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HEAT STERILIZABLE IMPACT RESISTANT CELL DEVELOPMENT

JET PROPULSION LABORATORY
CONTRACT NO. 951296

REPORT FOR SECOND AND THIRD QUARTER 1970

APRIL 1, 1970 TO SEPTEMBER 30, 1970

ESB INCORPORATED
EXIDE MISSILE AND ELECTRONICS DIVISION
RALEIGH, NORTH CAROLINA

JANUARY 1971

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Prepared By: A. M. Chreitzberg
Ass't. Dir. of Engrg.

Approved By: G. S. Hartman
Dir. of Engrg.

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ABSTRACT, CONCLUSIONS AND RECOMMENDATIONS

A. Ten prototype 5.0 AH cells designed for high impact have been delivered to JPL. One cell tested at 4,000 g and an impact velocity of 120 feet per second survived the shock in the terminals aft direction. Other tests scheduled. Design features needed for high impact after heat sterilization reduce operating energy density from 43 to 11 watt-hours per pound. Elimination of non-woven absorber on positive plate decreased discharge capacity 40% from the expected 6.0 AH at the 4.6 A rate.

B. Seven advanced high cycle life cell designs have each delivered 22-27 AH an initial cycling tests at 100% depth at the 2, 8, and 16 ampere discharge rates. A total of 60 cells, all of 20 AH nominal capacity, are now on 400 cycle tests on two routines: (1) 10-hour charge/14 hour discharge and (2) 21-hour charge/3 hour discharge.

C. Seventy ampere-hour long life 4-cycle cells have been developed through prototype stage. Reliability life tests were underway at termination of the task to verify optimum techniques for interplanetary travel: charged, discharged, or float stand. Initial 100% depth cycles after 72 hours heat sterilization at 135°C gave 53 WH/lb. and 3.7 WH/in^3 discharge energy at the 5-hour rate.

D. Eight prototype 25 AH cells designed to survive shocks of 4000 g from 120 feet per second are under evaluation at JPL. Cycle life tests at ESB after 72 hours heat sterilization at 135°C have exhibited 72-75 cycles at 50% depth, 2 cycles per day, on a 90 cycle goal. Energy density at the rated C/2 load is 21.5 WH/lb. and 1.6 WH/in^3 of sealed cell.

E. Development of the 5 and 25 AH high impact (4,000 g) cells and the 70 AH long life 4-cycle cells has been terminated. Tables II, VIII, and X provide a summary of objectives vs accomplishments at termination for each cell design. Complete design disclosure has been made to JPL in the drawing lists:

Cell Design	ESB Model Number	Drawing List Number
5 AH High Impact Cell	361	D/L 361 Rev. D
25 AH High Impact Cell	362	D/L 362 Rev. D
70 AH Long Life 4-Cycle Cell.	364	D/L 364 Rev. G

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FABRICATION AND TESTING OF CELLS

I. DEVELOPMENT OF HIGH IMPACT 5.0 AH CELLS - TASK 9

A. Objective and Past Work

5.0 AH sealed cells must be developed to meet the requirements of JPL Specification GMP-50437-DSN-C and Engineering Memorandum 342-70 with a simulated hard landing impact of 2,800 ±200 g from 115 ±3 feet/second velocity. Cells heat sterilized 72 hours at 135°C unformed, and then charged, have delivered 11.0 AH at 3.3 AH to 1.25 volts at 43 WH/lb in a non-high impact design. With silver sheet plate reinforcements, impacts of 2,400 g were survived with some evidence of failure in the tab bending mode when shocked terminals forward. Prototypes were shipped in a design with zirconium reinforced positives and massive negative grids having pockets for active material etched into the structure chemically.

B. Electrical Tests at ESB and Shock Tests at JPL

Twelve 5.0 AH cells in the final design were fabricated, heat sterilized 72 hours at 135°C, and cycled through one cycle. Ten cells were shipped to JPL for impact testing to 4,000 g. Two cells were retained at ESB for cycle life tests. Table I summarizes cycling data on one of these cells. Performance after cycle 1 was only 60% of expected. The postulated explanation is the absence of a positive plate absorber and free electrolyte over entire face of positive plates. The 25 AH size high impact cell of Task 12 having a very similar plate design is performing well and has a positive plate absorber.

Initial attempts to pot the cells into the shock fixture at JPL produced cracks in the polyphenylene oxide cell cover. The epoxy apparently triggered crazing in areas stressed during molding of the covers. Since leakage to ground was minor, the cell was shocked terminals aft at over 4,000 g and survived the test. Covers on the remaining cells are to be milled off and replaced with annealed covers prior to the remaining shock tests.

Table II summarizes 5 AH cell attributes vs specification requirements achieved to date. The cell design is completely controlled by ESB P/N 361-2000 and all drawings referenced.

C. Future Work

As directed by JPL work on the high impact cells has been terminated. JPL will retain the 10 prototype cells for additional shock test evaluation at 4,000 g.

II. DEVELOPMENT OF HIGH CYCLE LIFE 48 AH CELLS - TASK 10

A. Objectives and Past Work

JPL Specification 50436-DSN-B requires development of sealed Ag-ZnO cells capable of one year prelaunch storage, heat sterilization for 72 hours at 135°C, flight acceptance tests, launch, 9-month interplanetary cruise, soft landing impact of 200 g (0.7 msec), and 400 charge - discharge cycles at 50% of rated capacity. An experiment with 27, 16 AH cells, a one-third replication of a 3 factorial design, has been carried through 100 cycles. Effects on capacity maintenance of teflon (5, 7, 9 per cent) added to negative and sintered, wet thickness of GX membrane separator (2.0, 2.4, 2.8 mils) and electrolyte concentration (41, 43, and 45%) were not statistically significant. Capacity was shown to increase linearly with increasing ZnO/Ag weight ratio at levels 0.9, 1.2, and 1.5

when cells were not electrolyte limited. A negative plate wrap with no absorber on positives did not prevent electrolyte limitation.

B. Factorial Cycling Test

Cycling continued to 100 cycles at 100% depth on the 16 AH nominal capacity cells at which point the test was terminated. All cells were dissected and photographs made of erosion patterns on the negatives, corresponding black and white patterns on the positive plates, and Ag penetration through the SWRI GX membrane. Each photo showed one side of 4 positive plates, 5 negative plates, and the last 5 layers (of 9) GX membrane unfolded. Negative erosion of all plates was from top to bottom leaving a dome shaped pattern in the lower 50% of plate area at 100 cycles. At the same cycle life erosion was greater with increasing GX wet thickness allowance and decreasing ZnO/Ag ratio. Figure 1 gives the experimental design, the trends of Ag penetration, and cycles to failure by short or termination of test. Ag penetration increased with decreasing KOH concentration and increasing wet GX thickness allowance.

Capacity maintenance at cycles 1, 38, and the last cycle can be obtained on an average basis from the data accumulated. The significant trends are:

Weight Ratio ZnO/Ag	Number of Cells	Mean Discharge Capacity - AH					
		Cycle 1	Cycle 5	Cycle 38	Cycle 45	Cycle 52	Cycle 100
1.5	7	19.7	16.1	10.9	8.9	12.3	9.2
1.2	9	19.5	15.5	12.1	10.0	11.5	8.4
0.9	8	21.5	15.8	10.1	8.8	9.9	8.1

Between cycle 46 and cycle 48 electrolyte was adjusted to original weight plus 5% (by removing pressure gages), the cells were let down, and then cycling was resumed. The major and sustained increase in capacity from this treatment was in the 1.5 ratio group. In all groups, however, the rapid fall-off in capacity is attributed to lack of a positive plate absorber and the inability of the 9L GX separator to pass electrolyte freely to maintain the desired KOH concentration at both positive and negative plate surfaces.

C. Development of 20 AH High Cycle Life Cells

In accordance with Modification 25 of the contract development was concentrated on a 20 AH cell size to delete the cost of scale-up to a 48 AH size cell. Sixty cells were then manufactured in seven distinct designs selected to give 400 cycles at 50% depth of discharge. All designs have a non-woven polypropylene positive plate absorber - either Kendall EM476 (E-1488) irradiated to improve electrolyte wicking and retention or Pellon FT 2140 - both stable to attack by 45% KOH during heat sterilization at 135°C.[2] Experimental design will permit cycle life evaluation of 8 vs 10 layers SWRI-GX membrane, extended vs non-extended negative plates, positive or negative wrap, and a spiral wrap. All cells have the following common design features:

- Molded PPO jar, cover, and epoxy seal.
- Teflonated and sintered negatives with a minimum ZnO/Ag ratio of 1.5:1.0 by weight.
- 45% KOH saturated with ZnO.
- Four positive plates (17.8 g Ag active material) and five negative plates.

(2) JPL Contract 951972 Final Report December 31, 1969, p I-3.

All cells were activated by submerging inverted in electrolyte and pumping down to a vacuum of 29 in. Hg releasing gradually to atmospheric pressure. Calculated volumes to this flooded condition agreed closely with actual volumes calculated from observed weight increases.

After a bake-out period of 20 hours at 100°C, excess electrolyte was removed under 22 inch Hg vacuum and the final weight of electrolyte obtained by addition to a pre-determined value. All cells were then sealed with an "O" ring stainless steel plug assembly, and heat sterilized 72 hours at 135°C in nitrogen. Weight losses during heat sterilization ranged from 0.5 gram to 1.5 gram as water except for one cell which lost 10.2 grams around the plug assembly. This cell was resealed after replacing 8.5 grams of electrolyte.

A complete test procedure, prepared to describe all testing on this task in detail, was reviewed and approved by JPL. A brief summary of tests is given below for the 12 5-cell groups:

• Cycles 1 thru 3 at 100% depth	Charge Rate 0.4 A to 2.00 volts	Discharge Rate 8, 3, or 16A to 1.25 volts per cell
• Cycles 4 thru 400 at 50% depth 1 cycle/day	Charge Time hours	Discharge Time Hours
Group A (25 cells)	10	14
Group B (35 cells)	20 2/3	3 1/3

Table III summarizes the 5-cell group mean discharge capacity for each of the first three 100% discharge cycles. All cell groups are performing within expectations. On formation charge after heat sterilization the highest pressure reached by any cell was 7 psi with 20-30 psi anticipated. The decrease in pressure is attributed to the absence of an epoxy plate-lock considered essential for maximum protection against vibration damage.

D. Future Work

Cycling panels have been completed and during the next quarter daily cycles on the two routines will be run automatically. Problem areas anticipated are (1) decrease in positive plate surface and capacity on the 10-hour charge/14-hour discharge routine and (2) identification of optimum charge voltage settings for the various design groups to best maintain capacity on charge.

III. DEVELOPMENT OF RECHARGEABLE PRIMARY 70 AH CELLS - TASK 11

A. Objectives and Past Work

Sealed wet heat sterilizable 70 AH cells designed to meet the requirements of JPL Engineering Memorandum 342-71 have been developed and prototypes delivered to JPL. A sweeping sine vibration test at levels from 5 g at 17-50 cps to 35 g at 100 to 2000 cps demonstrated the need for sleeving on the massive plate lugs to increase lug tightness to eliminate severe voltage fluctuation. A single lot of 27 reliability cells was produced in the final design to evaluated performance after discharged, charged, or float stand at 50, 70, and 90°F.

B. Initial Cycles on Reliability Test Cells

Twenty-seven Model 364 cells, manufactured to ESB D/L 364 Revision F, completed preformation charge, heat sterilization of 72 hours at 135°C in nitrogen, formation charge, and cycles 1 and 2. Cell performance is presented in Table IV as the mean of 27 cells with minimum and maximum observations. Cycle 2 discharges are delivering energy at 53 WH/lb and 3.7 WH/in^3 at the 5 hour rate. Figure 2 shows performance as a function of discharge rate.

Because of the high pressures recorded during formation charge (mean 28 psig) two cells were manufactured and preformed to 50%, rather than 100% of the theoretical capacity of compound 323-43, preserving half of the compound to retard gassing during formation after heat sterilization. After 72 hours at 135°C the remaining 50% was converted at the preformation rate. At this point the formation was begun at the normal rate of 0.9A. Cell S/N 46 reached 44 psig and was vented; S/N 47 rose to a maximum pressure of 20 psig. These pressures affirm that decreasing the fraction of compound 323-43 preformed before heat sterilization will not eliminate gassing on formation. Related work on another contract has shown that gassing on formation charge can be controlled by decreasing the charge rate during the first 50% of the formation.

C. Storage Tests

Following the above cycling 22 cells were divided into three groups to evaluate wet life on charged stand, discharged stand, and float charge at 1.87 volts per cell. Tables V, VI, and VII summarize the trends in each group of voltages and pressures observed the first 31 days of test in the storage box at 72°±3°F. A marked fluctuation in float current was observed in the float charge group as the current decayed to 10 ma per series string of 9 cells. It is likely that some discharge may occur when all cells reach an equilibrium state at the selected 1.87 v/c float voltage. No sustained pressure rise was experienced in any group, and no cells exhibited evidence of shorting.

D. Future Work

Work on this task was terminated by Modification 24 of the contract. All cells under test were shipped to JPL with no failures experienced at that date due to stand. Table VIII summarizes achievements vs specification requirements at the time of termination of the task.

IV. DEVELOPMENT OF HIGH IMPACT 25 AH CELLS - TASK 12

A. Objectives and Past Work

This task covers the development and test of 25 AH sealed Ag-ZnO cells capable of 72 hours wet heat sterilization, 9-months interplanetary cruise, planet entry, a hard landing shock of 4,000 "g" in any axis plus 90 fifty per cent depth cycles. The governing specification is JPL Engineering Memorandum 342-68. Engineering design cell packs in machined Lucite jars tested at 4,200 "g" with no heat sterilization failed only in the terminals forward shock with bending of positive plate struts. Redesign stiffened the struts with molded shims wedged between positive struts. Prototype cells with molded PPO cell cases, covers, and subcovers were manufactured successfully. Negative active material was teflonated but not sintered on the massive grid in order to retain maximum column strength. Negative plates were inserted into slots molded in the jar walls while positive plates were suspended from the cover seal and wrapped with the cell separator system. All 12 cells survived heat sterilization 72 hours at 135°C; however, on formation charge at the normal rate, gassing at the negative plates was sufficient to bulge jar walls 100 mils and all cells were vented. Venting was required on at least one of 12 cells throughout the formation charge. Therefore, all cells were sealed and remained sealed. Charge input was 82% of theoretical and discharge output was 73-98% of input, more variable than desired. Eight cells were shipped to JPL for 4,000 "g" tests and four cells were retained at ESB for cycling tests.

B. Cycle Life Tests of 25 AH High Impact Cells

JPL specification objectives were a 12-cell battery package delivering 400 watt-hours rated capacity, and a capability of ninety (90) charge/discharge cycles at 50% depth after one year prelaunch storage, heat sterilization, 9-month interplanetary travel, and a 4,000 "g" hard impact landing on a planet. Figure 3 is the voltage vs time discharge curve of 4 cells at 12 amps. Table IX relates the 2 rate discharge requirement for the battery and the cell loads selected for the cycle test routine. To save test time the 10-hour charge/14-hour discharge was reduced to a 10-hour charge/2-hour discharge by a 6:1 increase in discharge energy at the high rate (16.7 watts/cell). Figure 4 shows the effect of discharge rate on voltage and wattage during 5-second pulse currents at 2, 6, 12, 25, and 50 amperes taken initially and at 40% depth of a 12 ampere discharge. The high impact cells were able to sustain the 2C discharge rate quite well. Cycling at the higher rates was therefore initiated as a conservative test of cycle life <u>before</u> the high impact. Figure 5 is a curve of the end of discharge voltages (high and low rates) as a function of cycle life. Out of four cells in the series group the first two cells failed by zinc penetration at cycles 72 and 75 respectively. The third cell failed by capacity at 121 cycles and the test was terminated.

Cycle life of this cell design thus appears to be 70-125 cycles in a wet charged life of 5-6 months including 72 hours heat sterilization at 135°C in the uncharged state. The separator system was 1L Kendall E-1488 and 7L Southwest Research Institute GX. High impact design requires all the zinc active material to be reinforced with a pocket type negative grid. Pocket area and volume is only 60-70 per cent of the grid area and volume, restricting the ratio of ZnO/Ag active material by weight to 0.8 in the cell pack design. Post-mortem of these cells showed erosion top to bottom although the teflon matrix remained in the etched pockets of the grid. The low ratio, the downward erosion pattern and resultant densification contributed to failure at 72 cycles by zinc penetration.

C. Future Work

Modification 24 of the contract terminated work on the 25 AH high impact cell. Missions in the future are most likely to be soft landers not requiring 4,000 "g" impact capability. Table X summarizes task objectives vs accomplishments at date of termination. The eight remaining cells are at JPL for continued evaluation of cycling after impact tests.

V. DEVELOPMENT OF 25 AH MEDIUM CYCLE LIFE CELL - TASK 13

This task was terminated by Modification 24 at 95% completion with objectives met or exceeded. All cells manufactured for test at ESB had completed scheduled tests except cycling after low impact shock and vibration at JPL. The cells designated for these tests were shipped to JPL and are being evaluated there. The final design version of this cell incorporating improvements to extend wet life is being evaluated for cycle life after 200 hours wet heat sterilization plus discharged and float charged stand for periods from 4 to 14 months on Martin-Marietta Company Contract RC9-841011.

TABLE I

FOUR CYCLE TEST ON 5 AH HIGH IMPACT CELL

	Charge		Discharge			Efficiency
Cycle No.	Current Amps	Capacity AH	Current Amps	Capacity AH	Voltage Volts	AH/gAg
1	0.15	7.27 (1)	3.20	5.55		0.26
			0.65	0.62		0.03
				6.17		0.29
2	0.20	6.14	3.20	3.20 (2)		0.15
3	0.20	4.40	4.6	4.50		0.21
			1.0	0.60		0.03
				5.10		0.24
4	0.20	4.90	4.6	3.68		0.17
5	0.15	4.35 (1)	4.6	3.90		0.19
6	0.15	4.04				

NOTES: (1) Cycles 1 and 5 charges included partial discharge - recharge.

(2) 30 day charged stand test.

(3) Test end voltages: 2.00 volts on charge, 1.25 volts on discharge.

TABLE II

DEVELOPMENT OBJECTIVES VS ACCOMPLISHMENT
5 AH HEAT STERILIZABLE HIGH IMPACT CELLS

	Design or Operating Parameter	Unit	Objective (1)	Accomplishment
1.	Energy Storage	WHr	80	76 (6.3 WHr/cell)
2.	Shelf Life before Use	Years	1	--
3.	Mission Environment			
	Heat Sterilization at 135°C	Hours	72	72
	Space Travel	Months	9	--
	Landing Shock & Velocity	g	4,000	up to 4,000
		ft/sec.	120	up to 120
	Operating Temperature	°C	+10 to +55	25
4.	Discharge Wattage (12 cells)	Watts	80	78 (6.5 watts/cell)
5.	Voltage (12 cells)	Volts	14.5 to 22.5	
6.	Capacity at 4.6A to 1.20 V	AH	4.7	4.5
7.	Cell Voltage at Rated Wattage	Volts	--	1.41
8.	Cycle Life, 100%, 80 Watts	Each	4	4 but less than 100% rated output (See Table I)
9.	Charging Time, max.	Hours	72	30-50
10.	Cell Dimensions and Volume			
	L	in.	--	1.13
	W	in.	--	1.97
	H (over jar)	in.	--	3.36
	Volume	in^3	--	7.48
11.	Cell Weight	lb.	--	0.60
12.	Energy Density	WHr/lb.	15	10.6 (cell only)
		WHr/in^3	--	0.9

(1) JPL Engineering Memorandum 342-70 Design Goals Power Subsystem Heat Sterilizable, Impact Resistant, 80 Watt Hour Battery, 9-16-68.

TABLE III

20 AH CELL 100% DEPTH INITIAL CYCLE
DISCHARGE CAPACITIES
VS
DESIGN PARAMETERS

Absorber Type	Number Layers	Number Layers SWRI-GX Membrane Wrap and Negative Plate Size				
		6	8	10		
		+	+	+		-
		E	E	NE	E	NE
Kendall E-1488 (Irradiated)	2			(2) *1 26.1 2 24.9 3 22.7	(4) 26.6 25.1 23.0	(1) 27.1 25.2 22.6
					(6W) 1 26.8 2 26.2 3 24.6	
	6	(3) 1 25.9 2 25.1 3 23.6				
Pellon 2140	1		(7) 1 26.6 2 25.2 3 24.2		(5) 26.5 25.7 24.3	

NOTES: (*) 1 Cycle 1 at 8A to 1.25 V.

2 Cycle 2 at 3A to 1.25 V.

3 Cycle 3 at 16A to 1.25 V.

Cells charged at 0.4A to 2.00 V.

( ) = design number

TABLE IV

INITIAL CYCLE TESTS ON 70 AH RELIABILITY CELLS
(AFTER HEAT STERILIZATION)

Test Event	Unit	Minimum	Mean	Maximum
Preformation Charge				
Theoretical	AH		1.93	
Actual	AH	1.81	1.99	2.00
Terminal Voltage	Volts	1.592	1.596	1.606
Formation Charge (0.9A to 1.97 V/C)	AH	88.8	95.6	109.0
Maximum Pressure	Psig	4	28	60
Cycle 1 Discharge (17.5A to 1.25 V/C)	AH	72.8	88.7	100.
Cycle 2 Charge (1.5A then 0.9A to 2.02 V/C)	AH	71.1	79.0	89.8
Partial Discharge (2.0A for 8.1 Hrs)	AH	16.2	16.2	16.2
Recharge as above	AH	30.1	34.8	40.5
Net Input	AH	90.9	97.6	105.
Cycle 2 Discharge (17.5A to 1.25 V/C)	AH	91.5	97.5	103.
Discharge Time	Hours		5.6	
Cell Weight	Lb.		2.74	
Cell Volume	in^3		40.6	
Energy Output	WHr.		146	
Energy Density	WH/lb.		53	
	WH/in^3		3.7	

TABLE V

PERFORMANCE OF 70 AH CELLS ON DISCHARGE STAND @ 72°F

Stand Time (Days)	Parameter	Units	Cell Serial Number 20	39	30	32	34	19	23	26	35
0	Open circuit voltage	Volts	0.48	0.48	0.46	0.48	0.46	0.46	0.48	0.48	0.46
	Pressure	Psig									
6	Open circuit voltage	Volts	0.39	0.38	0.38	0.38	0.37	0.38	0.47	0.48	0.37
	Pressure	Psig									
19	Open circuit voltage	Volts	0.37	0.36	0.37	0.36	0.36	0.38	0.36	0.27	0.36
	Pressure	Psig	7		8	7		3	8		8
25	Open circuit voltage	Volts	0.37	0.36	0.37	0.36	0.36	0.38	0.36	0.28	0.36
	Pressure	Psig	7.		9	9		3	10		10
31	Open circuit voltage	Volts	0.36	0.36	0.37	0.36	0.36	0.38	0.36	0.27	0.36
	Pressure	Psig	9.5		9	11		4	13		12

TABLE VI

PERFORMANCE OF 70 AH CELLS ON CHARGED STAND AT 72°F

Stand Time (Days)	Parameter	Units	Cell Serial Numbers 28	37	25	28
0	Open circuit voltage	Volts	1.855	1.855	1.855	1.855
13	Open circuit voltage Pressure	Volts In. Hg	1.858 -18	1.858	1.858 -12	1.858 -20
19	Open circuit voltage Pressure	Volts In. Hg	1.861 -17	1.861	1.861 -12	1,862 -20
31	Open circuit voltage Pressure	Volts In. Hg	1.855 -15	1.859 -13	1.860 -13	1.861 -21

TABLE VII

PERFORMANCE OF 70 AH CELLS ON FLOAT CHARGE AT 72°F

Parameters	Cell Serial Numbers									Current (Milliamps)
	41	22	45	44	29	43	40	24	42	
Cell Voltages (Volts)										
• Open Circuit	1.86	1.855	1.86	1.855	1.855	1.86	1.855	1.855	1.86	
• At Beginning of Charge	1.87	1.87	1.87	1.87	1.87	1.87	1.87	1.87	1.87	500
• After 45 minutes	↑	↑	↑	↑	↑	↑	↑	↑	↑	160
113 minutes										100
198 minutes										60
4.5 hours										50
7.8 hours										50
8.5 hours										50
9.5 hours	↓	↓	↓	↓	↓	↓	↓	↓	↓	45
4 days	1.87	1.88	1.88	1.87	1.87	1.87	1.90	1.87	1.87	14
13 days	1.868	1.922	1.884	1.868	1.869	1.868	1.870	1.868	1.868	6-9
19 days	1.863	1.930	1.932	1.863	1.863	1.863	1.926	1.863	1.863	11-14
25 days	1.862	1.860	1.862	1.863	1.861	1.862	1.923	1.861	1.866	6-14
Cell Pressures (psig)										
• After 13 days	8.0		5.5	-2.5		0	0		-7.5	-
19 days	8.0		31	-2.5		-2	-2.5		-8.0	-
25 days	5.5		10	-3.0		-2.5	-2.5		-8.0	-

(1) Float charge at C. P. of 9 x 1.87 = 16.83 ± 0.09 volts in series array.

TABLE VIII

OBJECTIVES VS ACCOMPLISHMENTS 70 AH
HEAT STERILIZABLE CELLS

	Design or Operating Parameter	Unit	Objectives (1)	Observed
1.	Energy Storage, Rated	WHr.	1200	
	Delivered (12 Cells)	"		1750
2.	Energy Density, Battery	WH/lb.	35	42 (est.)
3.	Energy Density, Cells	WH/lb.		53
4.	Voltage Regulation at 300 W Load	Volts/12 cell	14.5-22.5	
		Volts/Cell	1.21-1.87	1.25-1.87
5.	Cycle Life, 100% C	ea.	4	16+
6.	Charge Time to 100% C	Hrs.	72 (max.)	51 (2)
7.	Operating Temperature	°C	10 to 55	20-30 Tested
8.	Storage Life			
	Prelaunch, 0 to 25°C	Yr.	1	NT
	Transit, -10 to 25°C	Mos.	9	NT
9.	Wet Life to Short in Charged State	Mos.	10	16
10.	Heat Sterilization at 135 ±2°C	Hrs.	74	72+
	in Nitrogen in Discharged State Sealed			
11.	Shock - Launch & Transit	g	250	NT
	3 axis, 2 directions, 30 shocks	Msec.	0.7 ±.2	NT
12.	Vibration - Entry & Landing			
	Sine 100 to 2000 Hz	Grms.	35	32
	Random 20 to 2000 Hz	Grms.	25	25
13.	Deceleration, Entry, 20 secs.	g	250	NT

(1) JPL Engineering Memorandum 342-71 Heat Sterilizable 1200 Watt Hour Battery.

(2) Any cycle except formation cycle.

TABLE IX

ELECTRICAL PARAMETERS FOR 50% DEPTH
AUTOMATIC CYCLING
HIGH IMPACT 25 AH CELLS

	Specification Requirement		Actual
	Battery	Per Cell	Per Cell
High Rate Discharge			
Time (minutes)	10	10	56
Power (watts)	200	16.7	18 avg.
Energy (watt-hours)	33.3	2.8	16.8
Current	--	--	12.0 avg.
Low Rate Discharge			
Time (minutes)	830	830	64
Power (watts)	12	1.0	1.12
Energy (watt-hours)	166	13.8	1.20
Current (amperes)	--	--	0.72
Total Discharge			
Time (minutes)	840	840	120
Energy (watt-hours)	199.3	16.6	18.0
Charge			
Time (minutes)	600	600	600
Mode	C.P.	C.P.	C.P.
Float voltage (volts	--	--	1.96
Limiting current (amps)	--	--	0.130
Cycle Life, Cycles to Failure			
First Cell			72 (S)
Second Cell			75 (S)
Third Cell			121 (C)
			121+ (NF)

( ) Mechanism of failure: S, short; C, capacity

TABLE X

OBJECTIVES VS ACCOMPLISHMENT 25 AH HIGH IMPACT CELLS

	Design or Operating Parameter	Unit	Objective (1)	Observed
1.	Energy Storage (12-cells)	WHr.	400	530
2.	Shelf Life Before Use	Yr.	1	NT
3.	Mission Environment			
	Heat Sterilization at 135°C	Hours	72	72
	Space Travel	Mos.	9	NT
	Landing Shock, All Axis	g	4,000	4,200 before HS
	Landing Velocity	ft/sec.	120	(NT after HS)
4.	Cycle Life on Planet	Ea.		
	50% depth (10 hr. C/14 hrs. D)		90	72-121
5.	Operating Temperature	°C	10 to 55	25
6.	Voltage Regulation	Volts		
	13 cells (0-200 watts)		14.5 to 22.5	16.8-22.5
	1 cell (0-16.7 watts)		1.21 to 1.87	1.40-1.87
7.	Discharge Wattage (12 Cells)	Watts	200 max.	770
8.	Capacity at 200 W Load (12A)	AH	25	30
9.	Mean Cell Voltage at 16.7 watts	Volts		1.48
10.	Charging Time, Max.	Hours	72	30-50
11.	Cell Dimensions and Volume			
	L	in.	--	1.635
	W	in.	--	3.200
	H	in.	--	5.180
	Volume	in^3	--	27.1
12.	Cell Weight, Wet, Sealed	lb.	--	2.07
13.	Energy Density at Rated Load			
	Cell by Weight	WH/lb		21.5
	Cell by Volume	WH/in^3	--	1.6
	Battery (estimated)		20	17

(1) JPL Engineering Memorandum 342-68 Design Requirements, Heat Sterilizable, Impact Resistant, 4000 Watt-Hours Secondary Battery 9-16-68.

FIGURE 1

CYCLE LIFE, FAILURE MODE, CAPACITY MAINTENANCE

16 AH Cells 100% Depth Cycling

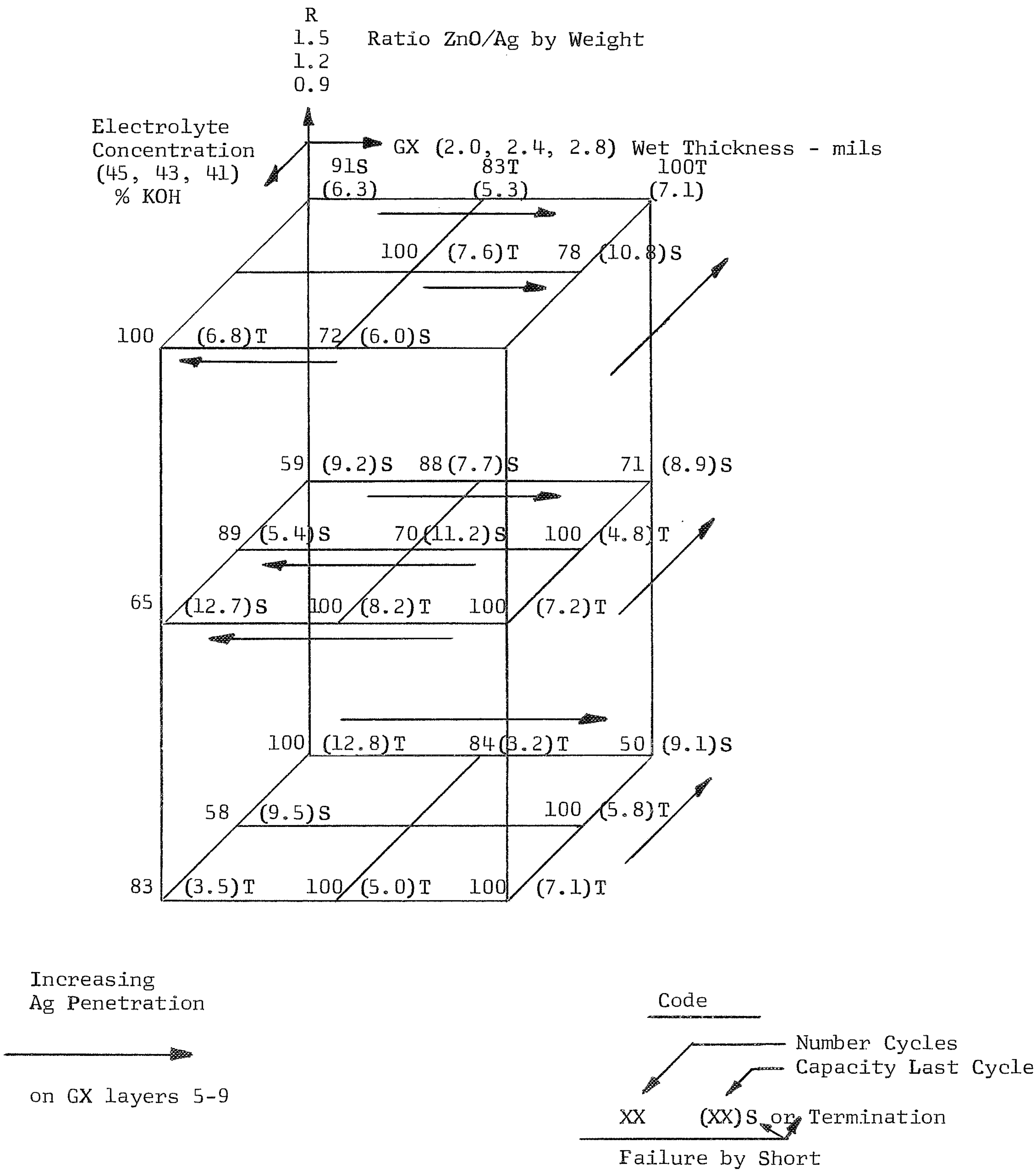

FIGURE 2

TYPICAL DISCHARGE CHARACTERISTICS 70 AH CELLS
ESB MODEL 364

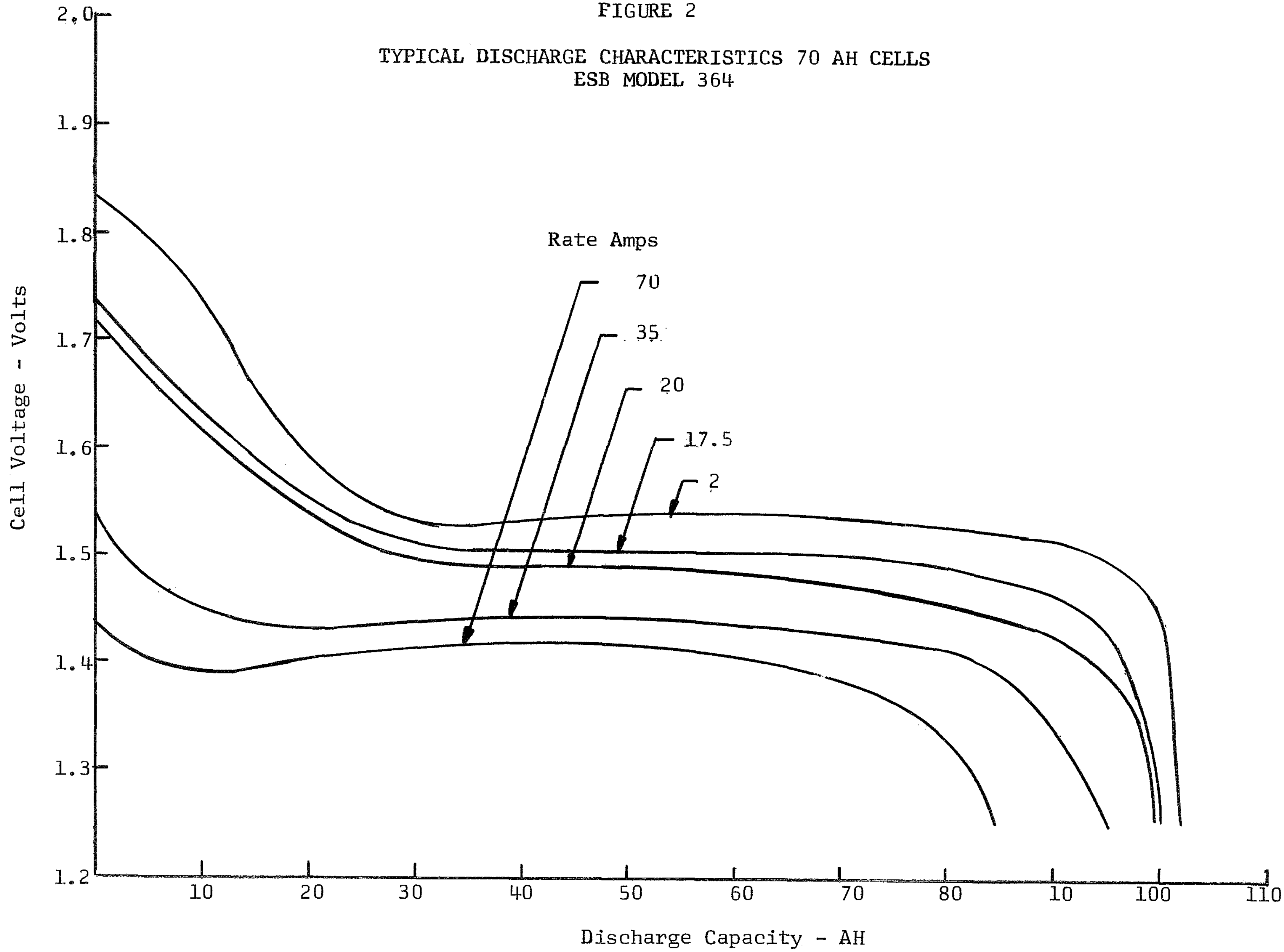

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FIGURE 3

DISCHARGE VOLTAGE VS TIME
HIGH IMPACT 25 AH CELL DESIGN

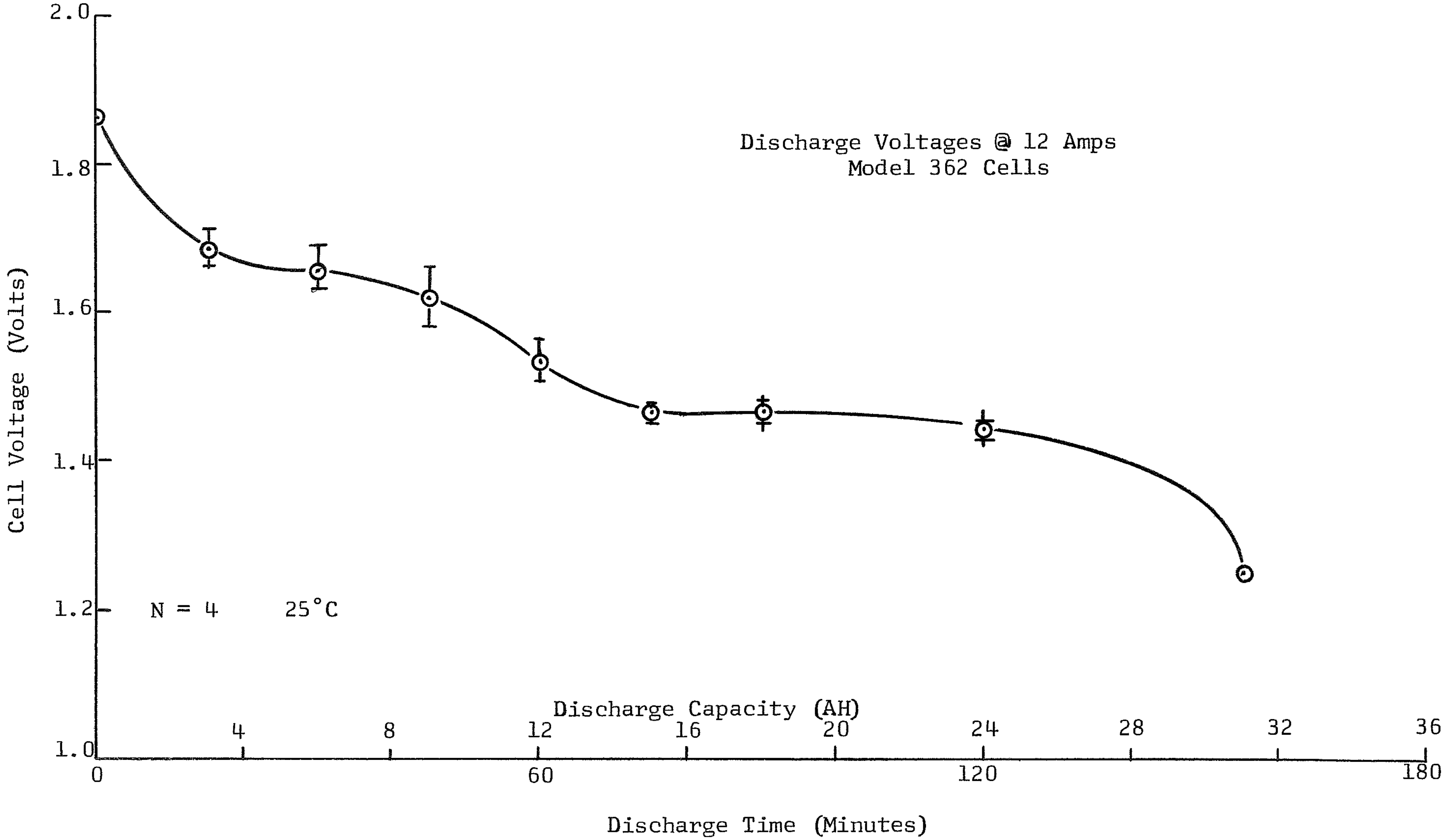


FIGURE 4

INITIAL AND 40% DEPTH PULSE VOLTAGES & WATTAGES
25 AH HIGH IMPACT CELLS

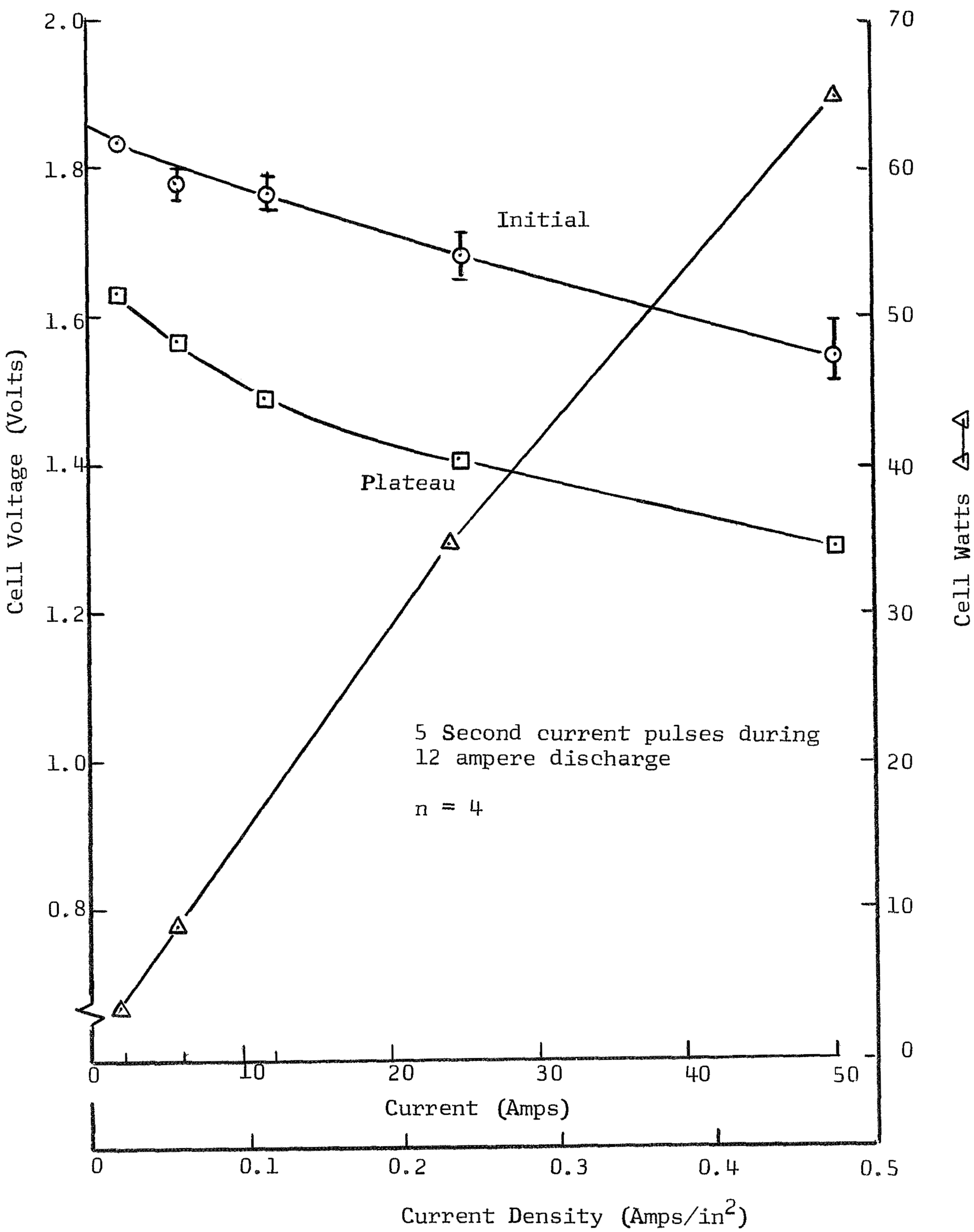
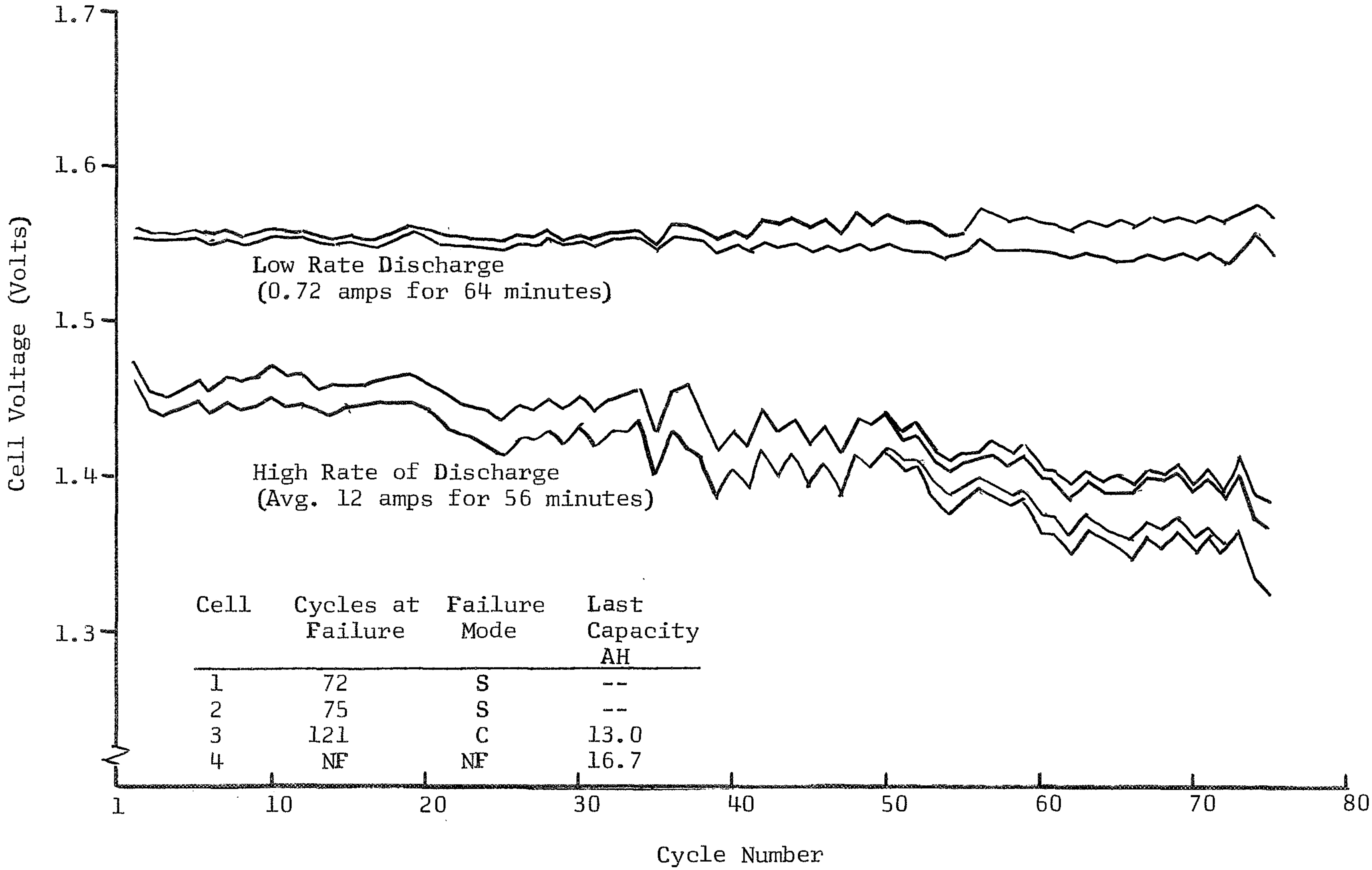


FIGURE 5

END OF DISCHARGE VOLTAGES OF 25 AH HIGH IMPACT
ON AUTOMATIC CYCLING AT 50% DEPTH



Cell	Cycles at Failure	Failure Mode	Last Capacity AH
1	72	S	--
2	75	S	--
3	121	C	13.0
4	NF	NF	16.7