General Disclaimer

One or more of the Following Statements may affect this Document

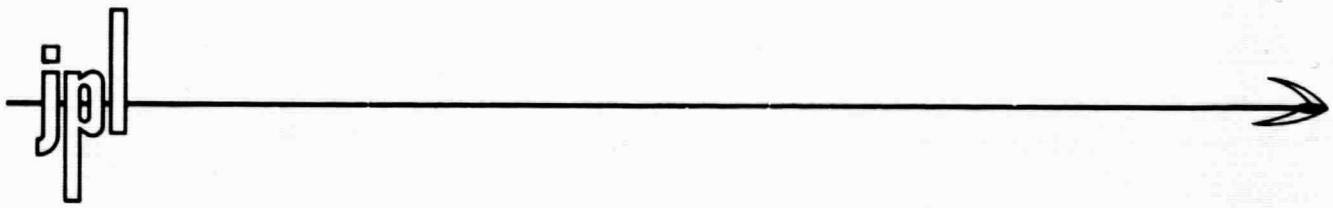
- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.

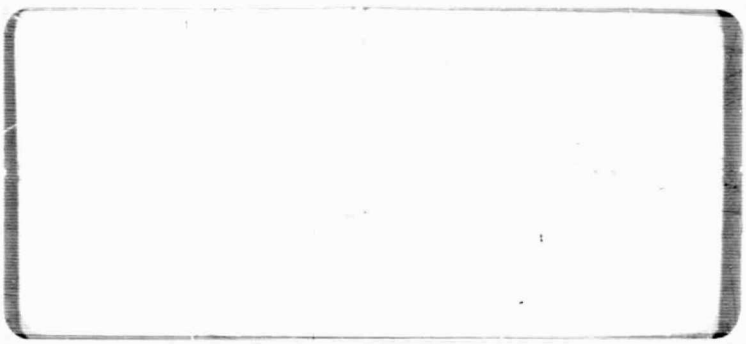
- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.

- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.

- This document is paginated as submitted by the original source.

- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.





JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

HIGH CYCLE LIFE SEALED SILVER OXIDE-ZINC CELL DEVELOPMENT

JET PROPULSION LABORATORY
CONTRACT NO. 952472

FINAL REPORT

(FEBRUARY 14, 1969 TO JUNE 20, 1970)

ESB INCORPORATED
EXIDE MISSILE AND ELECTRONICS DIVISION
RALEIGH, NORTH CAROLINA

8 SEPTEMBER 1970

HIGH CYCLE LIFE SEALED SILVER OXIDE-ZINC CELL DEVELOPMENT

JET PROPULSION LABORATORY
CONTRACT NO. 952472

FINAL REPORT

(FEBRUARY 14, 1969 TO JUNE 20, 1970)

ESB REPORT NO. E-42-70

This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, as sponsored by the National Aeronautics and Space Administration under Contract NAS7-100.

Prepared By: C. D. Farris
C. D. Farris
Project Engineer

Reviewed By: A. M. Chreitzberg
A. M. Chreitzberg
Ass't. Dir. Engrg.

Approved By: G. S. Hartman
G. S. Hartman
Director of Engineering

ESB INCORPORATED
EXIDE MISSILE AND ELECTRONICS DIVISION
RALEIGH, NORTH CAROLINA

8 SEPTEMBER 1970

TECHNICAL CONTENT STATEMENT

This report contains information prepared by ESB Incorporated, Exide Missile and Electronics Division, under Jet Propulsion Laboratory subcontract. Its content is not necessarily endorsed by the Jet Propulsion Laboratory, California Institute of Technology, or the National Aeronautics and Space Administration.

ABSTRACT

Seventy Phase I 30 AH sealed Zn/KOH/AgO cells of 7 different designs have completed 4 months 70°F charged stand, and 6 months of cycling, 1 cycle per day (50% depth/22 hr. charge/2 hr. discharge). Cells with four layers fibrous sausage casing, and tapered negative plates were still cycling after 170 cycles and more than 10 months wet life. Cells with 1.4:1 ZnO/Ag weight ratio.

One hundred twenty-nine Phase II cells of 6 of the 7 designs revised from Phase I have completed 6 months 70°F charged stand and are starting cycling tests at NAD Crane.

Phase I tests have demonstrated that 30 AH long cycle life cells can deliver over 170 50% depth of discharge cycles (1 cycle per day) after four (4) months of room temperature charged stand.

TECHNICAL SUMMARY

The purpose of the work was to develop a sealed silver oxide-zinc cell capable of 90 50% depth cycles (1 cycle per day) after a 7 month interplanetary trip and 1-2 months charged stand before launch.

A two phase program was initiated. Phase I involved a 70 cell cycle life experiment to test 7 different cell designs having the prime variables:

- Weight ratio ZnO to Silver: 1.4:1 and 1.2:1
- Concentration KOH electrolyte, 90% saturated with ZnO: 45% and 41%
- Negative electrode shape: flat and tapered (thicker at plate top).
- Mode of plate wrap: "Z" or accordion wrap (both plates wrapped), positive wrap, negative wrap.
- Type of separators: RAI 2291, fibrous sausage casing (FSC), irradiated EM 476, and EM 470 dynel.

Phase I cells were cycled on a 22 hour charge 2 hour discharge profile with modified constant potential charge (setting of 1.94 and 1.96 volts/cell) after four months 70°F charged stand. The four layer FSC designs and the tapered negative plate design were still cycling after 170 cycles. Other designs lost capacity with cycling due to negative plate erosion. ZnO/Ag weight ratio of 1.4:1 delivers higher energy during cycling than the ratio 1.2:1.

5

Phase II will measure cycle life of 19-cell strings of 6 of the 7 designs revised from Phase I. Initial cycles were satisfactory. Cells have completed 6 months 70°F charged stand and are now on cycle-life testing identical to the Phase I profile at NAD, Crane, Indiana.

Phase I cycling tests along with a Mariner '69 type cell control test demonstrated the 30 AH long cycle life cells to have improved cycle life capability (over 170 50% depth of discharge cycles) over the Mariner '69 type cell (32 50% depth of discharge cycles). Mariner '69 Battery packaging techniques can be directly applied to the 30 AH long cycle life cells without redesign. The 5-cell tests of Phase I must be verified by 19-cell battery tests of Phase II.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES - Continued

I. INTRODUCTION

ESB Incorporated, Exide Missile and Electronics Division was awarded JPL Contract 952472 for the continued development of float type Mariner cells and 18 cell batteries. This work was redirected by Modifications 1 through 5 to design and development of sealed high cycle life 30 ampere-hour silver oxide-zinc cells with the design considerations as listed below.

A. Design Goals--JPL Contract 952472. The minimum goals were battery cells.

1. Capable of ninety-six (96) or more charge/discharge cycles at 20% DOD to 70% DOD over a period of ten months or more as shown below:

Cycle	Depth of Dischg.	Lapsed Time
1	70%	1 Day
2	20%	2 Days
3	20%	5 Days
4	20%	15 Days
5	70%	7 Months
6 to 96 or More	50%	7 Mo. 1 Day to 10 Mo. (1 Cycle/Day)

2. Capable of one (1) to two (2) months room temperature (75°F) stand after activation but before cycling as required in paragraph 1. above.

3. Capable of the requirements in paragraph 1. above when operated in a plane 180° from normal and/or while being rotated.

4. Capable of meeting the environmental requirements set forth in JPL Specification TS500437, Revision B, entitled "Type Approval and Flight Acceptance Test Requirements and Preacceptance Test Limits (Assembly Level) Mariner Mars '69 Flight Equipment, General Specifications for."

5. The nominal 18 cell energy shall be 750 W/hr. when discharged at 75°F at a rate of 15 amperes.

6. Capable of operating as specified in paragraph 1. above in the temperature range of 50° to 100°F.

7. Capable of delivering 75% of the rated capacity during discharge at 50°F at a rate of 15 amperes. The cut-off voltage shall be 1.43 volts per cell.

8. Capable of recharge in twenty-four (24) hours.

9. Sealed cell design capable of operating during continuous exposure to space vacuum for one (1) year.

B. Design Considerations. Initially contract 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. 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.

II. TECHNICAL DISCUSSION

A. Cell Designs Selected. In order to meet the requirements set forth in the introduction, a two phase development program was initiated. Phase I involved 7 different cell designs and test groups of 5 cells each. The experimental design is summarized in Table I. Six of the above seven cell designs were revised for tests as 19-cell batteries in Phase II. Table II gives the Phase II experimental design. Major experimental variables were zinc oxide to silver active material ratio, separator system type, and negative electrode shape.

1. ZnO/Ag Active Material Ratio. A survey of the literature showed best cycle life had been obtained by Lander[1], Charkey[2], and predicted by Strauss[3] for ratios up to 1.5:1 by weight when tested on regimes of more than one cycle per day. Increasing the ratio decreases cell capacity per unit cell volume. The ratios chosen are contrasted to Mariner '69 cells to show the impact on capacity. All cells were designed to fit into the Mariner '69 cell compartment.

Application	Weight Ratio (ZnO/Ag)	Molar Ratio (ZnO/Ag)	Cell Capacity (AH)
Mariner '69	0.76	1.00	50.0
Phase I Test Cells	1.20 or 1.40	1.59 1.85	28-30
Phase II Test Cells	1.50	1.99	25-31

2. Separator Type. Separator systems were combinations of two absorbers and two membranes:

Absorbers	Membranes
Irradiated (Kendall EM476) polypropylene	Fibrous sausage casing (FSC)
Dynel (Kendall EM470)	Irradiated grafted polyethylene RAI 2291

Dynel has limited electrolyte absorption capability but was needed as a thin inert interseparator between the positive plate and the fibrous sausage casing. Tables I and II give the number of layers and orientation of each component of the systems selected to test the effects of wet thickness, plate wrap, and position of absorber. By contrast, the Mariner '69 system was a

positive wrap of 1 L EM476 and 6L 193 PUDO cellophane.

3. Other Design Features. Tabulated below are other design features selected for the high cycle life cells.

Design Features	Mariner '69 Cells	Phase I Cells	Phase II Cells
Negative Plate:			
Composition: ZnO,%	90	90	90
HgO,%	7	3	3
Teflon,%	3	7	7
Process: (dry paste)	none	sintered	sintered
Grid	1-2/0D	2-2/0D	2-2/0D
Edge turn-over	none	1/4"	1/4"
Retainer	Viskon	none	none
Positive Plate:			
Density, g/in^3	78.8	69.4	69.4
Electrolyte,% KOH:	45	41, 45 90% sat.	43 90% sat.
Separator:			
Dendrite barrier-length of separator fold-over at top	none	1/4"	1/4"
Plate-lock:	PPG 639/CH2	none	Furane 221/927
Cell Jar and Cover	ABS	same	same
Outside dimensions:			
L, in.	1.53	same	same
W, in.	3.43	same	same
H, in.	3.72	same	same
Volume, $in.^3$	19.5	same	same

Mariner '69 type cell cases and seals were used throughout for reliability and to permit a direct comparison in cycle life and capacity to a 9-cell Mariner '69 row assembly cycled to failure as a control.

B. Phase I Development Cells.

1. Cell Design Relationships. Cell designs 1 through 7 of Table I were based on a common set of design equations. The relative thickness of negative and positive active material (T-) and (T+) was obtained from

$$T- = \left(\frac{d+}{d-}\right) \cdot \left(\frac{W}{f-}\right) \cdot T+ = 1.71\ (W)\,T+ \qquad \text{[Equation 1]}$$

where d+ = positive active material density = 69.4 gm/in^3
d- = negative active material density = 45.0 gm/in^3
W = ratio by weight ZnO/Ag = 1.40 or 1.20
F = fraction ZnO in negative active material.

Cell pack components were fitted into the cell jar by addition of all wet thicknesses and equating to cell length (C.L.) at the jar bottom:

$$C.L. = N+T+ + N-T- + N_MT_M + N_AT_A + N_{G+}T_{G+} + N_{G-}T_{G-} + S$$

[Equation 2]

where M = separator membrane
A = separator absorber
G = grid (+) or (-) allowance
S = shim thickness
N = number of components of a particular type

2. Process Development. Plates were manufactured to prints based on the two design equations above. Tolerances on negative plates were ±3 mils on thickness and +0 -30 mils on width and height. New tooling and process development was found to be necessary to prevent loss of active material from negative plate edges during dry pasting operations. After sintering, the plates

had excellent green strength.

The wedge shaped negative plates of design 1 required process and tooling development. Final plates were to print and had the following thicknesses:

Type	Plate Top Mils ±3	Center Mils ±3	Bottom Mils ±3
Full	76	51	26
Half	38	26	14

Wet cell pack thickness and shim thickness were initially calculated using equation (2) and wet thickness values of RAI 2291 and FSC (45% KOH) at 40 oz/in^2 applied pressure obtained from Figure 1 and unpublished data. Wet thickness values of irradiated EM476 and EM470 absorbers were obtained at only one applied pressure, i.e. 2 oz/in^2 on a Randall-Stickney gage. To standardize cell pack tightness recalculations were made using the composite wet thickness of each separator system determined at 40 oz/in^2 on a Randall-Stickney gage after 120 hours in 45% KOH, see Figure 2. Wet thickness at 40 oz/in^2 was chosen as the lower limit design thickness since at this pressure the major wrinkles in the system have been smoothed out but some free electrolyte remains between layers.

3. Cell Production. One cell of each design was fabricated early to verify design tolerances. Designs 2, 3, and 5 having 2 or more layers of FSC could be inserted in the cell jar with good plate alignment giving a snug dry fit. In these three

designs, the dry separator systems have dry thicknesses less than half wet thicknesses permitting easy insertion of cell packs. Designs 1, 4, and 6 having no FSC expand only 10-30% when wetted and insufficient space exists for insertion tools to be forced into the cell jar with the dry pack without disturbing plate alignment upon withdrawal. The original design pack pressure was then reduced from 40 oz/in^2 to 2 to 12 oz/in^2 for designs 1, 4 and 6 by decreasing shim thicknesses.

C. Phase II Development Cells.

1. Major Design Differences from Phase I. Six cell designs were selected, modified, and approved by JPL for Phase II testing. Cell design relationships, as described above, were applied to Phase II cells with the following differences from Phase I:

a. Design 1, wedge negative plates, was eliminated.

b. One additional layer of irradiated EM476 was added to Designs 6 between positive and first layer of RAI 2291 to increase the electrolyte reserve and charge acceptance.

c. Epocast 221/Catalyst 927, ratio 105:8 was used as a vibration platelock in all cells of Phase II only.

d. Electrolyte concentration was optimized at 43% KOH containing 103 mg/ml ZnO.

e. ZnO/Ag weight ratio was set at 1.5/1 by weight to increase cycle life.

f. Shims were left out and cell packs were designed to the full jar width.

g. Three cells of Designs 2, 3, 4, 5, and 6 have negative additive compound 323-43 in an attempt to increase cell life by retarding the diffusion of dissolved silver oxides during charged wet stand.

2. Manufacturing Process Development. To measure the contribution of grid to the total negative plate thickness, a series of plates were made and pressed 10 seconds at 12 tons on a 2 inch diameter ram. The variable was active mix weight. Figure 3 shows the resultant data plotted from the derived relationship

$$T_p = \left(\frac{1}{d}\right)\left(\frac{W}{A}\right) + T_{grid}$$

Plate thickness T_p was the mean of 5 measurements, and the mix weight W per unit area A was controlled by weighing into the pressing platen. The calculated density d was 48 gm/in^3 and the grid thickness allowance determined by extrapolation was 0.008 inch. This grid allotment was used in all Phase II cells.

Plate insertion into cell jars did not present a problem on Phase II cells containing only RAI 2291 semi-permeable membrane separator.

3. Sealing Process Development. Noryl 731 tensile test samples were machined and bonded with two epoxies, catalyzed polystyrene cement, and a solvent cement containing Noryl chips. The best epoxy bond was obtained with a novalac epoxy (1280 psi butt tensile). The solvent cement bond gave 1786 psi but voids in the cement bond were frequent and gave unreliable tensile strengths. No bonding processes were found sufficiently reliable to warrant further consideration of Noryl 731 for this contract. More investigation of methods for sealing Noryl 731, such as ultrasonic welding, would be desirable to make use of this material in sealed cell cases.

D. Activation and Formation Charge. Phase I and II cells were activated and flooded under vacuum, allowed to stand 72 hours, and then formation charged. Table III compares adjusted electrolyte mean weights and volumes in all cell groups. More electrolyte remained in Phase II cells because shims were replaced by full outside negatives and electrolyte was added to bring all volumes up to the group mean.

Phase I cells were formation charged at 10 ma/in^2 to an input of 0.38 AH/g silver. To reduce cell to cell variation, the charge rate was reduced to 7 ma/in^2 for all Phase II cells. After final seal, Phase II cells were topped off and the total input in all cell designs ranged from 0.38 to 0.42 AH/g silver, considered quite acceptable.

E. Cycling Tests Before Charged Stand.

1. Phase I Cells. Design proofing early cycles were performed on Phase I cells before Phase II cell design was frozen. First cycle discharge at 97 to 122 ma/in^2 (C/2) rate gave satisfactory capacities and voltages except for design 5 cells. See Table IV. Second cycle discharge rate was reduced to 52 ma/in^2 (C/4) on designs 3 and 5. Output was low on design 5 again. On recharge design 3 cells failed to accept full recharge. See Table V. Cell to cell variation was large in these groups. During the scheduled four month wet charged stand, a third cycle was performed to balance and fully form all cells. Charging was 2-step with final rate at 5 ma/in^2 to 1.97 volts per cell. Discharges were also 2-step: (1) 100 ma/in^2 to 1.25 volts, then 33 ma/in^2 to 1.25 volts. See Table VI for results. Minimum cell performance was greatly improved in all cells except design 5. It was concluded that design 5 cell pack tightness was excessive, and should be lowered from 80 to 40 oz/in^2 for Phase II.

2. Phase II Cells. Phase II cells consisted of six (6) major design groups numbered 2 through 7. Each group contained 22 cells, except the design 7 group which contained 19 cells. Three of each set of 22 contained an additive, compound 323-43, in the negative plate to extend life to failure by silver penetration. The effect of the additive on the first three cycles was as follows: (summed over the five designs).

Test	Mean Voltages %	Mean Capacity Change %
Cycle 1 Charge		+ 4.5
1 Discharge	-4.2	- 6.3
2 Recharge		- 17.4
2 Discharge	-3.5	- 20.7
3 Recharge		- 12.8

Performance of cells without compound 323-43 was comparable to or better than the corresponding cells of Phase I. Design 5 cells increased in discharge capacity from 30.7 AH to 40.9 AH on the first two cycles showing improvement due to a reduction in pack pressure from 80 to 40 oz/in^2.

F. Charged Stand Tests. Phase I cells were subjected to a 4-month charged stand at 70 ± 3°F. Phase II cells were given a 6-month charged stand at the same temperature. Cell open circuit voltages were read and recorded twice monthly. Voltages ranged from 1.86 to 1.85 volts for all Phase I cells during the 4-months. Voltages ranged from 1.86 to 1.85 volts for all Phase II cells during six months except for one design 4 cell S/N 57 which dropped to 1.58 volts after 3 months and remained at that voltage. A. C. impedances were measured with a Keithley Model 502 milliohmmeter before and after formation charge and after stand. Table IX is a summary of the data. All Phase I cells exhibited a 3 to 20 fold increase in impedance. Design 5 cells already rejected for low capacity and excessive pack tightness showed the 20 fold increase. These cells have the smooth side of FSC adjacent the dynel absorber on the positive plate and RAI 2291 adjacent the negative plate. Design 3 cells

with the relative positions reversed had the lowest impedances after stand.

Following stand, Phase II cells were shipped to NAD, Crane Indiana for cycling tests as 19-cell strings.

G. Auto-Cycling of Phase I Cells.

1. Cycling Parameters. Ten test circuits were designed and assembled to cycle 5 and/or 10-cell groups on a 22 hour charge, 2 hour discharge routine at 75 ± 5°F. A modified constant potential charge at [1.94 ± .01 volts per cell] x n, the number of cells in series (5 or 10) with current limited at 1.5 amperes was used for the first 65 cycles. The voltage was then raised to 1.96 volts per cell. All discharges were through a constant resistance adjusted to discharge 15 AH (C/2) in the 2 hour time period. An Esterline-Angus 24 point recorder monitored and recorded both current and group voltage for each of the 10 groups of cells on test.

2. Automatic Cycling. Test groups were placed on automatic cycling and were not removed until the third or median cell voltage dropped to 1.0 volt. Every 25-30 cycles a 100% depth of discharge cycle was performed to measure group residual capacity to the first cell to 1.30 volts. When a single cell failed, that cell was removed and cycling continued after adjustment of charge voltage and discharge load resistance to the correct values.

Figures 4 through 10 are plots of group mean cell test end voltages. Figures 11 and 12 summarize the decay of residual capacities during 50% depth of discharge cycling for each major design group.

Throughout all cycling, optimum performance was achieved by Designs 2 (both 41% and 45% KOH groups) and 1 (wedge negative group only) which exhibited no electrochemical failures out to 170 odd cycles when the cells were shipped to JPL at contract end. Residual capacities were 27 to 30 AH when measured last at 135 cycles. The rate of decrease in capacity with cycling at 50% depth on the 22/2 orbit at 75 ± 5°F was calculated to be:

Group Design	Initial First Cycle AH/Volts	Cycle 135 AH	Loss Per Cycle %
Wedge sintered negative; 45% KOH; 1.2 ZnO/Ag weight ratio; negative wrap 1L EM476I, 6L RAI229I (Design 1 W)	40.6 1.46	30.0	0.19
Standard sintered negative; 1.2 ZnO/Ag weight ratio; positive wrap 1L EM470, 4L FSC			
45% KOH group	40.1/1.47	29.5	0.20
41% KOH group (Design 2)	40.1/1.48	27.0	0.24

During auto-cycling the state of charge decreased on some groups to the point where capacity failures were imminent. Evidence for this condition was falling discharge test end voltages and rising end of charge currents. See Figure 6 for design 3 at cycles 45-50. The constant potential setting was raised .02

volts per cell to 1.96 volts per cell on all groups at this time. Recovery was immediate for design 3, but a high pressure failure mode was set up for design 7 cells, 2 of which leaked a few cycles later. See Figure 9. The effect of increasing residual capacity is shown in Figures 11 and 12 for designs 1, 2, 3, 4, and 5. For each 100% depth discharge capacity test the previous modified constant potential charge was allowed to decay to 0.15 amperes time uncontrolled instead of the 22-hour charge during other auto-cycles. The increase in voltage setting thus definitely increased the state of charge but may have contributed to failure of design 7 type cells.

Cell designs 4 and 6 cycled as 10-cell groups out to cycle 90. At this point each was split and cycled as a 5-cell group. Only at this point did the marked advantage of the higher ZnO/Ag ratio (1.4 vs. 1.2) become readily apparent. See Figures 7 and 8.

All cell failures were due to decrease in capacity by negative plate erosion, or cells leaking from overpressure. One cell in each group was sealed in polysulfone to observe electrolyte level fluctuations and this seal proved unreliable. No cells failed by cell shorting.

3. Mariner '69 Control Test. An eight-cell row assembly rejected from Mariner '69 battery production was cycled under the same routine at the same period as a control. A cycle life of 32 cycles (50% depth of discharge based on a nominal capacity of

50 AH) was achieved in 6-months of wet life at 75 ± 5°F. Failure was by one cell shorting through the 1L EM476, 6L cellophane system, which caused overcharge of the remaining good cells until failure of jar walls. Negative plate erosion was 75% with most active material in the lower 25% of the plate area.

4. Phase I Cell Failure Analysis. A representative sample of 10 cells from Phase I tests were dissected and inspected visually. Table X gives design features, cycle life of the group, cycle life or cycles at time of dissection, and visual observations. The primary failure mode was erosion of the sintered teflonated negatives as a function of cycle life increasing from 45% erosion at 80-100 cycles to 65% erosion at 120-135 cycles. Cells with higher ZnO/Ag ratio exhibited the same erosion pattern as a lower ratio cell but at a slightly greater cycle life. Where FSC or EM476 was a part of the separator design, erosion patterns moved upward from the bottom of the plate. An anomaly not seen before was the deterioration of FSC with smooth side adjacent the negative plates in design 3, cells 18 and 26 after 128 cycles. Ag was stopped by the RAI 2291 yet physical degradation was great and was presumed to be oxygen attack in the presence of high zincate ion concentration. Where FSC was positioned next to the positive interseparator, FSC was physically intact: (1) in design 5 after 85 33% cycles, and (2) in design after 115 50% depth cycles.

Additional dissections should be made on the cells continuing to cycle to understand these trends.

III. QUALITY ASSURANCE PROVISIONS

During the first quarter of 1969, Quality Assurance submitted to JPL the draft of the ESB Quality Assurance Plan on this contract.

Amendment A to ESB Quality Assurance Specification 251 was written. QAS 251 is a general document intended to cover quality and traceability requirements of a statistical type experiment. Amendment A qualifies QAS 251 for this contract. It specifies percent inspection, plate color coding for traceability and the particular attribute to be verified during inspection. QAS 251 and Amendment A were released on a 30 day tentative approval, then reviewed and placed on full release.

A. Phase I. A cell color coding system was devised and applied to all cells on test to eliminate mixing of cell designs during testing. Mixed designs led to over-discharge and rupture of two cells, S/N 15 and 21. Post mortem results follow:

1. S/N 15 (Design 2). Positive wrap, 1L EM 470, 4L FSC, 80 oz/in^2, 41% KOH.

History - Rupture occurred after 34.8 AH discharge at 15 amps (.12 amp/in^2) to 1.25 volts on cycle 2 discharge.

Conclusion - Pack tightness aggravated by no stagger on FSC folds. Positive plates were relatively dry.

2. S/N 21 (Design 3). Positive wrap, 1L EM 470, 4L RAI 2291, 2L FSC, 40 oz/in^2, 45% KOH.

History - Rupture occurred at 13.0 AH input of cycle 3 charge at 1.53 amps at voltage in excess of 2.0 volts. Other four cells in group accepted 20 AH to 1.97 volts.

Conclusion - Cell was overcharged at test rate and burst from excessive O_2 pressure. Pack tightness excessive. Quantity of KOH in this group may be marginal. Charge rate should be reduced.

Design 7 cells S/N 66 through 70 have negative plates fabricated with grid material ESB MS-276 Type 2 rather than ESB MS-276 Type 3 used in all other Phase I and II cells. Cells were accepted on MRR 10018 on the basis that Type 2 and Type 3 grid material are both 2/0 distorted silver and are similar in weight, thickness and dimensions of the diamond pattern. Plate drawing active material weight, total plate weight and thickness were achieved. No differences in cell performance were expected in these cells.

Replacement cell S/N 72, Design 3, had the polarity markings reversed on the cell and was charged 0.08 AH in reverse. After correcting the polarity on the cell the formation charge was normal and the cell was accepted on MRR 10021. The coding system to distinguish the many different plate types in Phase I and II was not read correctly.

B. Phase II. During plate fabrication, lot plots of thickness and weight distribution were made and sent to JPL. Of the first lot of 508 Model 386 negative plates, 79 were rejected on weights 0.2 to 0.9 gram below minimum. Material review report 10010 accepted plates for use as end negatives only on Designs 4 and 6 where the end negatives are full negatives and low weight would not be less than the design 1.5:1.0 ZnO/Ag ratio. Corrective action instituted by EMED Quality Assurance required inspectors to monitor plate fabrication processes twice during each shift plus 100% inspection of finished plates for thickness and weight. Color coding on negative leads was devised to distinguish between half and full negatives and two active material lots.

Cell S/N 79 leaked through a vertical crack in a jar corner when overcharged on cycle 3. The cell jar was immediately repaired using catalyzed ABS cement and ABS sheet. The cement was cured and the cell electrolyte was adjusted by the following procedure:

1. Vacuum activated to flooded condition.
2. Electrolyte weight adjusted by withdrawal to the Design 5 cell final adjusted weight range.
3. Sealed with a new vent plug per drawing.

Care was taken during the above operations to exclude oxygen from the cell by sealing with tape between steps.

Traceability of cell serial numbers of 19 cells of design 7 was

lost during clean up of cell case prior to shipment to NAD, Crane. These cells contain the same known lot numbers of FSC, RAI 2291, EM 470, electrolyte, positive, negative and half negative plates. Small differences in final sealed cell weight allowed serial numbers to be reassigned to cells in 1 to 6 cell groups. Corrective action was to identify all cells, with permanent ink immediately after assembly rather than temporarily with removable tape.

Of 129 Phase II cells, two cells, S/N's 79 and 16 exhibited minor terminal leakage and were not shipped to NAD. All data, cell travelers, MRR documents and color code information were shipped with Phase II cells.

IV. CONCLUSIONS AND RECOMMENDATIONS

A. The wedge negative plate design and the 4 layer FSC design are clearly the most reliable designs to deliver 90 50% depth cycles over 10 months wet life.

B. It is strongly recommended that a cell design combining the wedge negative, the 4 layer FSC separator system, 45% KOH, and 1.5:1.0 ZnO/Ag ratio be investigated for long-lived, high cycle life deep space missions.

C. ZnO/Ag weight ratio of 1.4:1 delivers higher energy and gives better cycle life than 1.2:1.

D. The cause of Phase I cell failure was erosion of the negative plate and loss of cell capacity. No cell shorting was detected.

E. Pack pressure of 80 oz/in^2 is not excessive for the positive wrapped 4 layer FSC system but is excessive for negative wrapped combinations of FSC and RAI 2291.

V. NEW TECHNOLOGY

The wedge shaped negative plate design and its associated negative absorber system and grid is identified as new technology. This negative design improves capacity maintenance of cell designs using an all irradiated polyethylene membrane separator system to a degree competitive with cellulosic systems. The design and performance has been described in references 4, 5, 6, and 7. The innovator is C. D. Farris. The wedge shaped negative plate concept originated from technical discussions with JPL.

VI. REFERENCES

1. John J. Lander - Sealed Ag-Zn Batteries, AIAA Paper 64-749, September 1-4, 1964.

2. A. Charkey - Performance Characteristics of Nickel-Zinc Cells, 23rd Annual Power Sources Conference, 22 May 1969.

3. Howard J. Strauss - General Theoretical Principles of Cell Design, Electrochemical Society Paper, Montreal Meeting, 1968.

4. C. Farris - First Quarterly Report Contract 952472, February 14, 1969 - May 14, 1969, p.5.

5. C. Farris - Second Quarterly Report Contract 952472, May 14, 1969-September 14, 1969, p. 10, 11, 13, 14, 15.

6. C. Farris - Third Quarterly Report Contract 952472, September 14, 1969 - February 14, 1970, p. v, 4, 5, 6, 8, 11, 13, 15.

7. C. Farris - Second Monthly Progress Report Contract 952472, 16 April 1969, p. 1.

TABLE I

PHASE I 70 CELL EXPERIMENTAL DESIGN
VARIABLES AND REPLICATION

Contour of Negative Plate	KOH 90 % Sat. With ZnO	ZnO/Ag Weight Ratio	Wrap Order (+) to (-)						
			Positive Wrap		Negative Wrap				Combined
			1L EM470 4L FSC	1L EM470 4L RAI2291 2L FSC	1L EM4761 6L RAI2291	1L EM4761 6L RAI2291	1L EM470 2L FSC(3) 4L RAI2291	1L EM470 4L RAI2291 2L FSC	3L RAI2291 1L EM4761 4L RAI2291
Wedge(2)	45	1.2:1			40 / 5				
Standard	45	1.2:1	80 / 5	40 / 5	2 / 5		80 / 5	12 / 5(1)	
Standard	41	1.2:1	80 / 5	40 / 5		2 / 5	80 / 5	12 / 5(1)	12 / 5
Standard	41	1.4:1				12 / 5			12 / 5
Total Cells			10	10	10	10	10	10	10
Design No.			2	3	1	4	5	7	6

Note: (1) 28 ampere-hours; other designs 30 ampere-hours (0.25 ampere-hour/gm Ag).
(2) Thicker at plate top; pack pressure value less overall.
(3) FSC was positioned with the smooth side toward the positive plate.
(4) Pressure on separator system at design wet thickness allowance.

Code: Oz/in^2 (4) / No. Cells

TABLE II

PHASE II 129 CELL EXPERIMENTAL DESIGN

Number of Plates +/-/ Half Neg.	Rated Capacity AH	Wrap Order (+) to (-)					
		Positive Wrap			Negative Wrap		Combined
		1L EM470 4L FSC	1L EM470 2L FSC 4L RAI2291	1L EM470 4L RAI2291 2L FSC	1L EM470 6L RAI2291	1L EM470 2L FSC (3) 4L RAI2291	1L EM476I 3L RAI2291 1L EM476I 4L RAI2291
8/7/2	25	(1) 80					
9/8/2	28		40	40		40	
10/11/0	31				6		
9/10/0	28						12
Total Cells		(4) 22	22	19	22	22	22
Design[2] No.		2	3	7	4	5	6

NOTES: (1) Cell design pack pressure in oz/in^2.

(2) ZnO to Ag active material weight ratio 1.5:1; KOH concentration 43% plus 103 mg/ml ZnO.

(3) FSC smooth side toward positive plate.

(4) Three of each group of 22 cells have compound 323-43 negative plate additive.

TABLE III
COMPARISON OF MEAN ELECTROLYTE WEIGHT AND VOLUME

	PHASE I								PHASE II					
						Quantity Electrolyte						Quantity Electrolyte		
Design	Order of Wrap (+) to (-)	Plate Wrapped & Wet Thick. (mils)	Pack Pres. oz/in^2	ZnO/Ag Weight Ratio	KOH (%)	Mean GMS	Mean CC	CC/ GM.Ag	Order of Wrap (+) to (-)	Plate Wrapped & Wet Thick. (mils)	Pack Pres. oz/in^2	Mean GMS	Mean CC	CC/ GM.Ag
2	1 EM470 4 FSC	+ (36.0)	80	1.2:1	45 41	163 161	106 109	.86 .89	1 EM470 4 FSC	+ (36.0)	80	176	118	1.2
7	1 EM470 4 RAI2291 2 FSC	- (26.0)	12	1.2:1	45 41	153 159	100 108	.90 .97	1 EM470 4 RAI2291 2 FSC	+ (23.5)	40	152	101	.91
5	1 EM470 2 FSC 4 RAI2291	- (23.5)	80	1.2:1	45 41	147 144	96.1 98.0	.78 .80	1 EM470 2 FSC 4 RAI2291	- (23.5)	40	158	106	.96
3	1 EM470 4 RAI2291 2 FSC	+ (23.5)	40	1.2:1	45 41	143 141	93.5 96.0	.76 .78	1 EM470 2 FSC 4 RAI2291	+ (23.5)	40	153	102	.92
1	1 EM4761 6 RAI2291	- (14.0)	2 40(1)	1.2:1	45	119 150	77.8 98.0	.63 .80				None		
4	1 EM476I 6 RAI2291	(12.0) - (14.0)	12 2	1.4:1 1.2:1	41	118 109	80.3 74.2	.65 .60	1 EM476I 6 RAI2291	- (13.0)	6	139	92.8	.75
6	3 RAI 1 EM476I 4 RAI	Both (14.0)	12	1.4:1 1.2:1	41	119 110	81.0 75.0	.66 .61	1 EM476I 3 RAI 1 EM476I 4 RAI	Both (14.0)	12	147	97.9	.88

NOTES: (1) Wedge negative plate; thicker at top.
(2) Phase II cells ZnO/Ag weight ratio 1.5:1; KOH concentration 43% (90% saturated with ZnO).

TABLE IV

CYCLE 1 DISCHARGE CAPACITY, MIDPOINT VOLTAGE, AND CYCLE 2 CHARGE CAPACITY, PHASE I CELLS

Contour of Negative Plate	% KOH 90% Sat. With ZnO	ZnO/Ag Weight Ratio	Units	Separator System and Order of Wrap (+) to (-)						
				Positive Wrap		Negative Wrap				Combined
				1 EM470 4 FSC	1 EM470 4 RAI2291 2 FSC	1 EM476I 6 RAI2291	1 EM476I 6 RAI2291	1 EM470 2 FSC(2) 4 RAI2291	1 EM470 4 RAI2291 2 FSC	3 RAI2291 1 EM476I 4 RAI2291
Wedge (1)	45	1.2	AH Volts AH			40.6 1.46 40.6				
Standard	45	1.2	AH Volts AH	38.5 1.47 41.4	40.1 1.45 39.7	41.8 1.47 46.6		15.1 1.40 23.3	37.1 1.48 44.0	
Standard	41	1.2	AH Volts AH	38.5 1.48 38.9	40.1 1.46 40.2		40.6 1.49 39.8	15.1 1.40 21.6	32.7 1.47 38.9	40.6 1.47 39.8
Standard	41	1.4	AH Volts AH				41.8 1.47 47.8			40.6 1.47 39.8
Design Pack Pressure			oz/in^2	80	40	40/2	2/12	80	12	12
Design Number			--	2	3	1	4	5	7	6
Discharge Rate			Amps	15	15	15	15	15	14	8
Discharge Test End voltage			volts	1.25	1.25	1.25	1.25	1.25	1.30	1.30

NOTES: (1) Thicker at plate top; pack pressure value less overall.
(2) FSC was positioned with the smooth side toward the positive plate.

TABLE V
CYCLE 2 DISCHARGE CAPACITY/CYCLE 3 CHARGE CAPACITY, PHASE I CELLS

Contour of Negative Plate	% KOH 90% Sat. With ZnO	ZnO/Ag Weight Ratio	Units	Separator System and Order of Wrap (+) tp (-)						
				Positive Wrap		Negative Wrap				Combined
				1 EM470 4 FSC	1 EM470 4 RAI2291 2 FSC	1 EM476I 6 RAI2291	1 EM476I 6 RAI2291	1 EM470 2 FSC(2) 4 RAI2291	1 EM470 4 RAI2291 2 FSC	3 RAI2291 1 EM476I 4 RAI2291
Wedge(1)	45	1.2:1	AH			39.5 38.2				
Standard	45	1.2:1	AH	32.8 35.9	40.5 30.1	45.2 41.3		25.7 20.2	39.1 37.7	
Standard	41	1.2:1	AH	38.9 38.1	41.8 32.8		40.1 44.6	22.9 21.4	40.1 34.0	34.5 43.4
Standard	41	1.4:1	AH				45.7 41.9			35.9 42.2
Design Pack Pressure			oz/in^2	80	40	40/2	2/12	80	12	12
Design				2	3	1	4	5	7	6
Discharge Rate Step I/Step II			Amps	15	8	15	15	8	14/4	15

NOTES: (1) Thicker at plate top; pack pressure value less overall.
(2) FSC was positioned with smooth side toward the positive plate.
(3) All discharge test end voltages 1.25 volts per cell.

TABLE VI

CYCLE 3 DISCHARGE CAPACITY/CELL VOLTAGE/CYCLE 4 RECHARGE CAPACITY PHASE I CELLS

Contour of Negative Plate	% KOH 90% Sat. With ZnO	ZnO/Ag Weight Ratio	Units	Separator System and Order of Wrap (+) to (-)					
				Positive Wrap		Negative Wrap			Combined
				1 EM470 4 FSC	1 EM470 4 RAI2291 2 FSC	1 EM476I 6 RAI2291	1 EM476I 6 RAI2291	1 EM470 2 FSC(2) 4 RAI2291	3 RAI2291 1 EM476I 4 RAI2291
Wedge(1)	45	1.2:1	AH Volts AH			40.7 1.45 49.7			
Standard	45	1.2:1	AH Volts AH	46.6 1.49 43.3	44.4 1.46 43.2	36.3 1.46 52.7		27.1 1.42 26.2	
Standard	41	1.2:1	AH Volts AH	50.0 1.49 44.4	46.4 1.46 43.8		46.8 1.51 43.8	29.1 1.42 27.0	45.9 1.45 45.0
Standard	41	1.4:1	AH Volts AH				47.5 1.49 43.5		37.9 1.45 34.9
Design Pack Pressure			oz/in^2	80	40	40/2	2/12	80	12
Design				2	3	1	4	5	6
Discharge Rate Step I/Step II			Amps	12/4	15/5	15/5	15/5	15/5	15/5

NOTES: (1) Thicker at plate top; pack pressure value less overall.
(2) FSC was positioned with smooth side toward the positive plate.
(3) Discharge test end voltage all steps 1.25 volts.

TABLE VII

PHASE II CYCLES 1-2 GROUP MEAN PERFORMANCE

Design Number--Sample Size	2-19	3-19	4-19	5-19	6-19	7-19
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 Pack Pressure, oz/in^2	80	40	6	40	12	40
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 1.30 V 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	.97
Step 2 (4 ma/in^2)	0.50	0.55	0.62	0.55	0.55	.60

TABLE VIII

CYCLES 1-2 GROUP MEDIAN PERFORMANCE, PHASE II CELLS - WITH COMPOUND 323-43

Design Number--Sample Size	2-3	3-3	4-3	5-3	6-3
Plate Wrapped	+	+	-	-	Both
Order of Separation, + to -	1EM470, 4FSC	1EM470, 2FSC, 4RAI	1EM476I, 6RAI	1EM470, 2FSC, 4RAI	1EM476I, 3RAI 1EM476I, 4RAI
Cell Nominal Capacity, AH	25	28	31	28	28
Cell Pack Pressure, oz/in^2	80	40	6	40	12
Cell S/N	20, 21 & 22	42, 43 & 44	64, 65 & 66	86, 87 & 88	108, 109 & 110
Cycle 1					
• Charge, Formation, AH					
7ma/in^2 to Input or 2.1V 1st Cell	37.8	42.4	41.2	42.2	39.3
7ma/in^2 to 1.97V 1st cell(after seal)	3.8	4.4	6.5	4.1	7.6
• Total AH	41.6	46.8	47.7	46.3	46.9
• AC Impedance, Before Formation, mohms	34	44	36	36	34
• AC Impedance, After Cycle 3 Charge, mohms	46	143	23	150	58
• Discharge, AH					
52 ma/in^2 to 1.30V 1st cell	32.6	36.1	39.6	35.1	37.2
• Mid Voltage during Discharge,Volts	1.47	1.44	1.44-1.45	1.42	1.44
Cycle 2					
• Charge, AH					
Step 1 to 2.0V 1st Cell	30.0	14.5	39.7	33.1	35.7
Step 2 to 1.98V/cell	2.0	16.2	0.8	2.4	1.0
Total AH	32.0	30.7	40.5	35.5	36.7
• Discharge, AH					
0.052 amp/in^2 to 1.30V/cell	28.4	30.0	42.0	29.9	35.0
• Mid Voltage during Discharge,Volts	1.50	1.44-1.45	1.44	1.41-1.42	1.44
Cycle 3					
• Charge, AH					
Step 1 to 2.0V 1st Cell	27.1	26.0	33.0	26.0	31.9
Step 2 to 1.98V/cell	3.5	10.2	3.0	2.2	2.4
Total, AH	30.6	36.2	36.0	28.2	34.3
Discharge Current,Amps (52 ma/in^2)	6.4	7.2	8.0	7.2	7.2
Charge Current,Amps,Step 1(7ma/in^2)	0.86	0.97	1.08	0.97	0.97
Step 2 (4 ma/in^2)	0.50	0.55	0.62	0.55	0.55

TABLE IX

AC IMPEDANCE BEFORE AND AFTER 4 MONTHS CHARGED STAND
PHASE I CELLS AT 70 ± 3°F

Design No.	Order of Wrap (+) to (-)	Wrap & Wet Thick. (Mils)	Pack Pressure oz/in^2	ZnO/Ag Weight Ratio	KOH (%)	Impedance at Formation Charge, mohms		Impedance After 4 Months Stand, Mohms Cell Number					Mean
						Before	After	1	2	3	4	5	$\bar{X}$
2	1 EM470 4 FSC	Positive (36.0)	80	1.2	45	58	58	210	203	242	222	145	204
					41	59	48	224	250	(2)	130	235	210
5	1 EM470 2 FSC 4 RAI2291	Negative (23.5)	80	1.2	45	45	21	1120	890	1060	960	900	986
					41	47	20	650	692	600	670	650	652
3	1 EM470 4 RAI2291 2 FSC	Positive (23.5)	40	1.2	45	58	17	210	125	170	130	(2)	159
					41	57	15	200	111	95	120	130	131
1	1 EM476I 6 RAI2291	Negative (14.0)	2	1.2	45	36	17	360	420	580	300	350	442
			40	1.2(1)		51	23	430	220	230	160	120	232
6	3 RAI2291 "Z" Folded 1EM 476I 4 RAI2291 "U" Folded	Both (14.0)	12	1.4	41	40	30	180	146	233	200	260	204
				1.2		43	34	206	203	208	300	195	223
4	1 EM476I 6 RAI2291	Negative (12.0)	12	1.4	41	39	23	294	290	270	217	215	257
		Negative (14.0)	2	1.2		38	18	229	173	205	147	132	177

NOTES: (1) Wedge negative plate, thicker at plate top.
(2) Replacement cells - less than 4 months stand.

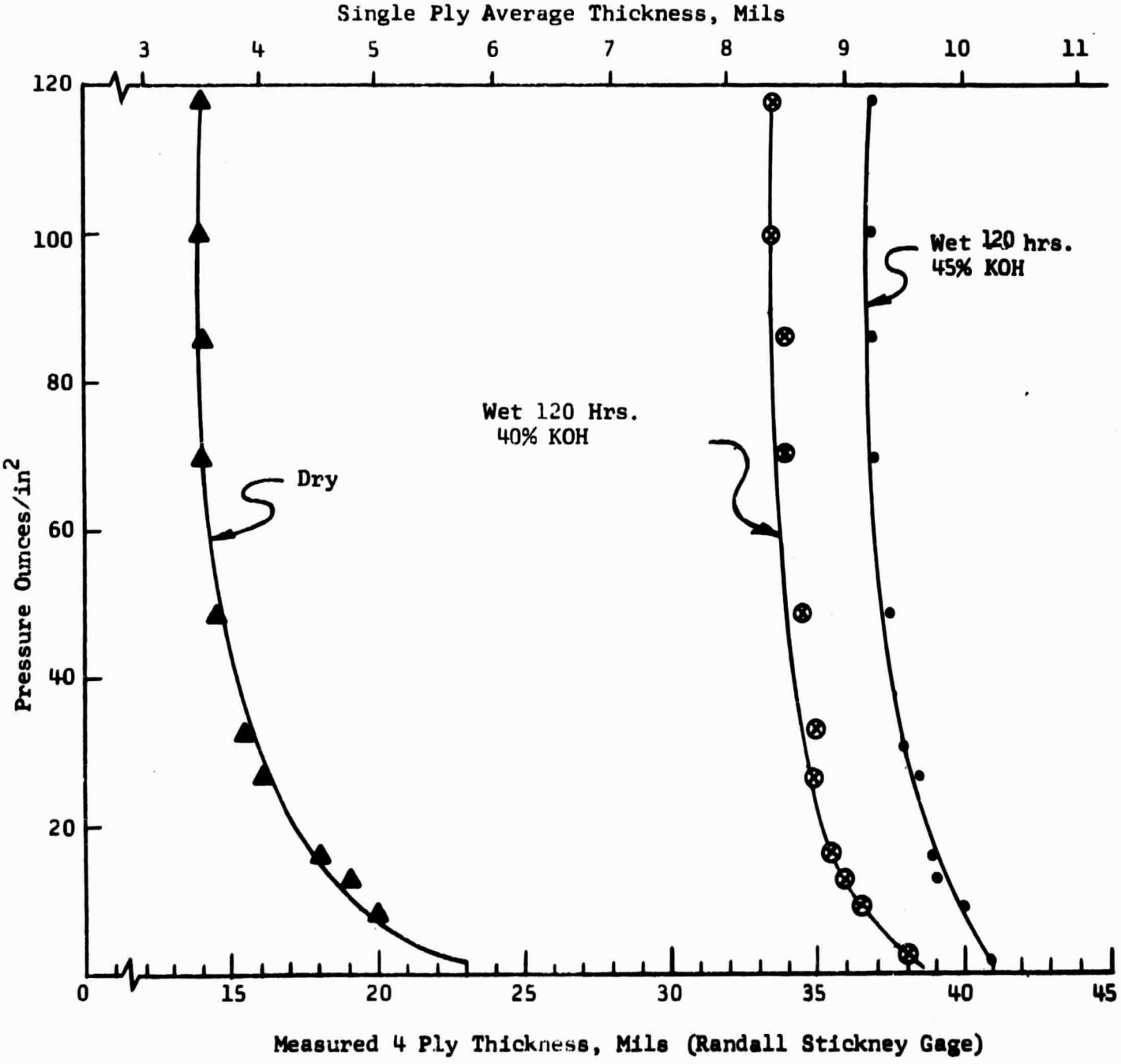
TABLE X
PHASE I CELL DISSECTIONS AND CYCLE LIFE

Des. No.	Order of Wrap (+) to (-)	Plate Wrap.	Pack Pres. oz/in^2	ZnO/Ag Wgt. Rat.	KOH (%)	Cycle Life at Obser.	% Eros. on Neg.	S/N	Observations	Test Group Cycles to Failure or Termination (T)[1] 1st Cell	2nd Cell	3rd Cell
7	1EM470 4RAI2291 2FSC	Neg.	12	1.2	45				NOT DISSECTED Leaked at ABS cover to jar seal	55	77T	
					41					57	76	76T
5	1EM470 2FSC(2) 4RAI2291	Neg.	80	1.2	45	85	45	31	-1 lay.RAI stop. most all Ag. -FSC was intact			
					41		45	37	-Free KOH was present	85T		
6	3RAI2291 "Z" Folded 1EM476I 4RAI2291 "U" Folded	Both	12	1.4	41	99	45	48	-6 layers RAI contained Ag -Zn grew into 1 layer RAI2291 -Positives wet	99[3]	123	133T
				1.2		100	55	60	-Neg. eroded toward center	100	109	109
3	1EM470 4RAI2291 2FSC	Pos.	40	1.2	45	128	60	18	-2 lay. RAI stop. most Ag -FSC deteriorated adj. neg.	128[3]	138	144
					41	128	60	26	-No free KOH present -Positives were dry	8[4]	128	134
4	1EM476I 6RAI2291	Neg.	12	1.4	41	132	60	29	-6 layers RAI contained Ag -Zn grew into 1 layer RAI2291 -Positives wet -Negatives eroded all around	132	141T	
			2	1.2		122	65	52		122	131	135
1	1EM476I 6RAI2291	Neg.	2	1.2	45	135	65	6	-6 layers RAI contained Ag -Zn grew into 1 layer RAI2291 -Free KOH present--pos. wet	136	151	157T
2	1EM470 4FSC	Pos.	80	1.2	45	115	50	9	-All 4 lay.FSC contained Ag -FSC was intact, all layers -Positives were wet	Seal(3) leak at 115 cyc.	no failure	no failure

NOTES: (1) 22 hr charge/2 hr discharge 50% depth except design 5 at 33% depth.
(2) Smooth side of FSC facing positive plate.
(3) Polysulfone jar to cover seal leak.
(4) Case ruptured when timer failed.
(5) Cyc. = cycles; adj. = adjacent; lay. = layers; Eros. = Erosion

FIGURE 1

WET AND DRY THICKNESS OF FIBROUS SAUSAGE CASING AT VARYING PRESSURES



Note: Average one ply dry thickness was 3.0 mils measured on a hand micrometer with pressure applied to the point where the micrometer clutch slipped.

FIGURE 2

EFFECT OF PRESSURE CHANGE ON SEPARATOR SYSTEM THICKNESS

Separator Systems:	Design
A. 4-FSC, 1 EM-470	2
B. 4-RAI 2291, 2-FSC, 1 EM-470	3 & 5
C. 6-RAI 2291, 1 EM-476I	4 & 1
D. 7-RAI 2291, 1 EM-476I	6

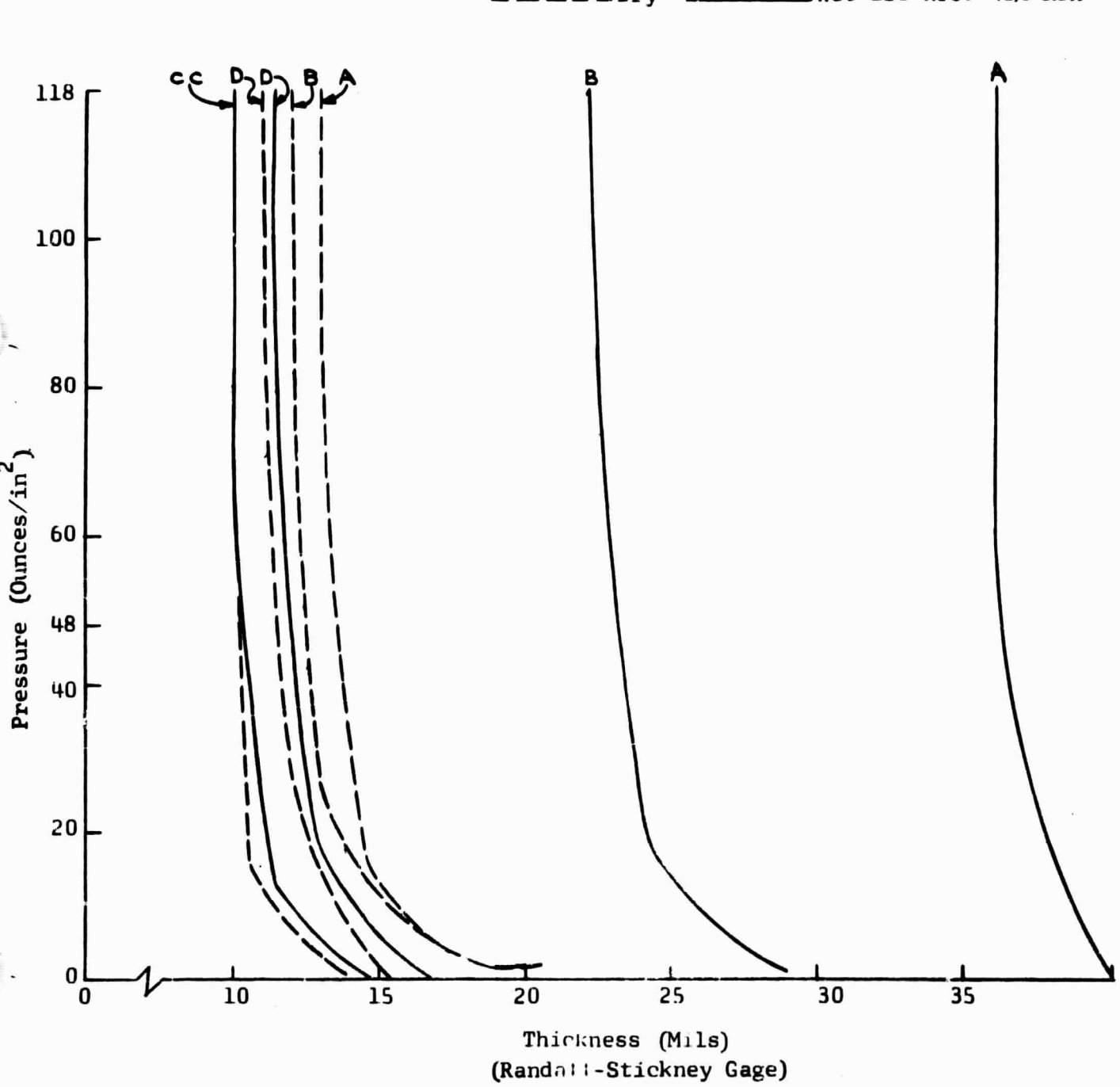


FIGURE 3

MEAN PLATE THICKNESS VS. MIX WEIGHT/SQ. IN.
PHASE II

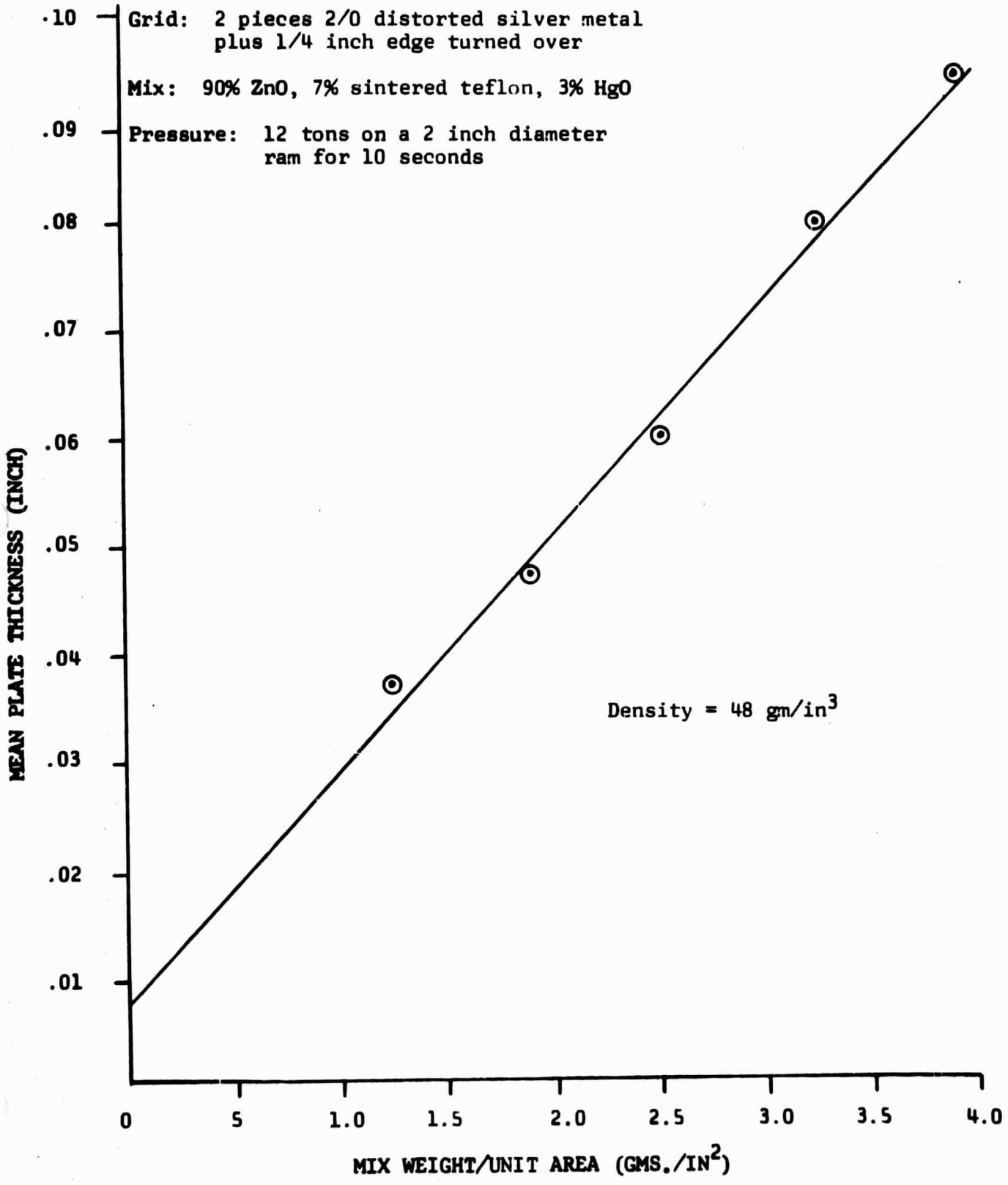


FIGURE 4
PHASE I END OF DISCHARGE VOLTAGE DURING AUTOCYCLING
(22 HOUR CHARGE 1.94 VOLT/CELL - LIMITING CURRENT 1.5 AMPS)

(Design 2; Plate wrapped, positive; Order of wrap, + to -, 1EM 470, 4 FSC; Pack pressure, 80 oz/in^2; ZnO/Ag weight ratio 1.2:1)

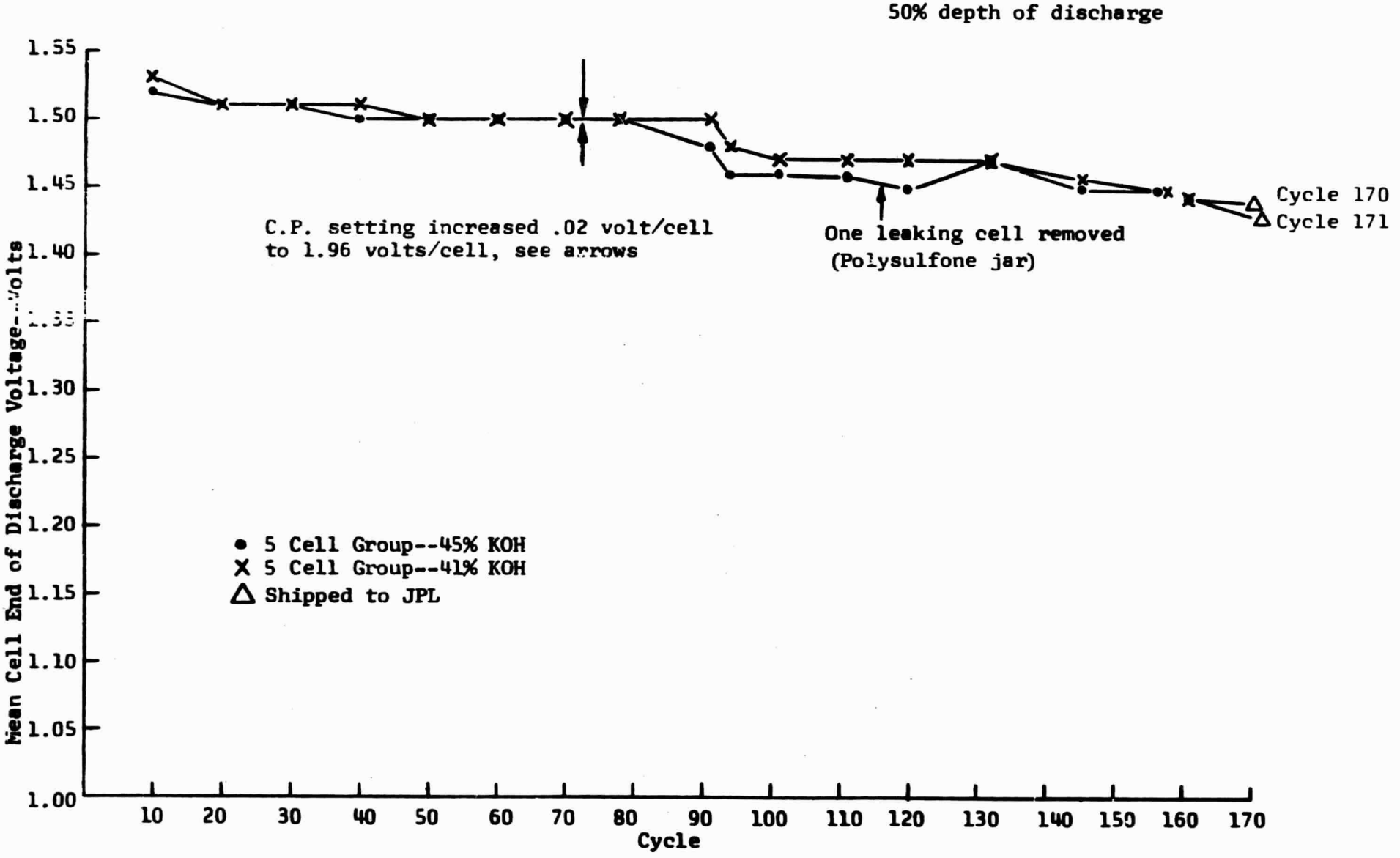


FIGURE 5
PHASE I END OF DISCHARGE VOLTAGE DURING AUTOCYCLING
(22 HOUR CHARGE, 1.94 VOLTS/CELL - LIMITING CURRENT 1.5 AMPS 78 ± 12°F)

(Design 1; 45% KOH; Plate wrapped-negative; Order of wrap, + to -, 1 EM 476 irradiated, 6 RAI 2291)

50% depth of discharge

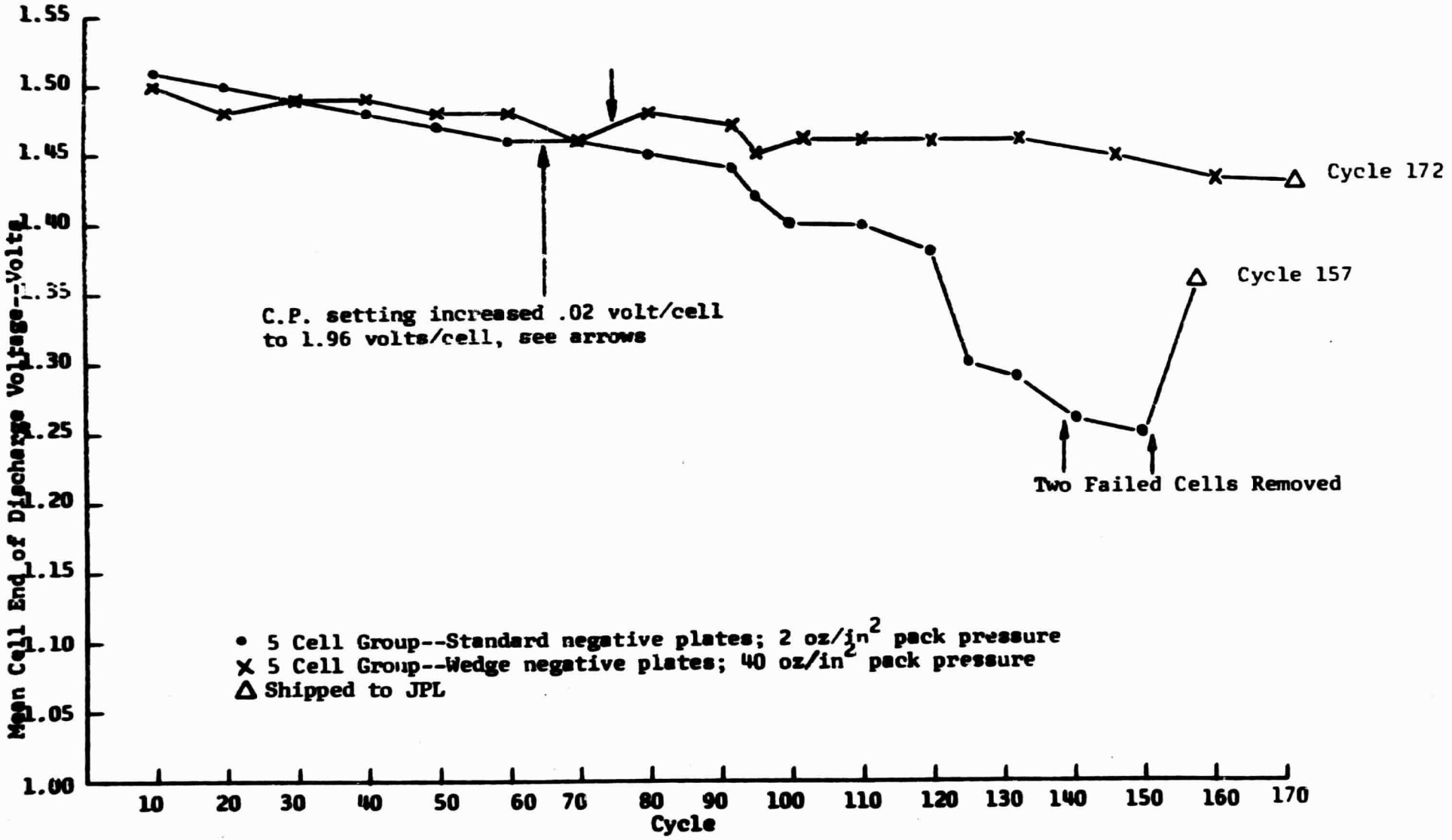


FIGURE 6
PHASE I END OF DISCHARGE VOLTAGE DURING AUTOCYCLING
(22 HOUR CHARGE 1.94 VOLTS/CELL - LIMITING CURRENT 1.5 AMPS)

(Design 3; Plate wrapped, positive; Order of wrap, + to -, 1 EM 470, 4 RAI2291, 2FSC; Pack pressure, 40 oz/in^2, ZnO/Ag weight ratio 1.2:1)

50% depth of discharge

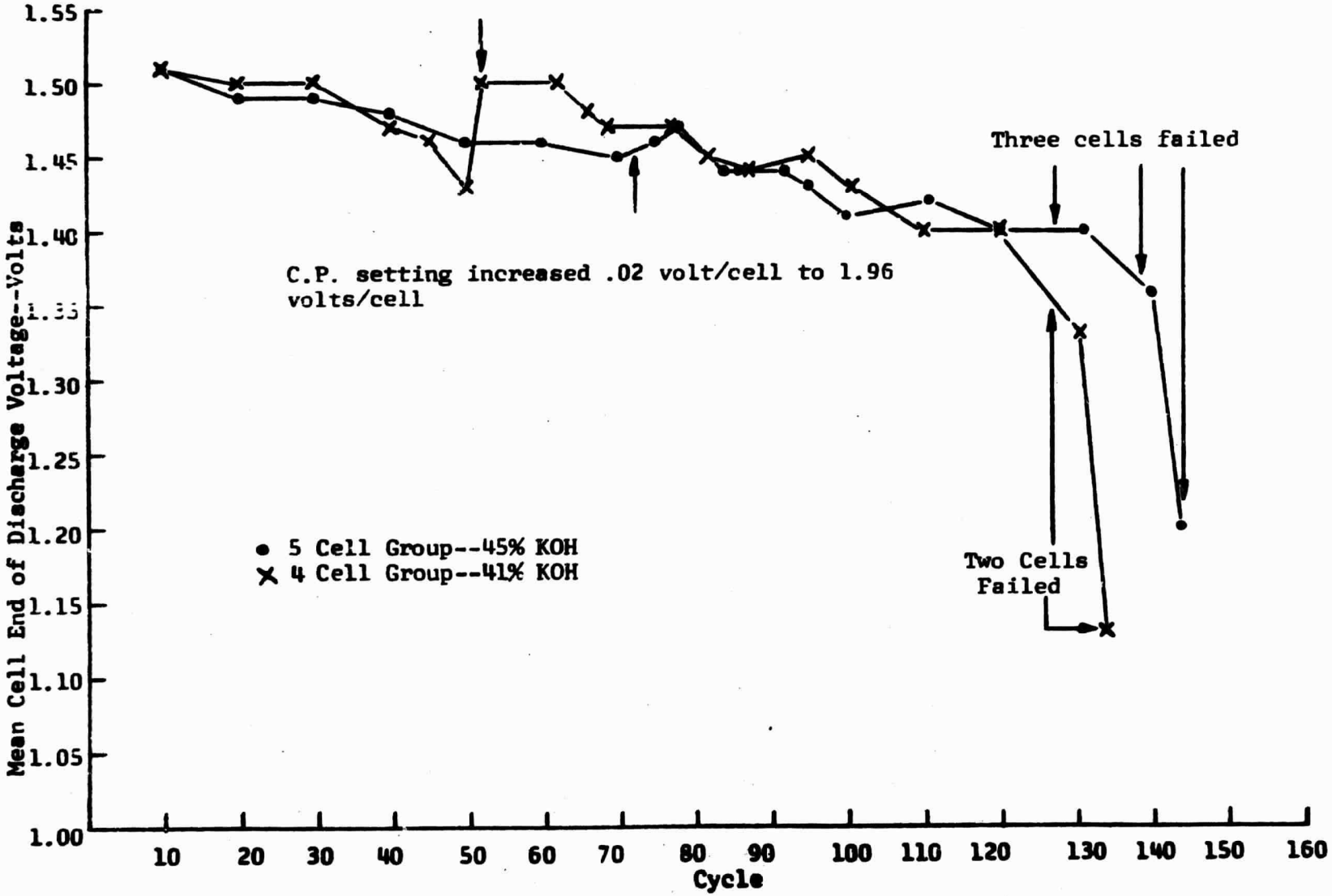


FIGURE 7
PHASE 1 END OF DISCHARGE VOLTAGE DURING AUTOCYCLING
(22 HOUR CHARGE, 1.94 VOLTS/CELL - LIMITING CURRENT 1.5 AMPS)

(Design 4; 41% KOH; Plate wrapped - negative; Order of wrap, + to -, 1EM 476 irradiated, 6 RAI 2291)

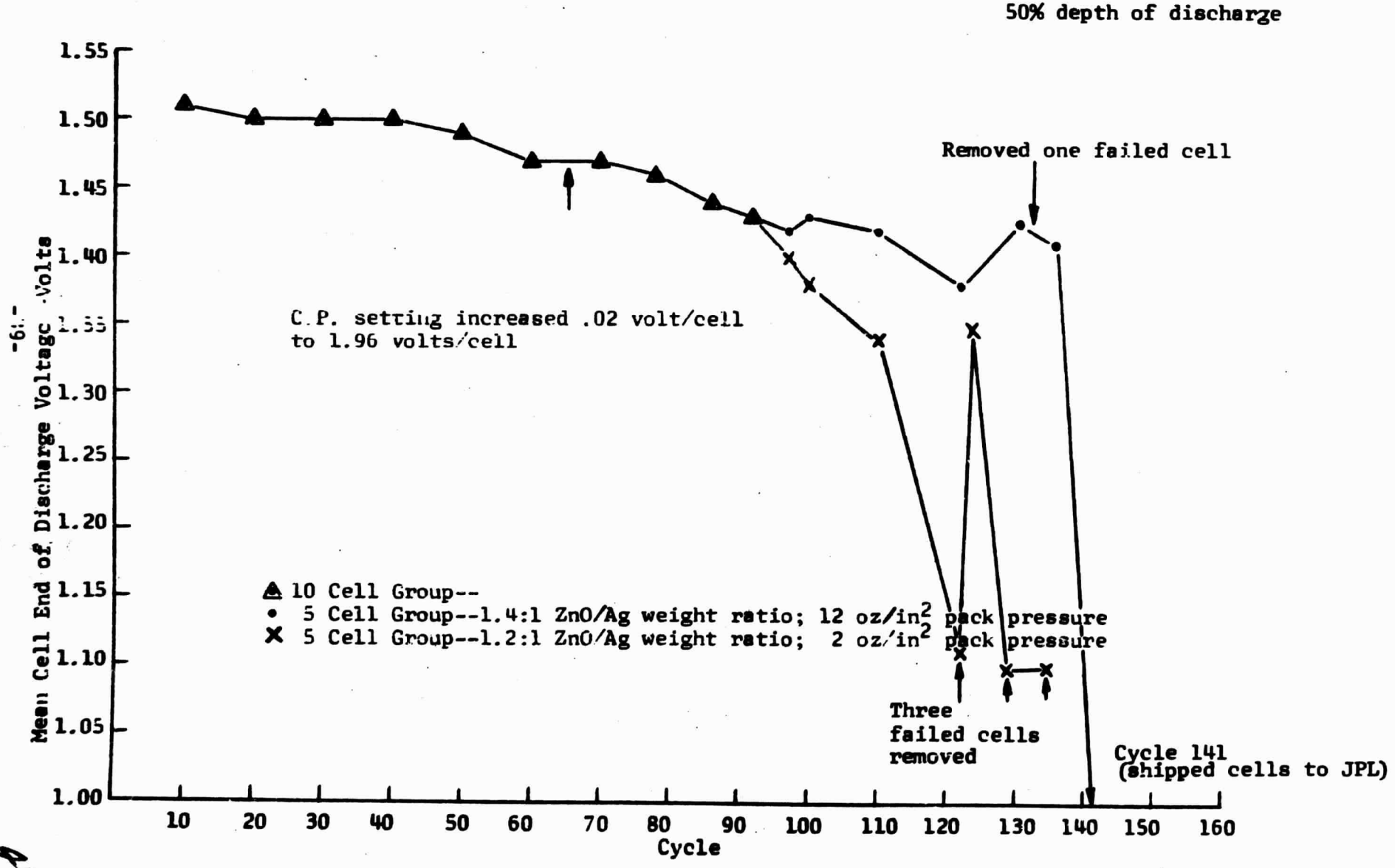


FIGURE 8
PHASE I END OF DISCHARGE VOLTAGE DURING AUTOCYCLING
(22 HOUR CHARGE 1.94 VOLTS/CELL - LIMITING CURRENT 1.5 AMPS)

(Design 6; 41% KOH; Plates wrapped-both; Order of wrap, + to -, 3 RAI 2291 "Z" folded, 1EM 476 irradiated, 4 RAI 2291 "U" folded; Pack pressure, 12 oz/in^2)

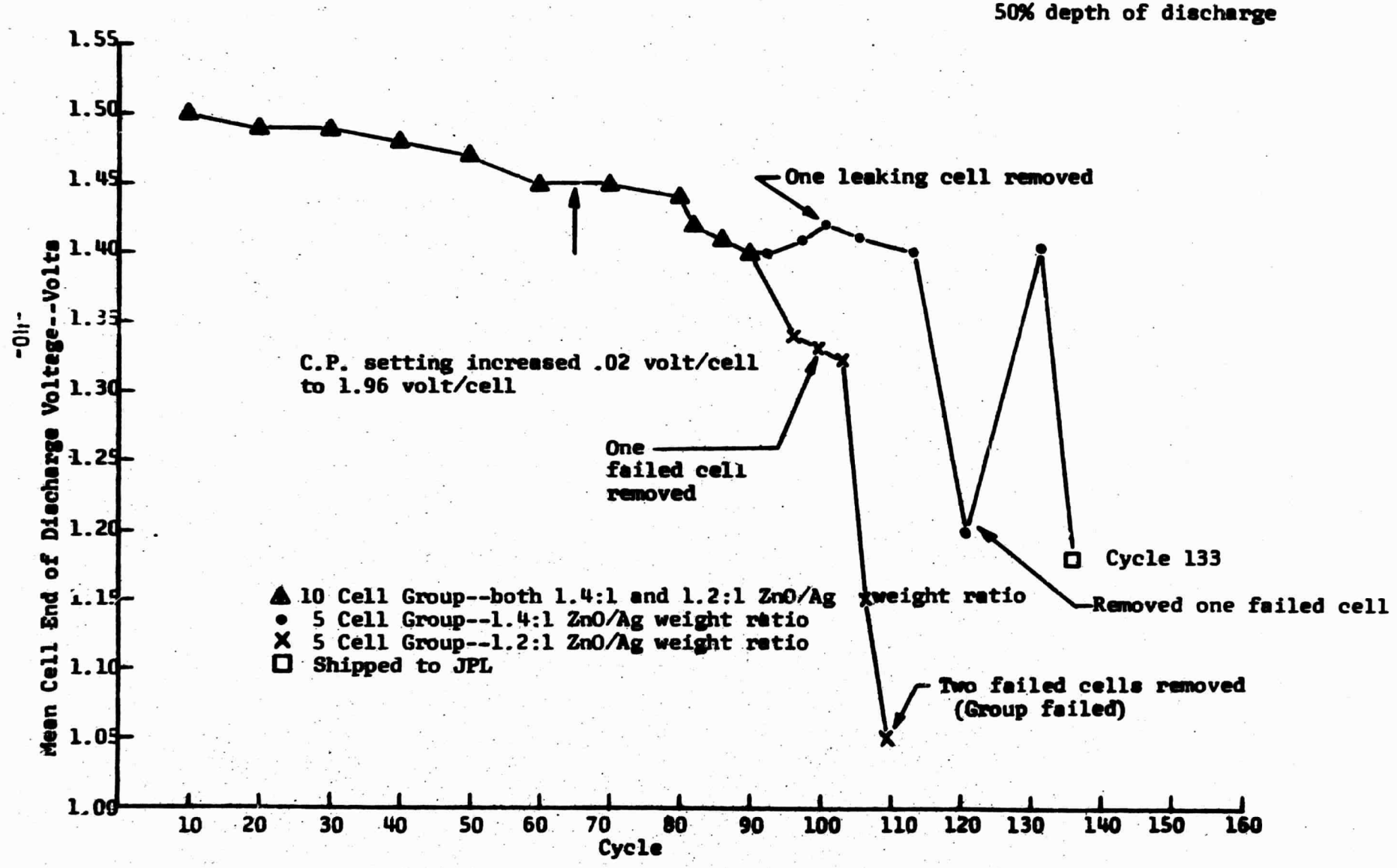


FIGURE 9
PHASE I END OF DISCHARGE VOLTAGE DURING AUTOCYCLING
(22 HOUR CHARGE 1.96 VOLTS/CELL - LIMITING CURRENT 1.5 AMPS)

(Design 7; Plate wrapped, negative; Order of wrap, + to -, 1 EM 470, 4 RAI 2291, 2 FSC; Pack pressure, 12 oz/in^2; ZnO/Ag weight ratio, 1.2:1)

50% depth of discharge

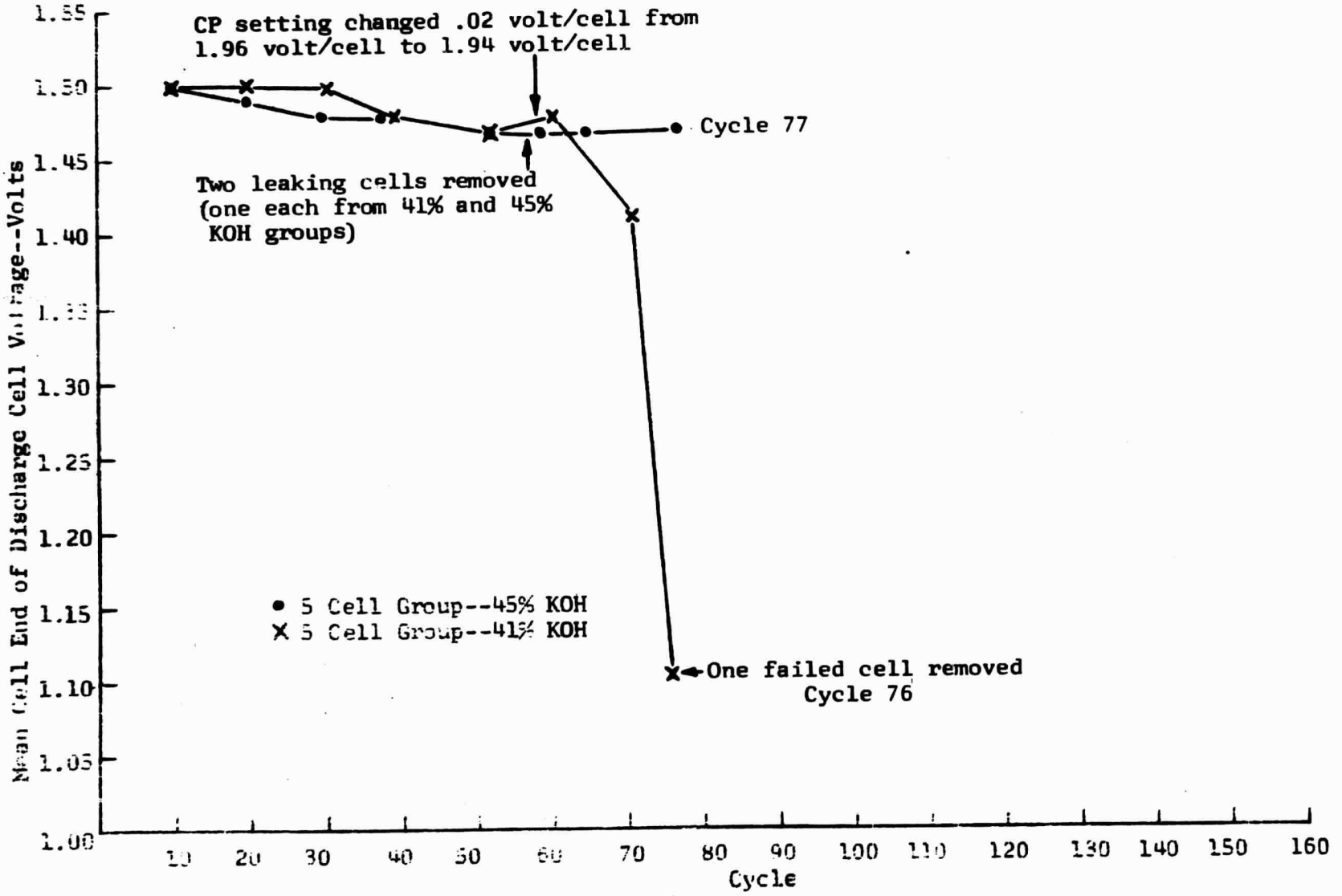


FIGURE 10
PHASE I END OF DISCHARGE VOLTAGE DURING AUTOCYCLING
(22 HOUR CHARGE 1.94 VOLTS/CELL - LIMITING CURRENT 1.5 AMPS)

(Design 5; Plate wrapped, negative; Order of wrap, + to -, 1 EM 470, 2 FSC, 4 RAI 2291; Pack pressure, 80 oz/in^2; ZnO/Ag weight ratio, 1.2:1)

33% depth of discharge

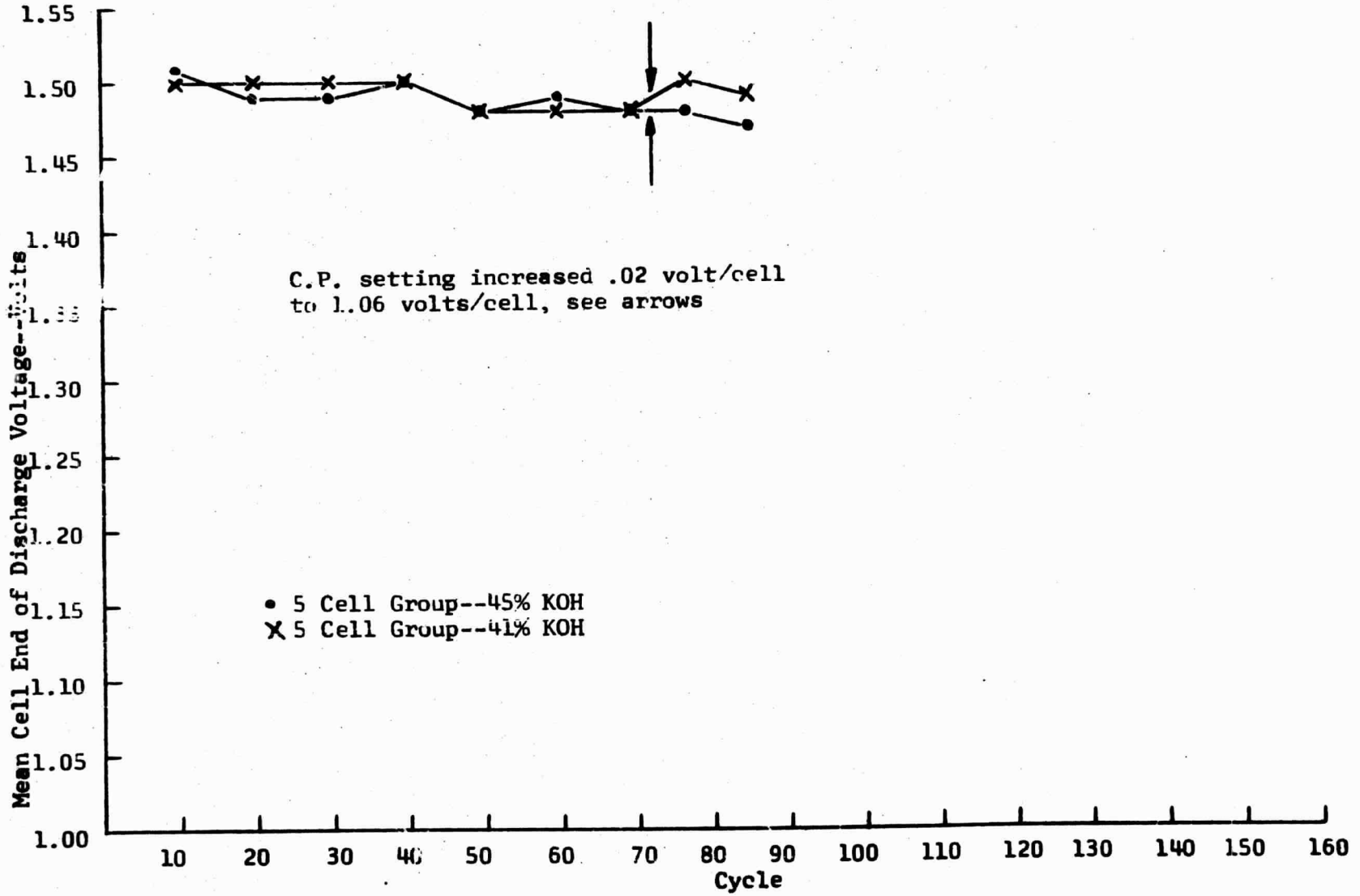
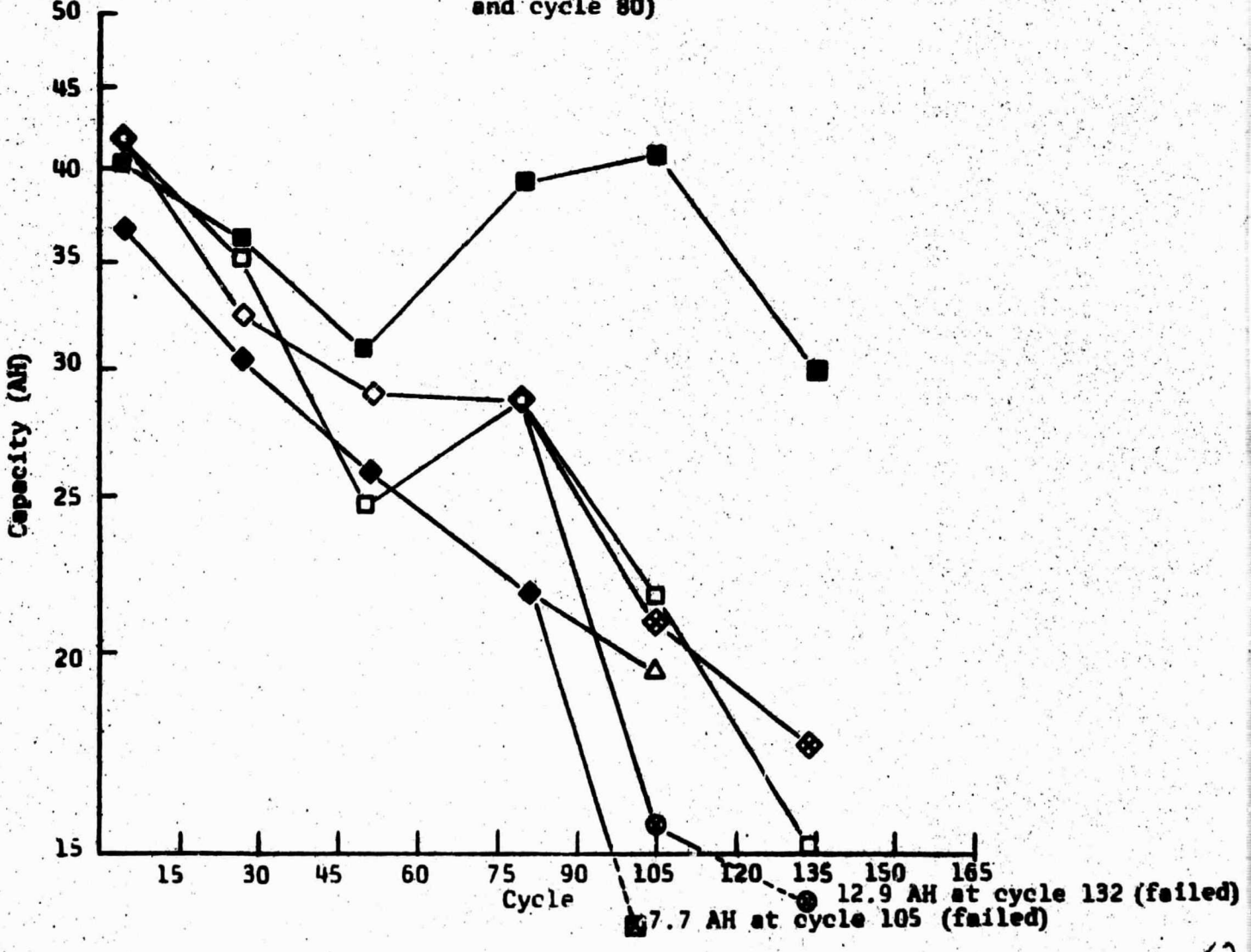


FIGURE 11
PHASE I GROUP 100% DOD CAPACITY DURING 50% DOD AUTOCYCLING

Code		ZnO/Ag Wt. Ratio	Pack Pres, oz/in^2	Order Wrap +to-	Plate Wrap	Design
	□	1.2:1	2	1 EM 476I 6RAI	-	1 45% KOH
	■		40 Wedge Neg.			
◇	◈	1.4:1	12	1 EM 476I 6RAI	-	4 41% KOH
	⊗	1.2:1	2			
◆	△	1.4:1	12	3RAI 1 EM 476I 4RAI	Both	6 41% KOH
	⊠	1.2:1				

(C.P. setting increased .02 volt/cell to 1.96 volts/cell between cycle 50 and cycle 80)



52

FIGURE 12
PHASE I GROUP 100% DOD CAPACITY DURING 50% DOD AUTOCYCLING

Code	KOH %	ZnO/ Ag Wt Ratio	Pack Pres. oz/in^2	Order Wrap +to-	Plate Wrap	Design	Code	KOH %	ZnO/ Ag Wt Ratio	Pack Pres. oz/in^2	Order Wrap +to-	Plate Wrap	Design
●	45	1.2:1	80	1 EM 470 4FSC	+	2	△	45	1.2:1	80	1 EM 470 2FSC 4RAI	-	5
×	41						▲	41					
○	45	1.2:1	40	1 EM 470 4RAI 2FSC	+	3	▽	45	1.2:1	12	1 EM 470 4RAI 2FSC	-	7
⬡	41						▼	41					

(C P. setting increased .02 volt/cell to 1.96 volts/cell between cycle 50 and cycle 80)
Note: Design 5 cycled at 33%; all others at 50% depth of discharge.