

The results obtained from the use of RAI 2291 separator membranes were disappointing. Future development work should investigate the effects of the interactions of pack pressures, electrolyte volume, and thicker, more absorbent absorbers.

Since cell failures in this investigation were due to capacity loss and not shorting, the optimum number of layers of separators was not determined. Future work should optimize the number of layers of separators for a given life to prevent shorting.

Table 1. Phase I cell design matrix (10 cells/design)

DESIGN NUMBER	SEPARATOR[a] SYSTEM ABSORBER	MEMBRANE	ELECTROLYTE 41% KOH	45% KOH	ZnO/Ag WT RATIO 1.2:1	1.4:1	PACK PRESSURE N/cm^2
1	P/P	6 2291-	-	10	10b	-	0.08-1.64b
2	DYNEL	4 FSC -	5	5	10	-	3.29
3	DYNEL	4 2291+ 2 FSC +	5	5	10	-	1.64
4	P/P	6 2291-	10	-	5	5	0.08-0.49
5	DYNEL	4 2291- 2 FSC -	5	5	10	-	3.29
6	P/P	3 2291+ 4 2291-	10	-	5	5	0.49
7	DYNEL	2 FSC - 4 2291-	5	5	10	-	0.49
MARINER 69	P/P	6 CELLO +	45		0.76:1		

[a] ORDER OF PLATE WRAP IS AS LISTED
[b] 5 CELLS CONTAINED WEDGE NEGATIVES

\- NEGATIVE WRAP
\+ POSITIVE WRAP

Table 2. Phase I and II common design features

NEGATIVE PLATE		%
COMPOSITION:	ZnO	90
	HgO	3
	TEFLON	7
PROCESS:	DRY POWDER-SINTERED	
DENSITY:	2.75 g/cm^3	
GRID:	SILVER	2 - 2/0 D
POSITIVE PLATE		
COMPOSITION:	100% Ag	
DENSITY:	4.24 g/cm^3	
PROCESS:	PROPRIETARY	
GRID:	SILVER	
CELL JAR AND COVER	ABS (CYCOLAC T)	
	T	3.88 cm
	W	8.72 cm
	H	9.45 cm
SEALANT	EPOCAST 31/CA9216	

Table 3. Electrolyte quantities in Phase I cells

Design No.	Design Variation	Units	Adjusted Electrolyte Quantity					
			Cell Number					$\bar{X}_5$
			1	2	3	4	5	
1	Flat Plates	gm	121	118	119	118	118	119
		cc	79.2	77.2	77.8	77.2	77.2	77.8
	Wedge Plates	gm	149	149	150	151	151	150
		cc	97.5	97.5	98.0	98.6	98.6	98.0
2	45% KOH	gm	163	164	161	166	161	163
		cc	106	107	105	108	109	106
	41% KOH	gm	161	162	159	159	162	161
		cc	109	110	108	108	110	109
3	45% KOH	gm	141	143	143	143	144	143
		cc	92.1	93.6	93.6	93.6	94.1	93.5
	41% KOH	gm	139	139	139	146	141	141
		cc	94.6	94.6	94.6	99.3	96.1	96.0
4	1.4:1	gm	110	119	121	122	119	118
		cc	75.0	81.0	82.3	83.0	81.0	80.3
	1.2:1	gm	111	109	109	109	109	109
		cc	75.5	74.2	74.2	74.2	74.2	74.2
5	45% KOH	gm	142	147	149	151	148	147
		cc	92.8	96.2	97.4	98.7	96.8	96.1
	41% KOH	gm	143	147	142	143	144	144
		cc	97.3	100.0	96.6	97.3	98.0	98.0
6	1.4:1	gm	122	114	119	119	121	119
		cc	83.1	77.6	81.0	81.0	82.6	81.0
	1.2:1	gm	114	113	106	109	106	110
		cc	77.6	76.8	72.2	74.1	72.2	75.0

Table 4. Charge and discharge rates, Design Group 1

Design 1 (45% KOH)	Flat Negative Plates						Contoured Negative Plates					
Cell S/N	6	40	41	42	43	$\bar{X}_5$	8	44	45	46	47	$\bar{X}_5$
-Wrap, 6 RAI; 1 EM-476I(+)												
Cycle 1												
• Charge (formation), AH 1.53 amps to Input	47.2	47.2	47.2	47.2	47.2	47.2	47.2	47.2	47.2	47.2	47.2	47.2
• AC Impedance												
before charge, mohms	39	34	36	34	39	36	48	51	51	52	55	51
after charge, mohms	20	15	13	15	22	17	18	32	32	15	18	23
• Discharge, AH												
@ 15 amps to 1.25V (1st cell)	41.8	41.8	41.8	41.8	41.8	41.8	40.5	40.6*	40.6*	40.6*	40.6*	40.6
Midpoint voltage, volts	1.46	1.47	1.47	1.46	1.47	1.47	1.45	1.46	1.45	1.47	1.47	1.46
Cycle 2												
• Charge, AH								**	**	**	**	
Step 1 @ 1.53 amps to 1.99V	45.6	47.9	46.2	45.6	47.9	--	44.0	39.8	39.8	39.8	37.8	--
Step 2 @ 0.6 amp to Input											2.0	
Total											39.8	
• Discharge, AH							Procedural Change					
@ 15 amps to 1.25V/cell	42.8	46.8	46.3	42.6	42.7	45.2	(* 8 amps to 1.30 volts, 1st cell)					
Midpoint voltage, volts	1.45	1.46	1.48	1.45	1.45	1.46	(** 1.53 amps to input)					
Cycle 3												
• Charge, AH												
Step 1 @ 1.53 amps to 1.97V	22.6	43.1	46.2	32.9	38.2	--						
Step 2 @ 0.6 amp to input	14.0	--	--	4.8	4.8	--						
Total	36.6	43.1	46.2	37.7	43.0	--						
• Top off Charge, AH	--	--	--	--	--	--	--	--	--			
0.6 amp to 1.97V/cell										1.7	1.7	
Total										39.9	37.8	
• Discharge, AH												
Step I @ 15 amps to 1.25V (1st cell)	21.3	21.3	21.3	21.3	21.3	--	20.0	21.3	21.3	38.7	38.7	--
Step II @ 5 amps to 1.25 V/cell	14.4	20.5	23.1	14.4	21.3		0.9	17.5	19.1	3.4	1.9	
Total	35.7	41.8	44.4	35.7	42.6	40.0	20.9	38.8	40.4	42.1	40.6	
Midpoint Voltage, Volts, Step I	1.44	1.45	1.44	1.45	1.44	1.44	1.44	1.44	1.44	1.47	1.48	1.45
Cycle 4												
• Charge, AH												
Step I @ 1.5 amps to 1.97V/cell	37.9	37.9	36.9	36.2	36.2	--	45.7	36.2	36.2	36.9	36.9	--
Step II @ 0.6 amp to 1.97V/cell										12.2	11.4	
Total										49.1	48.3	
• Discharge, AH												
Step I @ 1.5 amps to 1.25V/1st cell	34.2	34.2	34.2	34.2	34.2	--	34.2	34.2	34.2	44.8	40.5	--
Step II @ 0.5 amp to 1.25V/cell	2.9	2.8	2.1	1.6	1.2		10.8	2.2	2.4	--	--	
Total	37.1	37.0	36.3	35.8	35.4	36.3	45.0	36.4	36.6	44.8	40.5	40.7
Midpoint Voltage, Volts, Step 1	1.45	1.46	1.46	1.46	1.46	1.46	1.45	1.44	1.44	1.46	1.46	1.45
Cycle 5												
• Charge, AH												
Step I @ 1.5 amps to 1.97V/cell	47.3	50.6	51.8	49.3	47.3	49.3	47.3	44.2	44.9	38.8	38.2	42.7
Step II @ 0.6 amp to 1.97V/cell	4.0	2.5	2.5	4.6	3.7	3.5	6.3	6.9	6.3	7.7	7.7	7.0
Total	51.3	53.1	54.3	53.9	51.0	52.7	53.6	51.1	51.2	46.5	45.9	49.7

Table 5. Charge and discharge rates, Design Group 2

Design 2	45% KOH						41% KOH					
S/N of Cell	1	9	10	11	12	$\bar{X}_5$	13	14	15	16	17	$\bar{X}_5$
+ Wrap: 1 EM-470, 4 FSC												
Cycle 1												
• Charge (formation), AH 1.23 amps to Input	47.0	47.0	47.0	47.0	47.0	47.0	47.0	47.0	47.0	47.0	47.0	47.0
• AC Impedance before charge, mohms	62	74	62	58	32	58	56	60	63	60	56	59
after charge, mohms	90	80	90	80	70	82	60	60	50	50	60	56
• Discharge, AH @ 15 amps to 1.25V (1st cell)	38.5	38.5	38.5	38.5	38.5	--	38.5	38.5	38.5	38.5	38.5	--
midpoint voltage, volts	1.47	1.47	1.47	1.46	1.47	1.47	1.48	1.48	1.48	1.48	1.48	1.48
Cycle 2												
• Charge, AH Step 1 @ 1.23 amps to 1.99V	39.6	43.6	39.6	20.5	37.4	36.1	41.0	41.0	38.0	33.8	40.5	38.9
Step 2 @ 0.70 amp to 2.00V	--	--	--	26.2	--	--						
Total	39.6	43.6	39.6	46.7	37.4	41.4						
• Discharge, AH @ 15 amps to 1.25V/Cell	41.2	45.6	23.5	43.7	33.0	37.4	43.1	42.5	34.8	32.8	42.1	39.1
midpoint voltage, volts	1.46	1.50	1.42	1.51	1.40		1.48	1.48	(Jar burst)	1.48	1.48	--
Cycle 3												
• Charge, AH Step 1 @ 1.23 amps to 1.97V	38.4	36.3	38.5	16.8	36.3		39.2	39.2		34.4	39.4	--
Step 2 @ 0.6 amp to 1.97V	--	--		13.1	--							
Total	38.4	36.3	38.5	29.9	36.3							
• Top off charge, AH .6 amps to 1.97V/cell	17.8	18.0	18.0	17.8	18.6	--	18.6	17.0	22.2	19.1	--	
Total	56.2	54.3	56.5	47.7	54.9	53.9	57.8	56.2	56.6	58.5	57.3	
• Discharge, AH* Step I @ 12 amps to 1.25V (1st Cell)	42.3	42.3	42.3	42.3	42.3	42.3	42.3	42.3	42.3	42.3	42.3	
Step II @ 4 amps to 1.25V/Cell	4.8	5.3	6.3	1.4	3.7	4.3	8.3	7.1	6.5	9.1	7.7	
Total	47.1	47.6	48.6	43.7	46.0	46.6	50.6	49.4	48.8	51.4	50.0	
Midpoint voltage, volts, Step I	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49	
Cycle 4												
• Charge, AH Step I @ .9 amps to 1.97V/cell	33.1	39.8	38.6	39.8	33.1	36.9	39.8	39.8	37.0	39.8	39.1	
Step II @ .6 amps to 1.97V/cell	11.1	2.2	4.0	3.5	11.5	6.4	5.9	5.4	4.0	5.9	5.3	
Total	44.2	42.0	42.6	43.3	44.6	43.3	45.7	45.2	41.0	45.7	44.4	
• AC Impedance, mohms after Cycle 4 charge	47	58	63	65	59	58	57	64	27	42	48	
Cell pack pressure: 80 ounces/in^2 Plate wrapped: Positive Order of Wrap, pos. to neg.: 1 EM470, 4 FSC ZnO to silver weight ratio 1.2:1												

(*) Step I 0.10 amp/in^2
Step II 0.33 amp/in^2

Table 6. Charge and discharge rates, Design Group 3

Design 3	45% KOH						41% KOH					
Cell S/N	2	18	19	20	21	$\bar{X}_5$	22	23	24	25	26	$\bar{X}_5$
+ Wrap: 1 EM-470, 4 RAI, 2 FSC												
Cycle 1												
• Charge (formation, AH 1.53 amps to Input	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1	47.1
• AC Impedance												
before charge, mohms	57	53	56	56	70	58	56	59	57	57	56	57
after charge, mohms	19	14	20	19	14	17	16	14	12	20	12	15
• Discharge, AH @ 15 amps to 1.25V (1st cell)	40.1	40.1	40.1	40.1	40.1	40.1	40.1	40.1	40.1	40.1	40.1	40.1
midpoint voltage, volts	1.42	1.46	1.45	1.45	1.46	1.45	1.46	1.46	1.46	1.46	1.47	1.46
Cycle 2												
• Charge, AH												
Step 1 @ 1.53 amps to 1.99V	16.6	20.1	33.7	19.3	38.5	--	37.0	36.2	39.2	38.5	38.6	--
Step 2 @ 0.70 amp to 2.00V	23.4	24.2	5.1	27.6	--	--	7.0	4.4				
Total	40.0	44.3	38.8	46.9	38.5	39.7	44.0	40.6	39.2	38.5	38.6	40.2
• Discharge, AH @ 8 amps to 1.40V/cell	40.3	43.7	38.5	43.7	36.4	40.5	43.7	39.8	41.8	36.0*	37.6*	39.8
midpoint voltage, volts	1.50	1.50	1.50	1.50	1.43	--	1.51	1.51	1.51	1.45	1.45	--
Cycle 3												
• Charge, AH												
Step 1 @ 1.53 amps to 1.97V	20.0	20.0	20.0	20.0	13.0		20.0	20.0	20.0	32.9	36.4	
Step 2 @ 0.6 amp to 1.97V	12.1	4.1	12.1	12.1	(Jar Burst)		10.3	8.6	15.7	--	--	
Total	32.1	24.1	32.1	32.1			30.3	28.6	35.7	32.9	36.4	32.8
• Top off Charge 0.6 amp to 1.97V/cell	8.8	14.0	13.8	8.7		13.2	17.8	11.6	13.7	13.2		
Total	40.9	38.1	45.9	40.8		43.5	46.4	47.3	46.6	49.6		
• Discharge, AH												
Step I @ 15 amps to 1.25V/(1st cell)	39.0	39.0	39.0	39.0	39.0	43.0	43.0	43.0	43.0	43.0	43.0	
Step II @ 5 amps to 1.25V/cell	3.9	3.4	8.5	6.0	6.0	5.4	5.6	3.4	4.3	1.8	3.4	
Total	42.9	42.4	47.5	45.0	44.4	48.6	46.4	47.3	44.8	44.8	46.4	
Midpoint Voltage, Volts Step I	1.47	1.46	1.46	1.46	1.46	1.48	1.46	1.46	1.46	1.46	1.46	
Cycle 4												
• Charge, AH												
Step I @ 1.1 amps to 1.97V/cell	39.8	34.6	34.6	34.6	35.9	34.8	34.8	34.8	34.8	34.8	34.8	
Step II @ 0.6 amp to 1.97V/cell	3.3	11.8	2.4	11.8	7.3	3.0	9.6	10.8	10.0	12.0	9.0	
Total	42.1	46.4	37.0	46.4	43.2	37.8	44.4	45.6	44.8	46.8	43.8	

Table 7. Charge and discharge rates, Design Group 4

Design 4 (41% KOH)	ZnO: Ag Weight Ratio = 1.4:1						ZnO: Ag Weight Ratio = 1.2:1					
Cell S/N	3	27	28	29	30	$\bar{X}_5$	52	53	54	55	56	$\bar{X}_5$
- Wrap, 6 RAI; 1 EM-4761 (+)												
Cycle 1												
• Charge (formation), AH 1.53 amps to Input	47.2	47.2	47.2	47.2	47.2	47.2	47.2	47.2	47.2	47.2	47.2	47.2
• AC Impedance												
before charge, mohms	39	39	37	39	39	39	36	36	37	38	41	38
after charge, mohms	20	24	18	36	17	23	16	23	16	23	12	18
• Discharge, AH @ 15 amps to 1.25V (1st cell)	41.8	41.8	41.8	41.8	41.8	41.8	40.6*	40.6*	40.6*	40.6*	40.6*	40.6
midpoint voltage, volts	1.46	1.47	1.46	1.47	1.48	1.47	1.50	1.49	1.50	1.49	1.49	1.49
Cycle 2												
• Charge, AH Step 1 @ 1.53 amps to 1.99V	47.9	47.9	48.0	47.5	47.5	47.8	(* 8 amp rate to 1.30V, 1st cell)					
• Discharge, AH @ 15 amps to 1.25V/cell	44.3	42.4	45.6	48.2	47.9	45.7						
midpoint voltage, volts	1.45	1.45	1.45	1.46	1.47	1.46						
Cycle 3												
• Charge, AH												
Step 1 @ 1.53 amps to 1.97V	22.6	36.4	43.1	43.8	44.6							
Step 2 @ 0.6 amp to Input	14.0	4.8	--	--	--							
Total	36.6	41.2	43.1	43.8	44.6	41.9						
• Top off charge 0.6 amp to 1.97V/cell	12.7	6.1	6.1	5.3	5.3	7.0	6.9	9.0	9.0	9.0	11.4	9.1
Total	49.3	47.3	49.2	49.1	49.9	48.9	44.4	45.5	47.0	46.7	46.4	46.0
• Discharge, AH												
Step I @ 15 amps to 1.25V (1st cell)	44.5	44.5	44.5	44.5	44.5	44.5	45.3	47.5	47.5	47.5	46.2	46.8
Step II @ 5 amps to 1.25V/cell	4.1	1.4	2.8	2.9	3.7	3.0	--	--	--	--	--	--
Total	48.6	45.9	47.3	47.4	48.2	47.5						
Midpoint Voltage, Volts, Step I	1.48	1.49	1.48	1.48	1.50	1.49	1.52	1.51	1.51	1.50	1.50	1.51
Cycle 4												
• Charge, AH												
Step I, @ 1.5 amps to 1.97V/cell	33.2	33.2	33.2	33.2	33.2	33.2	41.7	39.4	41.0	39.5	39.5	40.2
Step II @ 0.6 amp to 1.97V/cell	11.2	9.5	10.9	10.4	9.7	10.3	3.9	3.3	3.3	3.9	3.9	3.6
Total	44.4	42.7	44.1	43.6	42.9	43.5	45.6	42.7	44.3	43.4	43.4	43.8

Table 8. Charge and discharge rates, Design Group 5

Design 5	45% KOH						41% KOH					
Cell S/N	4	31	32	33	34	$\bar{X}_5$	35	36	37	38	39	$\bar{X}_5$
(4 RAI/2 FSC/1 EM-470/(+) - Wrap)												
Cycle 1												
• Charge (formation), AH 1.53 amps to Input	47.2	47.2	47.2	47.2	47.2	47.2	47.2	47.2	47.2	47.2	47.2	47.2
• AC Impedance												
before charge, mohms	45	39	44	47	49	45	50	46	48	45	48	47
after charge, mohms	23	21	25	16	20	21	22	25	19	18	17	20
• Discharge, AH												
@ 15 amps to 1.25V (1st cell)	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1
midpoint voltage, volts	1.35	1.42	1.39	1.42	1.42	1.40	1.42	1.43	1.44	1.43	1.43	1.43
Cycle 2												
• Charge, AH Step 1 @ 1.53 amps to 1.99V	26.4	28.4	21.4	21.3	19.2	23.3	21.8	21.4	21.4	21.1	22.3	21.6
• Discharge, AH												
@ 8 amps to 1.25V/cell	27.7	28.2	28.0	24.2	20.4	25.7	21.3	23.7	21.7	24.0	24.0	22.9
midpoint voltage, volts	1.46	1.48	1.46	1.47	1.48	1.47	1.48	1.46	1.46	1.48	1.47	1.47
Cycle 3												
• Charge, AH												
Step 1 @ 1.53 amps to 1.97V	13.8	18.3	17.7	17.7	14.2		17.6	14.4	16.7	17.2	17.2	
Step 2 @ 0.6 amp to Input	--	4.8	4.8	4.8	4.8		4.8	4.8	4.8	4.8	4.8	
Total	13.8	23.1	22.5	22.5	19.0	20.2	22.4	19.2	21.5	22.0	22.0	21.4
• Top off charge, AH												
.6 amps to 2.03 max. volts/cell	14.4	8.01	8.01	8.01	8.01	--	8.01	8.01	8.01	8.01	8.01	--
Total	28.2	31.1	30.5	30.5	27.0	31.5	30.4	27.2	29.5	30.0	30.0	29.4
• Discharge, AH												
Step I @ 15 amps to 1.25V (1st cell)	16.2	18.8	18.8	18.8	18.8	18.3	18.8	18.8	18.8	18.8	16.2	18.3
Step II @ 5 amps to 1.25V/Cell	5.4	10.8	11.5	7.5	9.1	8.9	10.8	11.9	9.4	9.6	12.3	10.8
Total	21.6	29.6	30.3	26.3	27.9	27.1	29.6	30.7	28.2	28.4	28.5	29.1
Midpoint voltage, volts, Step I	1.41	1.43	1.42	1.40	1.42	1.42	1.43	1.42	1.42	1.43	1.42	1.42
Cycle 4												
• Charge, AH												
Step I @ 1.53 amps to 1.97V/cell	19.6	20.0	20.0	21.6	21.6	20.6	23.2	20.0	22.6	22.6	22.6	22.2
Step II @ .6 amps to 1.97V/cell	4.9	6.7	6.9	6.9	2.9	6.4	4.9	4.4	4.0	6.4	4.7	4.8
Total	24.5	26.7	26.9	28.5	24.5	26.2	28.1	24.4	26.6	29.0	27.3	27.0
Cell pack pressure: 80 ounces/in^2												
Plate wrapped: negative												
Order of wrap: Positive to Negative: 1 EM470, 2 FSC, 4 RAI2291												
ZnO to Ag weight ratio: 1.2:1												

Table 9. Charge and discharge rates, Design Group 6

Design 6 (41% KOH)	ZnO/Ag Weight Ratio = 1.4:1						ZnO/Ag Weight Ratio = 1.2:1					
Cell S/N	5	48	49	50	51	$\bar{X}_5$	7	57	58	59	60	$\bar{X}_5$
(7 RAI/"Z" +, 1EM-476I, "U" -												
Cycle 1												
• Charge (formation, AH 1.53 amps to Input	47.2	47.2	47.2	47.2	47.2	47.2	47.2	47.2	47.2	47.2	47.2	47.2
• AC Impedance												
before charge, mohms	39	43	40	41	38	40	39	54	42	39	43	43
after charge, mohms	26	36	15	40	32	30	20	61	28	46	16	34
• Discharge, AH @ 8 amps to 1.30V (1st cell)	40.6	40.6	40.6	40.6	40.6	40.6	40.6	40.6	40.6	40.6	40.6	40.6
midpoint voltage, volts	1.46	1.46	1.47	1.48	1.48	1.47	1.45	1.48	1.48	1.47	1.45	1.47
Cycle 2												
• Charge, AH 1.53 amps	42.4	39.8	39.8	39.8	39.8	--	42.4	39.8	39.8	39.8	39.8	--
• Discharge, AH Step I @ 15 amps to 1.25V (1st cell)	21.9	44.7	43.2	37.2	32.5	35.9	15.8	37.1	36.7	44.5	38.2	34.2
Midpoint Voltage, Volts	1.42	1.43	1.44	1.43	1.45	1.43	1.38	1.44	1.43	1.45	1.42	1.42
Cycle 3												
• Charge, AH Step I @ 1.53 amps to 1.97V/cell	22.6	33.2	33.2	33.2	33.2		19.4	35.7	36.5	33.3	33.2	
Step II @ 0.6 amp to 1.97V/cell		9.8	6.9	8.6	10.1						8.0	
Total		43.0	40.1	41.8	43.3						41.2	
• Top Off Charge, 0.6 amp to 1.97 + .03 -0 volt/cell	19.9	2.1	2.5	1.7	1.7		17.1	8.8	8.8	8.8	2.6	
Total	42.5	45.1	42.6	43.5	45.0	43.7	36.5	44.5	45.3	42.1	35.8	40.8
• Discharge, AH Step I @ 15 amps to 1.25V 1st cell	35.7	35.7	35.7	35.7	35.7	35.7	42.8	47.5	46.2	46.2	46.8	45.9
Step II @ 5 amps to 1.25V/cell	1.5	2.6	2.1	2.6	2.2	2.2						
Total	37.2	38.3	37.8	38.3	37.9	37.9						
Midpoint Voltage, Volts, Step I	1.46	1.44	1.45	1.44	1.45	1.45	1.46	1.45	1.45	1.45	1.44	1.45
Cycle 4												
• Charge, AH Step I @ 1.5 amps to 1.97V/cell	40.0	37.0	37.0	31.4	31.4	35.4	41.0	35.3	35.3	41.0	38.2	38.2
Step II @ 0.6 amp to 1.97V/cell	4.1	7.2	7.2	5.0	3.5	5.4	4.0	7.3	7.4	8.0	7.5	6.8
Total	44.1	44.2	44.2	36.4	34.9	40.8	45.0	42.6	42.7	49.0	45.7	45.0

Table 10. Charge and discharge rates, Design Group 7

Plate Wrapped: Positive, Order of Wrap: 1 EM470, 4 RAI2291, 2 FSC												
	41% KOH						45% KOH					
Test Parameter and S/N	61	62	63	64	65	$\bar{X}_5$	66	67	68	69	70	$\bar{X}_5$
Cycle 1												
• Charge (formation), AH 0.97 amp to input	48.0	48.0	48.0	48.0	48.0	48.0	48.0	48.0	48.0	48.0	48.0	48.0
• AC Impedance												
Before formation, mohms	54	53	44	50	45	49	51	63	59	53	50	55
After formation, mohms	30	27	27	23	29	27	38	28	33	40	39	36
• Discharge, AH												
14 amps to 1.30V 1st cell	32.7	32.7	32.7	32.7	32.7	32.7	37.1	37.1	37.1	37.1	37.1	37.1
Midpoint Voltage	1.47	1.48	1.47	1.47	1.47	1.47	1.48	1.47	1.48	1.48	1.47	1.48
Cycle 2												
• Charge, AH												
Step I at 0.97 amp to 1.97V 1st cell	35.7	35.7	35.7	35.7	35.7	35.7	34.9	34.9	34.9	34.9	34.9	34.9
Step II at 0.6 amp to 1.97V/cell	5.1	3.9	2.0	3.6	1.4	3.2	14.5	1.4	0.8	14.5	14.5	9.1
Total	40.8	39.6	37.7	39.3	37.1	38.9	49.4	36.3	35.7	49.4	49.4	44.0
• Discharge, AH												
14 amps to 1.25V 1st cell	34.5	34.5	34.5	34.5	34.5	34.5	31.9	31.9	31.9	31.9	31.9	31.9
4 amps to 1.25V/cell	7.5	9.7	5.4	8.3	1.3	5.6	7.9	3.3	5.0	9.9	10.0	7.2
Total	42.0	44.2	39.9	42.8	35.8	40.1	39.8	35.2	36.9	41.8	41.9	39.1
Midpoint Voltage at 14 amps	1.45	1.45	1.45	1.45	1.45	1.45	1.46	1.46	1.46	1.46	1.46	1.46
Cycle 3												
• Charge, AH												
Step I at 0.97 amp to 1.97V 1st cell	30.0	30.0	30.0	30.0	30.0	30.0	34.8	34.8	34.8	34.8	34.8	34.8
Step II at 0.6 amp to 1.97V/cell	4.4	4.4	4.4	2.6	4.4	4.0	1.8	2.8	5.4	4.2	4.2	2.9
Total	34.4	34.4	34.4	32.6	34.4	34.0	36.6	37.6	40.2	39.0	35.0	37.7

NOTES: (1) Cell nominal capacity 28 AH based on 0.25 AH/gram silver.
(2) Date of activation: 11/3/69 - Date on charged stand: 11/21/69.

Table 11. Phase II design group construction features

Design Group	Separator[a] System	Pack Pressure N/cm^2	Number of Plates			Plate Thickness, mm			Rated* Capacity Ah	Electrolyte ave/cell	
			Positive	Full Negative	Half Negative	Positive	Full Negative	Half Negative		gm	cc
2	1EM470 + 4FSC +	3.29	8	7	2	6.35	17	8.64	25	176	118
3	1EM470 + 2FSC + 4RAI2291 +	1.64	9	8	2	6.35	17	8.64	28	153	102
4	1EM476 I - 6RAI -	0.25	10	11	0	6.35	17	None Used	31	139	93
5	1EM470 - 2FSC - 4RAI2291 -	1.64	9	8	2	6.35	17	8.64	28	158	106
6	7RAI2291[b] 2EM476 I	0.49	9	10	0	6.35	17	None Used	28	147	98
7	1EM470 + 4RAI2291 + 2FSC +	1.64	9	8	2	6.35	17	8.64	28	152	101

*Rated at 0.25 Ah/gm of Silver

[a]Order of wrap is as listed: - Negative plate wrap, + positive plate wrap

[b]Both electrodes wrapped: + EM476I, 3RAI 2291; - 4RAI2291, EM476I

Table 12. Phase II adjusted electrolyte quantities

Design No.	2		3		4		5		6		7	
Quantity KOH	GMS	CC	GMS	CC	GMS	CC	GMS	CC	GMS	CC	GMS	CC
Cell No.												
1	175	117	154	103	138	92.0	160	107	145	96.7	152	101
2	177	118	150	100	143	95.4	158	105	147	98.1	153	102
3	175	117	148	98.7	137	91.3	160	107	143	95.4	152	101
4	175	117	158	105	139	92.6	160	107	151	100	152	101
5	176	117	154	103	140	93.4	160	107	155	103	152	101
6	175	117	151	101	140	93.4	160	107	151	100	152	101
7	177	118	155	103	138	92.0	160	107	147	98.1	152	101
8	175	117	151	101	139	92.6	153	102	150	100	152	101
9	175	117	154	103	138	92.0	160	107	149	99.4	152	101
10	175	117	152	101	140	93.4	160	107	145	96.7	152	101
11	175	117	153	102	138	92.0	160	107	145	96.7	152	101
12	177	118	154	103	139	92.6	156	104	147	98.1	152	101
13	175	117	150	100	138	92.0	160	107	146	97.4	152	101
14	181	121	153	102	141	94.0	160	107	147	98.1	158	105
15	177	118	157	105	141	94.0	160	107	144	95.9	152	101
16	177	118	148	98.7	142	94.7	160	107	145	96.7	152	101
17	175	117	151	101	142	94.7	158	105	146	97.4	152	101
18	175	117	153	102	138	92.0	160	107	149	99.4	152	101
19	175	117	153	102	141	94.0	158	105	145	96.7	152	101
20	175	117	151	101	136	90.7	156	104	145	96.7	-	-
21	175	117	155	103	136	90.7	156	104	145	96.7	-	-
22	178	119	157	105	138	92.0	150	100	146	97.4	-	-
$\overline{X}$	176	118	153	102	139	92.8	158	106	147	97.9	152	101

Table 13. Cycling performance of Phase II Design 2 cells

Plate Wrapped: Positive; Order of Separation, + to -: 1EM470, 4FSC; Nominal Capacity: 25 AH											
Test Parameter and Cell S/N	1	2	3	4	5	6	7	8	9	10	11
Cycle 1											
• Charge (formation), AH											
0.86 amp to input or 2.1V 1st cell	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8
0.86 amp to 1.97V 1st cell (after seal)	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Total, AH	39.4	39.4	39.4	39.4	39.4	39.4	39.4	39.4	39.4	39.4	39.4
• AC Impedance before formation, mohms	76	72	76	76	73	69	74	72	61	84	76
• AC Impedance after cycle 3 charge, mohms	50	44	27	32	63	36	60	51	78	39	46
• Discharge, AH											
6.4 amps to 1.30V 1st cell	35.8	35.8	35.8	35.8	35.8	35.8	35.8	35.8	35.8	35.8	35.8
Cycle 2											
• Charge, AH											
Step 1 @ .86 amp to 2.0V (1st cell)	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1
Step 2 @ .50 amp to 1.98V/cell	4.2	3.5	2.4	2.5	3.5	1.2	2.4	2.4	2.4	2.4	1.0
Total, AH	39.3	38.6	37.5	37.6	38.6	36.3	37.5	37.5	37.5	37.5	36.1
• Discharge, AH											
6.4 amps to 1.30V/cell	39.6	39.6	38.4	39.0	39.9	39.0	39.2	39.2	40.0	39.4	37.8
Cycle 3											
• Charge											
Step 1 @ .86 amp to 2.0V (1st cell)	28.3	28.3	28.3	28.3	28.3	28.3	28.3	28.3	28.3	28.3	28.3
Step 2 @ .50 amps to 1.98V/cell	4.8	7 1	7.1	6.1	7.2	7.4	7.1	7.2	6.1	7.2	7.7
Total, AH	33.1	35.4	35.4	34.4	35.5	35.7	35.4	35.5	34.4	35.5	36.0

NOTES:
(1) Cell nominal capacity based on .25 AH/gm silver.
(2) Cell electrolyte: 43% KOH 90% saturated with Zn0.
(3) Zn0 to silver weight ratio: 1.5:1

Table 13 (contd)

Plate Wrapped: Positive; Order of Separation, + to -: 1EM470, 4FSC; Nominal Capacity: 25 AH								
Test Parameter and Cell S/N	12	13	14	15	16	17	18	19
Cycle 1								
• Charge (formation), AH								
0.86 amp to input or 2.1 volts 1st cell	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8
0.86 amp to 1.97V 1st cell (after seal)	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Total, AH	39.4	39.4	39.4	39.4	39.4	39.4	39.4	39.4
• AC Impedance before formation, mohms	78	79	70	78	81	69	75	73
• AC Impedance after cycle 3 charge, mohms	30	41	36	23	24	20	27	20
6.4 amps to 1.30V 1st cell	35.8	35.8	35.8	35.8	35.8	35.8	35.8	35.8
Cycle 2								
• Charge, AH								
Step 1 @ .86 amps to 2.0V (1st cell)	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1
Step 2 @ .50 amp to 1.98V/cell	1.1	4.7	4.7	2.2	1.0	1.1	2.5	3.7
Total, AH	36.2	39.8	39.8	37.3	36.1	36.2	37.6	38.8
• Discharge, AH								
6.4 amps to 1.30V/cell	35.8	40.6	41.0	39.6	37.6	38.8	40.2	40.2
Cycle 3								
• Charge								
Step 1 @ .86 amp to 2.0V (1st cell)	28.3	28.3	28.3	28.3	28.3	28.3	28.3	28.3
Step 2 @ .50 amp to 1.98V/cell	7.0	7.2	7.4	7.9	7.5	7.5	7.6	7.3
Total, AH	35.3	35.5	35.7	36.2	35.8	35.8	35.9	35.6

NOTES:
(1) Cell nominal capacity based on .25 AH/gm silver.
(2) Cell electrolyte: 43% KOH 90% saturated with Zn0.
(3) Zn0 to silver weight ratio: 1.5:1

Table 14. Cycling performance of Phase II Design 3 cells

Plate Wrapped: Positive; Order of Separation, + to -: 1EM470, 2FSC; 4RAI; Cell Nominal Capacity: 28 AH										
Test Parameter and Cell S/N	23	24	25	26	27	28	29	30	31	32
Cycle 1										
• Charge (formation), AH										
0.97 amp to input or 2.1V 1st cell	42.4	42.4	42.4	42.4	42.4	42.4	42.4	42.4	42.4	42.4
0.97 amp to 1.97V 1st cell (after seal)	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Total, AH	43.7	43.7	43.7	43.7	43.7	43.7	43.7	43.7	43.7	43.7
• AC Impedance before formation mohms	52	43	50	51	48	54	57	43	43	63
• AC Impedance after cycle 3 charge, mohms	36	36	65	42	54	34	35	28	27	41
• Discharge, AH										
7.2 amps to 1.30V 1st cell	39.4	39.4	39.4	39.4	39.4	39.4	39.4	39.4	39.4	39.4
Cycle 2										
• Charge, AH										
Step 1 @ 0.97 amp to 2.0V (1st cell)	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6
Step 2 @ 0.55 amp to 1.98V/cell	2.5	1.7	1.7	4.1	1.9	1.7	1.4	2.9	2.0	1.5
Total, AH	41.1	38.9	38.9	42.7	40.5	40.3	40.0	41.5	40.6	40.1
• Discharge, AH										
7.2 amps to 1.30V/cell	38.1	38.2	35.8	41.6	37.9	38.9	37.8	39.9	38.1	37.2
Cycle 3										
• Charge										
Step 1 @ 0.97 amp to 2.0V (1st cell)	36.8	36.8	35.0	36.8	36.8	36.8	36.8	36.8	36.8	36.8
Step 2 @ 0.55 amp to 1.98V/cell	1.0	0.9	2.2	2.5	1.2	3.0	2.6	1.9	3.2	1.8
Total, AH	37.8	37.7	37.2	39.3	38.0	39.8	39.4	38.7	40.0	38.6

NOTES: (1) Cell nominal capacity based on .25 AH/gm silver.
(2) Cell electrolyte: 43% KOH 90% saturated with ZnO.
(3) ZnO to silver weight ratio: 1.5:1.

Table 14 (contd)

Plate Wrapped: Positive: Order of Separation, + to -: 1EM470, 2FSC; 4RAI; Cell Nominal Capacity: 28 AH									
Test Parameter and Cell S/N	33	34	35	36	37	38	39	40	41
Cycle 1									
• Charge (formation), AH									
0.97 amp to input or 2.1V 1st cell	42.4	42.4	42.4	42.4	42.4	42.4	42.4	42.4	42.4
0.97 amp to 1.97V 1st cell (after seal)	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Total, AH	43.7	43.7	43.7	43.7	43.7	43.7	43.7	43.7	43.7
• AC Impedance before formation, mohms	53	45	64	53	47	47	58	46	45
• AC Impedance after cycle 3 charge, mohms	34	40	39	59	30	24	33	45	30
• Discharge, AH									
7.2 amps to 1.30V 1st cell	39.4	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
Cycle 2									
• Charge, AH									
Step 1 @ 0.97 amp to 2.0V (1st cell)	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6
Step 2 @ 0.55 amp to 1.98V/cell	2.0	1.8	3.6	2.4	3.7	3.4	2.2	1.8	4.1
Total, AH	40.3	40.4	42.2	41.0	42.3	42.0	40.8	40.4	42.7
• Discharge, AH									
7.2 amps to 1.30V/cell	31.2	36.4	40.5	37.5	42.1	40.3	41.1	38.4	41.9
Cycle 3									
• Charge									
Step 1 @ 0.97 amp to 2.0V (1st cell)	36.8	36.8	36.8	36.8	36.8	36.8	31.5	31.5	31.5
Step 2 @ 0.55 amp to 1.98V/cell	2.1	0.9	2.7	2.2	3.1	0.9	4.0	7.3	1.4
Total, AH	38.9	37.7	39.5	39.0	39.9	37.7	35.5	38.8	32.9

NOTES: (1) Cell nominal capacity based on 0.25 AH/gm silver.
(2) Cell electrolyte: 43% KOH 90% saturated with Zn0.
(3) Zn0 to silver weight ratio: 1.5:1

Table 15. Cycling performance of Phase II Design 4 cells

Plate Wrapped: Negative; Order of Separation, + to -: 1EM476I, 6RAI; Cell Pack Pressure:
Nominal Capacity: 31 AH

Test Parameter and Cell S/N	45	46	47	48	49	50	51	52	53	54
Cycle 1										
• Charge (formation), AH										
1.08 amps to input or 2.1V 1st cell	41.2	41.2	41.2	41.2	41.2	41.2	41.2	41.2	41.2	41.2
1.08 amps to 1.97V 1st cell (after seal)	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4
Total, AH	48.6	48.6	48.6	48.6	48.6	48.6	48.6	48.6	48.6	48.6
• AC Impedance before formation, mohms	43	44	35	35	34	36	40	48	36	40
• AC Impedance after cycle 3 charge, mohms	58	53	38	48	53	32	43	39	34	43
• Discharge, AH										
8.0 amps to 1.30V 1st cell	48.5	48.5	48.5	48.5	48.5	48.5	48.5	48.5	45.7	45.7
Cycle 2										
• Charge, AH										
Step 1 @ 1.08 amps to 2.0V (1st cell)	48.9	49.4	48.9	49.4	48.9	48.9	49.4	49.4	48.9	48.9
Step 2 @ .62 amp to 1.98V/cell	0.4	1.2	0.8	1.6	0.4	0.9	2.6	3.4	0.4	0.4
Total, AH	49.3	50.6	49.7	51.0	49.3	49.8	52.0	52.8	49.3	49.3
• Discharge, AH										
8.0 amps to 1.30V/cell	46.6	48.0	47.6	47.8	46.6	47.6	50.6	48.2	46.4	45.9
Cycle 3										
• Charge										
Step 1 @ 1.08 amps to 2.0V (1st cell)	33.6	33.6	33.6	34.2	35.4	35.4	33.7	32.7	32.7	32.3
Step 2 @ .62 amps to 1.98V/cell	4.5	9.2	9.2	7.2	9.2	9.2	5.9	3.0	7.2	3.7
Total, AH	38.1	42.8	42.8	41.4	44.6	44.6	39.6	35.7	39.9	36.4

NOTES:
(1) Cell nominal capacity based on 0.25 AH/gm silver.
(2) Cell electrolyte: 43% KOH 90% saturated with Zn0.
(3) Zn0 to silver weight ratio: 1.5:1

Table 15 (contd)

Plate Wrapped: Negative; Order of Separation, + to -: 1EM476I, 6RAI; Cell Pack Pressure: Nominal Capacity: 31 AH									
Test Parameter and Cell S/N	55	56	57	58	59	60	61	62	63
Cycle 1			123 g						
• Charge (formation), AH									
1.08 amps to input or 2.1 volts 1st cell	41.2	41.2	41.2	41.2	41.2	41.2	41.2	41.2	41.2
1.08 amps to 1.97V 1st cell (after seal)	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2
Total, AH	48.4	48.4	48.4	48.4	48.4	48.4	48.4	48.4	48.4
• AC Impedance before formation, mohms	42	32	34	30	36	48	34	40	40
• AC Impedance after cycle 3 charge, mohms	47	37	38	39	38	40	37	47	34
• Discharge, AH									
8.0 amps to 1.30V 1st cell	45.7	45.7	45.7	45.7	45.7	45.7	42.8	42.8	42.8
Cycle 2									
• Charge, AH									
Step 1 @ 1.08 amps to 2.0V (1st cell)	48.9	49.4	48.9	48.9	48.9	48.9	48.9	48.9	48.9
Step 2 @ .62 amps to 1.98V/cell	0.4	1.4	1.4	0.5	0.4	0.5	0.4	0.4	0.4
Total, AH	49.3	50.8	50.3	49.4	49.3	49.4	49.3	49.3	49.3
• Discharge, AH									
8.0 amps to 1.30V/cell	46.6	48.4	45.9	46.3	46.7	47.3	48.4	49.0	50.2
Cycle 3									
• Charge									
Step 1 @ 1.08 amps to 2.0V (1st cell)	32.3	32.7	32.7	34.2	34.2	32.7	32.7	35.4	32.8
Step 2 @ .62 amp to 1.98V/cell	5.4	3.0	6.6	5.6	3.6	6.8	3.7	5.6	3.7
Total, AH	37.7	35.7	39.3	39.8	37.8	39.5	36.4	41.0	36.5

NOTES:
(1) Cell nominal capacity based on 0.25 AH/gm silver.
(2) Cell electrolyte: 43% KOH 90% saturated with Zn0.
(3) Zn0 to silver weight ratio: 1.5:1

Table 16. Cycling performance of Phase II Design 5 cells

Plate Wrapped: Negative; Order of Separation, + to -: 1EM470, 2FSC, 4RAI;
Cell Nominal Capacity: 28 AH

Test Parameter and Cell S/N	67	68	69	70	71	72	73	74	75	76	77
Cycle 1											
• Charge (formation), AH .97 amp to input or 2.1V 1st cell	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2
• AC Impedance before formation mohms	49	36	48	51	48	42	26	57	43	54	44
• AC Impedance, after cycle 3 chg., mohms	42	49	82	66	44	60	58	54	58	44	84
• Discharge, AH 7.2 amps to 1.30V 1st cell	30.7	30.7	30.7	30.7	30.7	30.7	30.7	30.7	30.7	30.7	30.7
Cycle 2											
• Charge, AH											
Step 1 @ .97 amp to 2.0V (1st cell)	29.6	29.6	29.6	29.6	29.6	29.6	29.6	29.6	29.6	29.6	29.6
Step 2 @ .55 amp to 1.98V/cell	4.4	5.5	4.7	4.4	4.7	5.9	3.0	4.4	3.0	4.4	4.4
Total, AH	34.0	35.1	34.3	34.0	34.3	35.5	32.6	34.0	32.6	34.0	34.0
• Discharge, AH 7.2 amps to 1.30V/cell	42.6	42.1	41.1	41.1	42.8	39.8	39.8	37.2	39.8	42.8	42.6
Cycle 3											
• Charge											
Step 1 @ .97 amp to 2.0V (1st cell)	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6
Step 2 @ .55 amp to 1.98V/cell	7.8	9.4	8.6	6.9	8.3	6.0	11.7	3.5	6.8	5.6	6.8
Total, AH	38.4	40.0	39.2	37.5	38.9	36.6	42.3	34.1	37.4	36.2	37.4

NOTES: (1) Cell nominal capacity based on 0.25 AH/gm silver.
(2) Cell electrolyte: 43% KOH 90% saturated with ZnO.
(3) ZnO to silver weight ratio: 1.5:1.

Table 16 (contd)

Plate Wrapped: Negative; Order of Separation, + to -: 1EM470, 2FSC, 4RAI; Cell Pack Pressure: 40 oz/in^2; Cell Nominal Capacity: 28 AH

Test Parameter and Cell S/N	78	79	80	81	82	83	84	85
Cycle 1								
• Charge (formation), AH								
0.97 amp to input or 2.1V 1st cell	42.2	42.2	42.2	42.2	42.2	42.2	42.2	42.2
• AC Impedance before formation mohms	44	32	49	55	68	54	63	60
• AC Impedance after cycle 3 chg., mohms	67	32	43	75	58	51	63	52
7.2 amps to 1.30V 1st cell	30.7	30.7	30.7	30.7	30.7	30.7	30.7	30.7
Cycle 2								
• Charge, AH								
Step 1 @ .97 amp to 2.0V (1st cell)	29.6	29.6	29.6	29.6	29.6	29.6	29.6	29.6
Step 2 @ .55 amp to 1.98V/cell	4.1	4.4	4.1	4.1	4.4	5.6	3.0	4.4
Total, AH	33.7	34.0	34.0	33.7	34.0	35.2	32.6	34.0
• Discharge, AH								
7.2 amps to 1.30V/cell	38.5	31.8	43.0	42.1	42.6	42.3	42.5	42.4
Cycle 3								
• Charge								
Step 1 @ .97 amp to 2.0V (1st cell)	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6
Step 2 @ .55 amp to 1.98V/cell	6.0	6.0	7.8	10.0	7.8	7.8	10.0	6.0
Total, AH	36.5	36.6	38.3	40.5	38.3	38.3	40.5	36.5

NOTES:
(1) Cell nominal capacity based on 0.25 AH/gm silver.
(2) Cell electrolyte: 43% KOH 90% saturated with Zn0.
(3) Zn0 to silver weight ratio: 1.5:1.

Table 17. Cycling performance of Phase II Design 6 cells

Plate Wrapped: Both; Order of Separation, + to -: 1EM476I, 3RAI, 1EM476I, 4RAI;
Cell Nominal Capacity: 28 AH

Test Parameter and Cell S/N	89	90	91	92	93	94	95	96	97	98
Cycle 1										
• Charge (formation), AH										
.97 amp to input or 2.1V 1st cell	39.3	39.3	39.3	39.3	39.3	39.3	39.3	39.3	39.3	39.3
.97 amp to 1.97V 1st cell (after seal)	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3
Total, AH	45.6	45.6	45.6	45.6	45.6	45.6	45.6	45.6	45.6	45.6
• AC Impedance before formation, mohms	37	34	30	44	27	28	23	38	46	34
• AC Impedance after cycle 3 chg, mohms	50	41	59	37	48	64	62	42	57	58
• Discharge, AH										
7.2 amps to 1.30V 1st cell	39.4	39.4	39.4	39.4	39.4	39.4	39.4	39.4	39.4	39.4
Cycle 2										
• Charge, AH										
Step 1 @ .97 amp to 2.0V (1st cell)	47.6	47.6	47.6	47.6	47.6	47.6	47.6	47.6	47.6	47.6
Step 2 @ .55 amp to 1.98V/cell	0.6	2.4	1.5	2.4	2.4	2.0	2.0	2.4	0.9	0.9
Total, AH	48.2	50.0	49.1	50.0	50.0	49.6	49.6	50.0	48.5	48.5
• Discharge, AH										
7.2 amps to 1.30V/cell	40.8	44.2	39.6	44.3	42.5	40.7	43.0	44.8	42.5	41.5
Cycle 3										
• Charge, AH										
Step 1 @ .97 amps to 2.0V (1st cell)	31.4	31.4	31.4	31.4	31.4	31.4	31.4	31.4	31.4	31.4
Step 2 @ .55 amp to 1.98V/cell	7.8	5.2	5.6	6.6	5.6	6.9	10.5	10.8	9.2	4.8
Total, AH	39.2	36.6	37.0	38.0	37.0	38.3	41.9	42.2	40.6	36.2

NOTES:
(1) Cell nominal capacity based on 0.25 AH/gm silver.
(2) Cell electrolyte: 43% KOH 90% saturated with ZnO.
(3) ZnO to silver weight ratio: 1.5:1.

Table 17 (contd)

Plate Wrapped: Both; Order of Separation, + to -: 1EM476I, 3RAI, 1EM476I, 4RAI; Cell Nominal Capacity: 28 AH

Test Parameter and Cell S/N	99	100	101	102	103	104	105	106	107
Cycle 1									
• Charge (formation), AH									
.97 amp to input or 2.1V 1st cell	39.3	39.3	39.3	39.3	39.3	39.3	39.3	39.3	39.3
.97 amp to 1.97V 1st cell (after seal)	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3
Total, AH	45.6	45.6	45.6	45.6	45.6	45.6	45.6	45.6	45.6
• AC Impedance before formation, mohms	38	25	24	23	37	50	36	38	43
• AC Impedance after cycle 3 charge, mohms	47	41	52	43	35	43	42	41	37
• Discharge, AH									
7.2 amps to 1.30V 1st cell	41.6	41.6	41.6	41.6	41.6	41.6	41.6	41.6	39.4
Cycle 2									
• Charge, AH									
Step 1 @ .97 amp to 2.0V (1st cell)	47.6	47.6	47.6	47.6	47.6	47.6	47.6	47.6	47.6
Step 2 @ .55 amp to 1.98V/cell	0.9	3.3	3.8	3.6	3.3	3.6	3.3	0.9	2.4
Total, AH	48.5	50.9	51.4	51.2	50.9	51.2	50.9	48.5	50.0
• Discharge, AH									
7.2 amps to 1.30V/cell	41.2	42.4	43.4	44.0	41.8	41.5	41.3	39.0	43.2
Cycle 3									
• Charge									
Step 1 @ .97 amp to 2.0V (1st cell)	31.4	31.4	31.4	31.4	31.4	31.4	31.4	31.4	31.4
Step 2 @ .55 amp to 1.98V/cell	8.1	9.3	6.6	5.6	5.6	6.9	6.6	7.5	4.8
Total, AH	39.5	40.7	38.0	37.0	37.0	38.3	38.0	38.9	36.2

NOTES: (1) Cell nominal capacity based on 0.25 AH/gm silver.
(2) Cell electrolyte: 43% KOH 90% saturated with Zn0.
(3) Zn0 to silver weight ratio: 1.5:1.

Table 18. Cycling performance of Phase II Design 7 cells

Plate Wrapped: Positive; Order of Separation, + to -: 1EM470, 4RAI2291, 2FSC; Cell nominal capacity: 28 AH

Test Parameter and Cell S/N	111	112	113	114	115	116	117	118	119	120
Cycle 1										
• Charge (formation), AH										
0.97 amp to input or 2.1V 1st cell	40.6	40.6	40.6	40.6	40.6	40.6	40.6	40.6	40.6	40.6
0.97 amp top-off charge to 1.97V 1st cell (sealed)	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1
Total Input	45.7	45.7	45.7	45.7	45.7	45.7	45.7	45.7	45.7	45.7
• AC Impedance before formation, mohms	57	56	62	52	45	44	45	44	43	47
• AC Impedance after cycle 3 charge	84	25	40	24	28	42	25	92	90	14
• Discharge, AH										
7.2 amps to 1.30V 1st cell	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0
Cycle 2										
• Charge, AH										
Step I @ 0.97 amp to 2.00V 1st cell	29.6	29.6	29.6	29.6	29.6	29.6	29.6	29.6	29.6	29.6
Step II @ 0.6 amp to 1.98V/cell	9.0	6.9	8.7	8.2	9.5	10.5	8.2	7.1	10.2	5.8
Total	38.6	36.5	38.3	37.8	29.1	40.1	37.8	36.7	39.8	35.4
• Discharge, AH										
7.2 amps to 1.30V/cell	38.0	37.8	37.8	37.2	39.0	39.8	37.2	36.6	39.6	35.6
Cycle 3										
• Charge, AH										
Step I @ 0.97 amp to 2.00V 1st cell	34.7	34.7	34.7	34.7	34.7	34.7	34.7	29.9	29.9	29.9
Step II @ 0.6 amp to 1.98V/cell	1.5	2.1	2.9	0.2	0.9	2.9	1.5	1.0	9.1	1.4
Total	36.2	36.8	37.6	34.9	35.6	37.6	36.2	30.9	39.0	31.3

NOTES:
(1) Cell nominal capacity based on 0.25 AH/gram silver.
(2) Cell electrolyte: 43% KOH 90% saturated with Zn0.
(3) Zn0 to silver weight ratio: 1.5:1.
(4) Date of activation: 10/31/69 - Date on charged stand: 11/26/69.

Table 18 (contd)

Plate Wrapped: Positive; Order of Separation, + to -: 1EM470, 4RAI2291, 2FSC;
Cell Nominal Capacity: 28 AH

Test Parameter and Cell S/N	121	122	123	124	125	126	127	128	129	$\overline{X}_{19}$
Cycle 1										
• Charge (formation), AH										
0.97 amp to input or 2.1V 1st cell	40.6	40.6	40.6	40.6	40.6	40.6	40.6	40.6	45.1	--
0.97 amp top-off charge (sealed)	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	0.6	--
Total Input	45.7	45.7	45.7	45.7	45.7	45.7	45.7	45.7	45.7	45.7
• AC Impedance before formation, mohms	62	51	54	45	44	49	53	49	45	50
• AC Impedance after cycle 3 charge	78	28	90	31	72	44	48	20	22	47
• Discharge, AH										
7.2 amps to 1.30V 1st cell	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0
Cycle 2										
• Charge, AH										
Step I @ 0.97 amp to 2.00V 1st cell	29.6	29.6	29.6	29.6	29.6	29.6	29.6	29.6	29.6	29.6
Step II @ 0.6 amp to 1.98V/cell	11.7	7.9	11.9	8.4	8.2	11.5	9.4	11.1	9.4	9.1
Total	41.3	37.5	41.5	38.0	37.8	41.1	39.0	40.7	39.0	38.7
• Discharge, AH										
7.2 amps to 1.30V/cell	41.0	38.8	41.6	38.8	39.0	41.1	38.4	39.1	37.9	38.7
Cycle 3										
• Charge, AH										
Step I @ 0.97 amp to 2.00V 1st cell	29.9	29.9	29.9	30.3	30.3	30.3	30.3	30.3	30.3	31.8
Step II @ 0.6 amp to 1.98V/cell	9.6	11.5	11.1	5.8	8.7	9.8	7.4	7.2	6.8	5.4
Total	39.5	41.4	41.4	36.1	39.0	40.1	37.7	37.5	37.1	37.2

NOTES:
(1) Cell nominal capacity based on 0.25 AH/gram silver.
(2) Cell electrolyte: 43% KOH 90% saturated with Zn0.
(3) Zn0 to silver weight ratio: 1.5:1.
(4) Date of activation: 10/31/69 - Date on charged stand: 11/26/69.

Table 19. Phase II cycles 1 through 3 performance mean values

Design Number	2	3	4	5	6	7
Plate Wrapped	+	+	-	-	Both	+
Order of Separation, + to -	1EM470 4FSC	1EM470 2FSC 4RAI	1EM476I 6RAI	1EM470 2FSC 4RAI	1EM476I 3RAI 1EM476I 4RAI	1EM470 4RAI 2FSC
Cell Nominal Capacity, AH	25	28	31	28	28	28
Cell S/N	1 thru 19	23 thru 41	45 thru 63	67 thru 85	89 thru 107	111 thru 129
Cycle 1						
• Charge (formation, AH)						
7 ma/in^2 to input or 2.1V 1st cell	37.8	42.4	41.2	42.2	39.3	40.6-45.1
7 ma/in^2 to 1.97V 1st cell after seal	1.6	1.3	7.3	--	6.3	5.1-0.6
Total AH	39.4	43.7	48.5	42.2	45.6	45.7
• AC Impedance, Before Formation, mohms	74	50	38	48	34	50
• AC Impedance, After Cycle 3 Charge, mohms	39	38	42	57	47	47
• Discharge, AH						
52 ma/in^2 to 1.30V 1st cell	35.8	39.6	46.4	30.7	40.3	44.0
• Mid Voltage during Discharge, Volts	1.52-1.53	1.48-1.51	1.50	1.46-1.50	1.48-1.50	1.50-1.51
Cycle 2						
• Charge, AH						
Step 1 to 2.0V 1st cell	35.1	38.6	49.0	29.6	47.6	29.6
Step 2 to 1.98V/cell	2.6	2.3	1.0	4.4	2.2	9.1
Total AH	37.7	40.9	50.0	34.0	49.8	38.7
• Discharge, AH						
52 ma/in^2 to 1.30V/cell	39.2	38.6	47.6	40.9	42.2	38.7
• Mid Voltage during Discharge, Volts	1.50-1.52	1.49	1.48-1.50	1.48-1.50	1.46-1.50	1.49-1.50
Cycle 3						
• Charge, AH						
Step 1 to 2.0V 1st cell	28.3	35.9	33.5	30.6	31.4	31.8
Step 2 to 1.98V/cell	7.1	2.3	5.9	7.5	7.0	5.4
Total AH	35.4	38.2	39.4	38.1	38.4	37.2
Discharge Current, amps (52 ma/in^2	6.4	7.2	8.0	7.2	7.2	7.2
Charge Current, amps Step 1 (7 ma/in^2)	0.86	0.97	1.08	0.97	0.97	0.97
Step 2 (4 ma/in^2)	0.50	0.55	0.62	0.55	0.55	0.60

Table 20. Phase II limiting cells on capacity check cycles

DESIGN GROUP	CELL S/N									
2	11	11	24	8	12	12	8	9	11	11 (204)
3	24 32 34	34	34	34	25 (84)					
4	46 47	57	57 (52)							
5	74	74	74	74	74 (90)					
6	98	102	92 (39)							
7	115	112	112	128	128 (99)					
CYCLE NUMBER	0	25	50	75	100	125	150	175	200	225

(n) = CYCLE NUMBER WHEN 1st CELL FAILED TO DELIVER 50% DOD

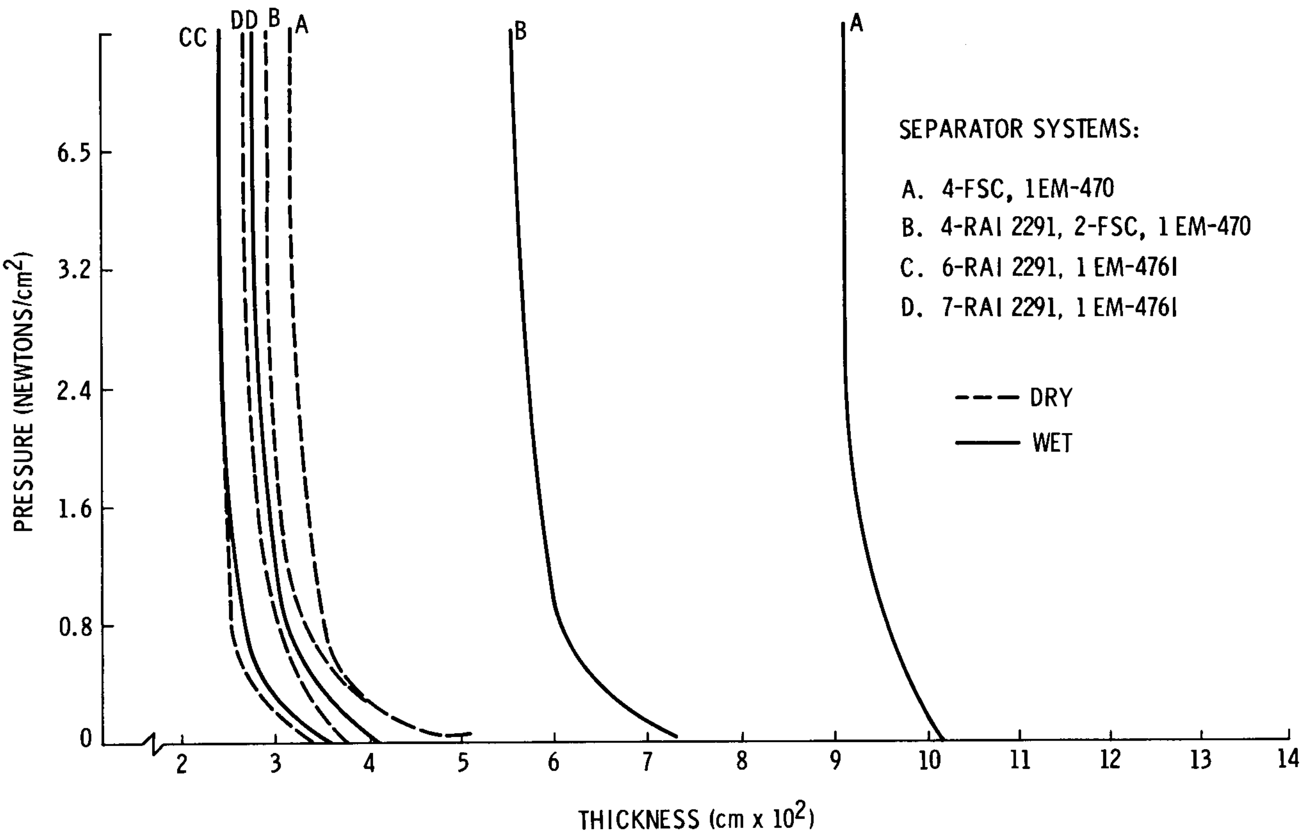

Fig. 1. Effect of pressure on separator system thickness

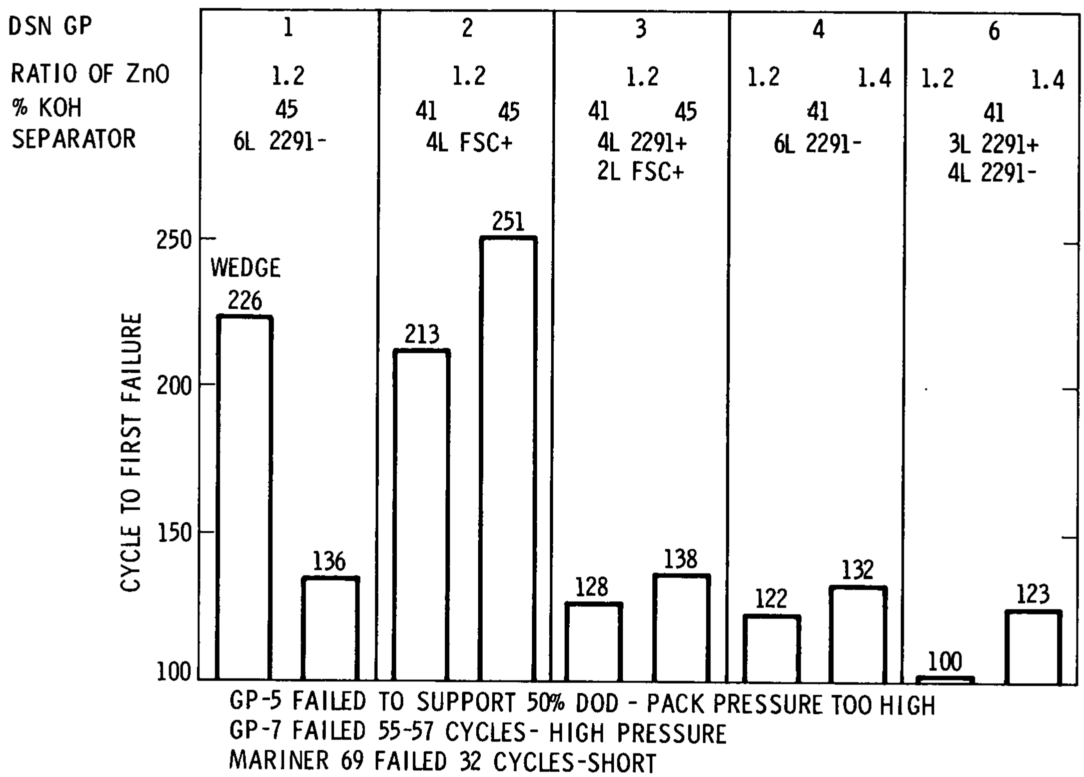

Fig. 2. Phase I cycle results (to first cell failure)

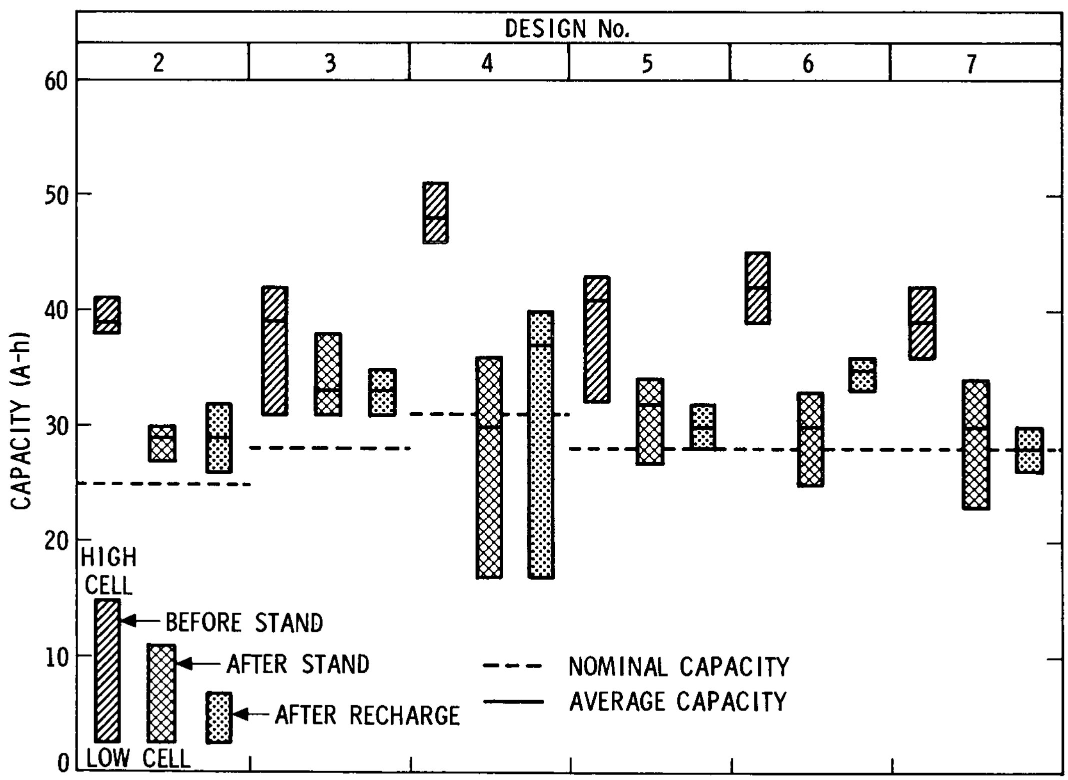

Fig. 3. Phase II cell capacity check results before and after stand

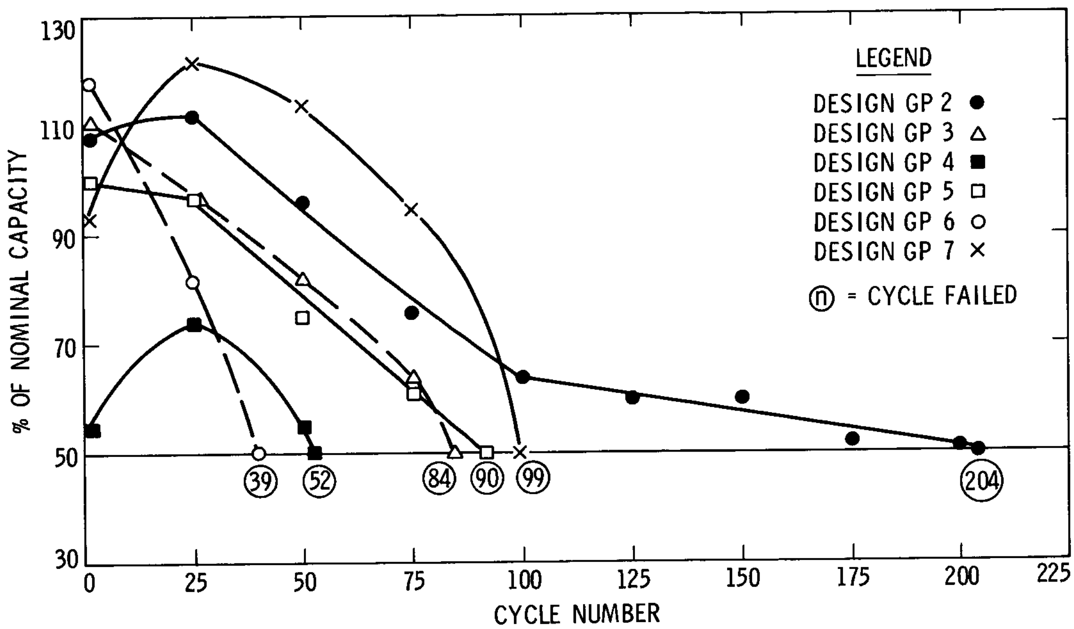

Fig. 4. Phase II capacity available during 50% DOD cycles, measured on lowest cell in battery (19 cell battery)

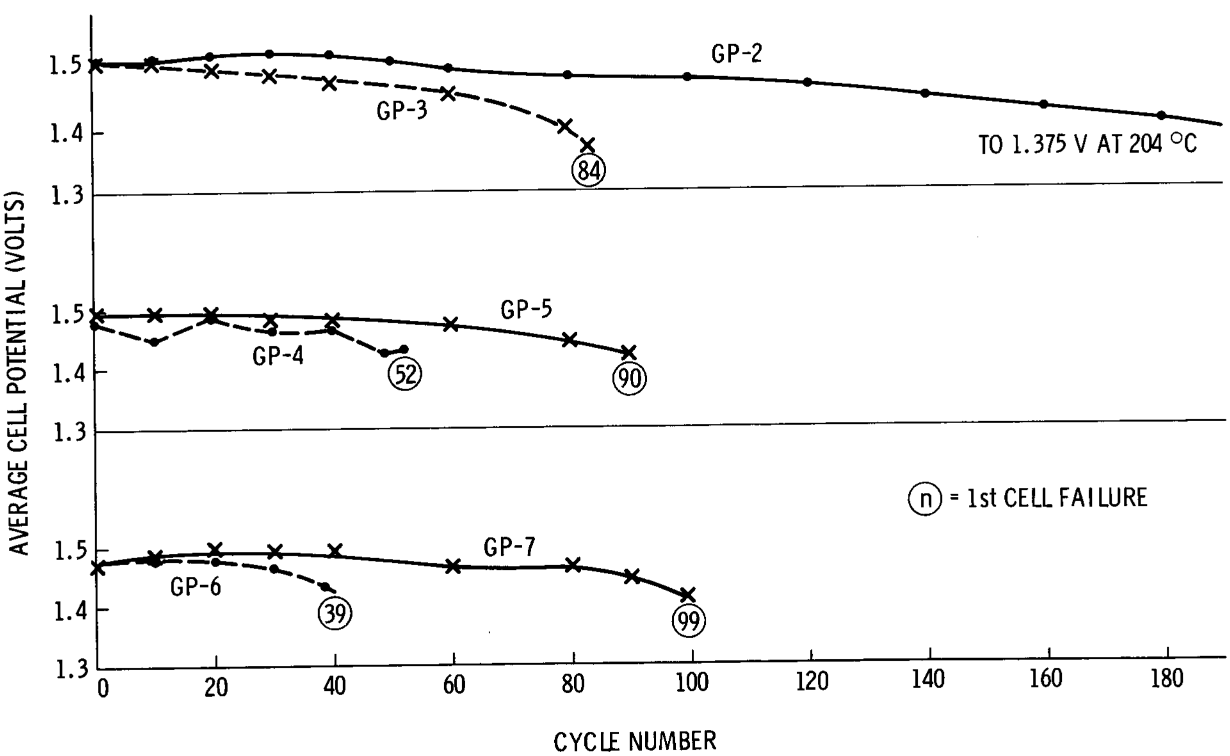

Fig. 5. Average cell potential of batteries at end of 2-h discharge on cycle test to first cell failure; discharge rate C/4'

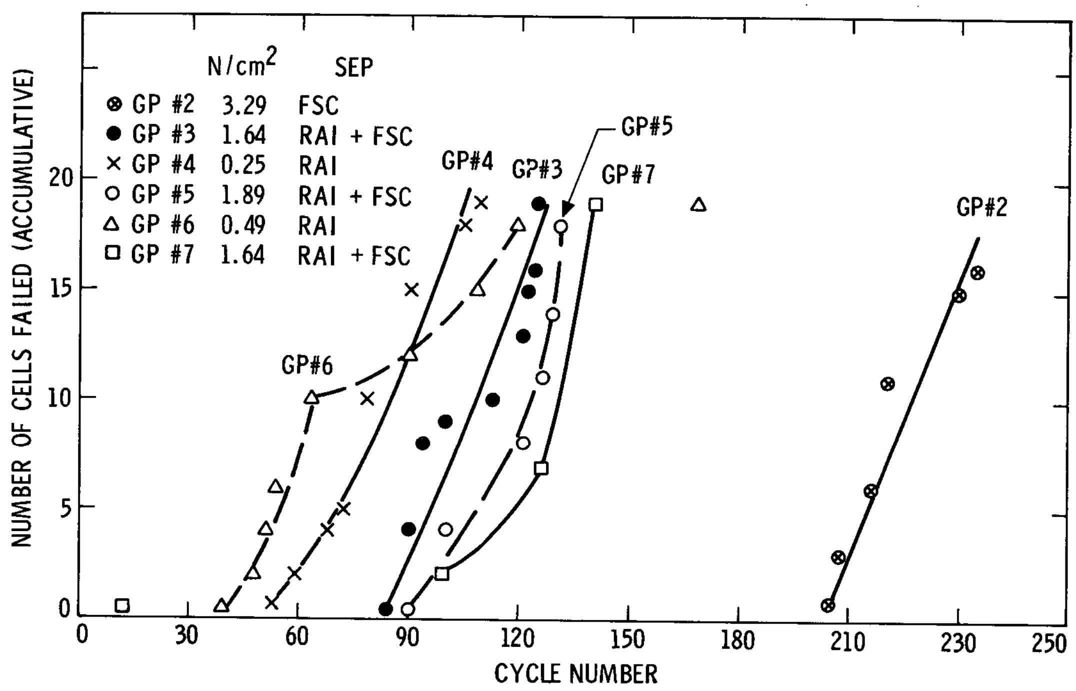

Fig. 6. Phase II failure rate during 50% DOD cycles

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