ASD-TR-61-636

TEST REPORT ON SEALED SILVER OXIDE-ZINC SECONDARY CELLS

TECHNICAL REPORT ASD-TR-61-636

FEBRUARY 1962

FLIGHT ACCESSORIES LABORATORY
AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

Project No. 3145, Task No. 314510

(Prepared under Contract No. AF 33(600)-41600
by Delco-Remy, Division of General Motors Corporation,
Anderson, Indiana.
Author: J. A. Keralla)

NOTICES

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

Qualified requesters may obtain copies of this report from the Armed Services Technical Information Agency, (ASTIA), Arlington Hall Station, Arlington 12, Virginia.

This report has been released to the Office of Technical Services, U. S. Department of Commerce, Washington 25, D. C., in stock quantities for sale to the general public.

Copies of ASD Technical Reports and Technical Notes should not be returned to the Aeronautical Systems Division unless return is required by security considerations, contractual obligations, or notice on a specific document.

400 - May 1962 - 31-1398 & 1399

FOREWORD

This report was prepared by Delco-Remy, Division of General Motors, Anderson, Indiana, on Air Force Contract AF 33(600)-41600, under Task Nr 61079 of Project Nr 3145, "Silver Oxide-Zinc Battery Program". The work was administered under the direction of Flight Accessories Laboratory, Wright Air Development Division. Mr. J. E. Cooper was task engineer for the laboratory.

The studies cover the period of the 25th of April 1961 to 4th of November, 1961.

This report is a continuation of work done earlier on the contract and reported in WADD TR 61-36.

The assistance of Dr. T. P. Dirkse, Professor of Chemistry, Calvin College, Grand Rapids, Michigan, as Consultant on this project is gratefully acknowledged. Dr. Dirkse gave valuable aid in the preparation of this report.

ABSTRACT

Sixty-five cells, constructed with hand-fabricated lucite containers and equipped with pressure gauges, were employed to determine cycle life using various combinations of separators and negative plate additives. Cycle life with one separator combination was also determined at three different depths of discharge in three different temperature ranges. The maximum cycle life obtained from the above group was 1760 cycles at 21% depth of discharge at room temperature.

Three cells with molded nylon containers and covers, with a metal terminal-to-plastic seal successfully passed the required environmental tests. This and five cells with the same construction have completed over 600 cycles to date. Eight additional cells with the same construction except for a negative plate variation have completed over 400 cycles.

Eight cells, employing the best design parameters from the previous eighty-one cells, were activated in lucite jars and placed on cycle life test. A projected battery energy-to-weight ratio utilizing these eight cells is about 8 watt hours/pound for the two hour cycle.

It will be necessary to furnish a supplement to this report covering cycle life results on the twenty-four cells still under test.

PUBLICATION REVIEW

The publication of this report does not constitute approval by the Air Force of the findings or conclusions contained herein. It is published for the exchange and stimulation of ideas.

FOR THE COMMANDER:

George W. Sherman, Chief
Flight Vehicle Power Branch
Flight Accessories Laboratories

TABLE OF CONTENTS

	Page
ADMINISTRATIVE DATA	1
FACTUAL DATA	2
Description of Test Apparatus	2
Test Procedure	2
Results of Tests	5
DISCUSSION	16
RECOMMENDATIONS	19
APPENDIX A	
Tables, Test Data Sheets, and Illustrations	20

LIST OF TABLES

TABLE		PAGE
1	CELL CONSTRUCTION DETAILS: SEPARATOR AND NEGATIVE PLATE VARIATIONS	21
2	TEMPERATURE AND CURRENT DENSITY TEST VARIATIONS	22
3	CELL CONSTRUCTION DETAILS: ADDITIONAL SEPARATOR AND NEGATIVE PLATE VARIATIONS	23
4	CELL CONSTRUCTION DETAILS: MOLDED NYLON CONTAINERS AND COVERS: NEGATIVE PLATE VARIATIONS	24
5	CELL CONSTRUCTION DETAILS: ADDITIONAL SEPARATOR AND NEGATIVE PLATE VARIATIONS	25

LIST OF ILLUSTRATION

FIGURE		PAGE
1	RECORDING VOLTMETER, BATTERY TIMER AND CELLS UNDERGOING CYCLE LIFE	29
2	CONSTANT POTENTIAL POWER SUPPLY UNIT	30
3	TERMINALS AND MOLDED PARTS OF THE CELL	31
4	END OF DISCHARGE VOLTAGE AND PRESSURE FOR SEALED BATTERY OF 3 CELLS	32
5	SILVER CONTENT IN SEPARATOR AFTER 1760 CYCLES IN EACH OF THREE CELLS	33
6	TYPICAL CHARGE AND DISCHARGE CURVES OF CELL OPERATING FOR 1760 CYCLES	34
7	SEALED BATTERY OF CELLS A, B, AND C	35
8	POSITIVE AND NEGATIVE PLATE SAMPLE FROM CELLS A, B, AND C	36
9	SEPARATOR SAMPLE FROM CELLS A, B, AND C	37
10	END OF DISCHARGE VOLTAGE AT EACH 100 CYCLE MARK, AND AVERAGE PRESSURE OF THREE CELLS IN EACH THREE-CELL GROUP FOR CELLS #1 THROUGH #9	38
11	END OF DISCHARGE VOLTS AND PRESSURES, CELLS #10 THROUGH #18	39
12	END OF DISCHARGE VOLTS AND PRESSURES, CELLS #19 THROUGH #27	40
13	SILVER CONTENT IN Mg/in^2 IN SEPARATORS OF CELLS #1 THROUGH #6	41
14	SILVER CONTENT IN Mg/in^2 IN SEPARATORS OF CELLS #7 THROUGH #12	42
15	SILVER CONTENT IN Mg/in^2 IN SEPARATORS OF CELLS #13 THROUGH #21	43
16	SILVER CONTENT IN Mg/in^2 IN SEPARATORS OF CELLS #22 THROUGH #27	44
17	GROUP 1 - AMPERE HOUR CAPACITY OF FIRST CYCLE OF CELLS A, B, C, RATED AT 48 a.h. AND 27 CELLS RATED AT 25 a.h.	45

LIST OF ILLUSTRATION (CONTINUED)

FIGURE		PAGE
18	NUMBER OF CYCLES OBTAINED BY GROUP 1 CELLS	46
19	END OF DISCHARGE VOLTAGES AND PRESSURES AT EACH 50 CYCLE INTERVAL AT 30°F FOR INDICATED CELLS	47
20	END OF DISCHARGE VOLTAGES AND PRESSURES AT EACH 100 CYCLE INTERVAL AT ROOM TEMPERATURE FOR INDICATED CELLS	48
21	END OF DISCHARGE VOLTAGES AND PRESSURES AT EACH 100 CYCLE INTERVAL AT 100°F FOR INDICATED CELLS	49
22	SILVER CONTENT IN Mg/in^2 IN SEPARATORS OF CELLS #28 THROUGH #33	50
23	SILVER CONTENT IN Mg/in^2 IN SEPARATORS OF CELLS #34 THROUGH #39	51
24	SILVER CONTENT IN Mg/in^2 IN SEPARATORS OF CELLS #40 THROUGH #45	52
25	SILVER CONTENT IN Mg/in^2 IN SEPARATORS OF CELLS #46 THROUGH #51	53
26	SILVER CONTENT IN Mg/in^2 IN SEPARATORS OF CELLS #52 THROUGH #54	54
27	GROUP 2 - AMPERE HOUR CAPACITY OF FIRST CYCLE	55
28	NUMBER OF CYCLES OBTAINED BY GROUP 2 CELLS	56
29	END OF DISCHARGE VOLTAGE AND PRESSURE AT EACH 100 CYCLE INTERVAL AT ROOM TEMPERATURE FOR THE INDICATED CELLS	57
30	SILVER CONTENT IN Mg/in^2 IN SEPARATORS OF CELLS #55 THROUGH #62	58
31	GROUP 3 - AMPERE HOUR CAPACITY OF FIRST CYCLE FOR CELLS #55 THROUGH #62	59
32	NUMBER OF CYCLES OBTAINED BY GROUP 3 CELLS	60
33	SEALED 3-CELL UNIT VIBRATION 3 CYCLES	61
34	VIBRATION OF PLANE #1 OF 3-SEALED CELLS	62
35	VIBRATION OF PLANE #2 OF 3-SEALED CELLS	63

LIST OF ILLUSTRATION (CONTINUED)

FIGURE		PAGE
36	VIBRATION OF PLANE #3 OF 3-SEALED CELLS	64
37	SEALED 3-CELL UNIT	65
38	SHOCK OF PLANE #1 OF 3-SEALED CELLS	66
39	SHOCK OF PLANE #2 OF 3-SEALED CELLS	67
40	SHOCK OF PLANE #3 OF 3-SEALED CELLS	68
41	ACCELERATION IN PLANE #1 OF 3-SEALED CELLS	69
42	ACCELERATION IN PLANE #2 OF 3-SEALED CELLS	70
43	ACCELERATION IN PLANE #3 OF 3-SEALED CELLS	71
44	SEALED 3-CELL UNIT PRESSURE TEST 3 CYCLES	72
45	PRESSURE TEST OF 3-SEALED CELLS	73
46	END OF DISCHARGE VOLTAGE FOR CELLS #63 THROUGH #78 . .	74
47	AMPERE HOUR CAPACITY OF FIRST CYCLE FOR CELLS #63 THROUGH #78 - GROUP 4	75
48	NUMBER OF CYCLES OBTAINED BY GROUP 4 CELLS (THESE CELLS ARE STILL CYCLING)	76
49	TYPICAL CHARGE AND DISCHARGE CURVE OF CURRENT FOR CELLS IN GROUP 1, 2, 3, 4	77
50	GROUP 5 - AMPERE HOUR CAPACITY OF FIRST CYCLE DISCHARGE	78

ADMINISTRATIVE DATA

Purpose of Tests:

The purpose of the tests was to develop in compliance with contract No. AF 33(600)-41600, Item II, a sealed silver oxide-zinc secondary cell capable of delivering at least 500 two-hour cycles within a temperature range of 0°F to 100°F. This cell shall be capable of enduring environmental conditions of vibration, acceleration, shock as prescribed by Mil-E-5272C, and withstand a pressure approaching 10^{-2}mm Hg for at least six hours during cycle operation. The final design of the cell shall be consistent with minimum weight and volume for a prototype battery operating in a voltage range of 27 $\pm$ 1.5.

Note: A cycle is defined as a 35 minute discharge at 20 amperes and an 85 minute recharge. Failure is determined by any cell unable to deliver 1.30 volts at the end of the 35 minute discharge. The number of cycles and the voltage limitations given above are those proposed by Delco-Remy and accepted by ASD for initial goals under this program.

Manufacturer: Delco-Remy Division of General Motors Corporation

Manufacturer's Type or Model No: 25 a.h. silver oxide-zinc secondary cell

Drawing Specification or Exhibit: X-44888

Quantity of Items Tested: 89 sealed cells

Security Classification of Items: Unclassified

Date Test Completed: October 1961

Tests Conducted by: Delco-Remy Division of General Motors Corporation

Disposition of Specimens: Inspected and scrapped.

Manuscript released by author (December 1961) for publication as an ASD Technical Report.

FACTUAL DATA

Description of Test Apparatus:

Throughout this cell testing program, the following equipment was used as pictured in Fig. 1:

1) Constant potential charger type TRM 40-120 manufactured by the NJE Corporation.

2) Battery cycle timer manufactured by Delco-Remy Division of G. M. C. (Fig. 2).

3) 24 Point Recording Voltmeter

4) Two 0-3 volt Weston 901 D.C. Voltmeters

5) Two 0-500 ampere Weston 901 D.C. ammeters with appropriate 50 mv shunts.

All of these instruments were new from the manufacturer and calibrated just prior to the start of this program. All cycles were run automatically.

Test Procedure:

Contract No. AF 33(600)-41600, Item II, of the work statement calls for design fabrication and testing both electrically and environmentally of sealed silver oxide-zinc secondary cells under a 2-hour cycle regimen with a design goal of at least 5000 such cyoles throughout a temperature range of $0^{o}F$ to $100^{o}F$, maintaining a seal sufficient to withstand pressure of at least 10^{-2}mm Hg. The cycle is defined under Purpose of Test.

The basic variables considered necessary for study during the cell-development program were:

1) Separators

2) % depth of discharge

3) Current density

4) Cell sealing

5) Environment

In general, an attempt was made to develop a sealed cell to deliver the highest watt-hour/pound utilization for a minimum 500 cycles through the best combination of these variables. (DRD-102 proposed that 500 cycles would be feasible).

Of the 89 cells discussed in this report, the first 3 were constructed prior to the start of this test program and were of a nominal 48 a.h. capacity. They were discharged in series, as a battery, at 20 amperes through a constant resistance load and recharged at a constant potential to 1.97 volts per cell. These cells were tested early in an effort to determine the possibility of reaching 500 cycles under this program.

Nine cells were of a nominal 18 a.h. capacity representing a 29% depth of discharge.

Nine cells were of a nominal 13 a.h. capacity representing a 40% depth of discharge.

The bulk of the remainder of the cells were of a nominal 25 a.h. capacity, discharged at 9 amperes through a constant resistance load and recharged at constant potential to 1.97 volts per cell.

An attempt was made to cycle some cells at 0°F under varying depths of discharge. Early cycles (5 to 10) showed that at 0°F the internal resistance of the cells was so high that full recharge in a time of 85 minutes was being rejected by the cells, and cell reversals were encountered during discharge. Subsequently, the minimum temperature was raised to 30°F for the remainder of the life cycle test.

The first sixty-five cells were made with lucite jars equipped with pressure gauges, while awaiting molded nylon jars and covers with the metal terminal-to-plastic seal. Some cells in the lucite jars ruptured due to bad jar seals. This rupturing was not due to excessive gas pressure build-up but to expansion of separator membranes.

The eighty-nine cells tested may be divided into five major groups. Group 1 consisted of thirty cells employing various separator combinations and certain methods of negative plate processing. Table 1 describes the construction features of these cells.

Group 2 consisted of twenty-seven cells to determine cycle life at varying depths of discharge at three different temperatures. The current density varied as the depth of discharge. Table 2 describes the construction features of these cells.

Group 3 consisted of eight cells employing new separators recently available and some repetition of cells in Group 1 that failed due to cell container breakage. Table 3 describes the construction features of these cells.

Group 4 consisted of sixteen cells constructed in molded nylon containers and covers with the metal terminal-to-plastic seal. Eight of these cells incorporated the best features resulting from testing the cells in Groups 1, 2 and 3. These features are:

1) Separation: 1 layer Dynel, 4 layers fibrous sausage casing
2) Electrolyte: 40% KOH - saturated ZnO
3) Negative plate: Polyvinyl alcohol added to the ZnO-HgO mix.
4) Current Density: .070 amps/in^2; this entails 21% depth of discharge.

The other eight cells of Group 4 contained the above features except that no polyvinyl alcohol was added to the negative plate mix, but an excess of ZnO was used.

These cells were designed primarily to prove out manufacturing techniques in making sealed 25 a.h. rated cells and to test the seal features.

Three of the first eight cells in this group were used in the environmental tests which are described in Results of Test. They have subsequently reached 600 cycles on cycle-life testing.

Table 4 describes the construction features of these cells, and Fig. 3 shows molded nylon parts used in fabrication of tho cells.

Group 5 consists of eight cells employing the best features of all the previous cells and represents the initial cell design developed in this program to meet the cell requirements stated in the Purpose. These features for four cells are:

1) Separation: 1 layer Dynel, 3 layers fibrous sausage casing
2) Electrolyte: 40% KOH - saturated ZnO
3) Current density: .052 amps/in^2
4) Negative plate process: Polyvinyl alcohol added to ZnO-HgO mix

The features of the remaining four cells are the same except that the use of Permion 300* ion exchange membrane in place of Dynel and excess ZnO in place of polyvinyl alcohol.

---

* Permion 300 is a trade-mark of Radiation Applications Incorporated, Long Island City, N. Y.

Table 5 describes the construction features of these cells.

All cells in the program were given a capacity discharge on the first cycle and then placed on automatic life cycle test. The end of life was determined when any cell failed to deliver 1.30 volts at the end of the 35 minute discharge.

The electrolyte used throughout the test was 40% KOH-zinc saturated. This concentration was chosen because the silver migration is apparently less in 40% KOH than at lower concentrations, and 40% KOH is more suitable for a wider range of temperature operation than higher concentrations.

A constant potential charge insures 98% to 100% of the charge returned to the cells while maintaining consistent end of charge voltages.

Figure 49 shows typical current-time curves for charge and discharge of cells in this program.

Results of Tests:

Group 1, Cells #A, B, C:

These cells failed at 1760 cycles. Fig. 4 shows end of discharge voltages and pressures for 1760 cycles. The cause of failure was due to corrosion of the positive plate lugs but the positive plates were in excellent condition. The separators were in excellent condition. They maintained the same pliant strength as is usually evident in cells after 10 to 20 cycles under other cycle conditions. Fig. 5 shows silver content analysis in the separators of the three cells.

The negative plate material did not grow in any direction and remained encapsulated in one wrapping of separator material. There was no evidence of washing of negative material from the grid. The material itself appeared coarse and gritty to the touch, but it is estimated that if the positive lugs had not corroded, this battery would have continued cycling well over 2000 cycles. Fig. 6 shows typical charge and discharge current-time curves over 1760 cycles.

Fig. 7 shows the three cell battery prior to tear down inspection.

Fig. 8 shows a random sample of the positive and negative plates from one of the cell groups.

Fig. 9 shows a random separator sample from one cell.

Cell #1 failed at 297 cycles. The cause of failure was due to shorts. Examination of the cell showed the zinc material penetrating through one layer of separator material in spots, touching the layer next to the positive plate. The silver had migrated through one layer and touched the layer next to the negative plate. There was considerable zinc treeing along the edges of the plates. The zinc plates did show good coverage of material on the grids, i.e., no washing effect in spite of the excessive treeing.

Cell #2 failed at 442 cycles. Cause of failure was shorting in the same manner as cell #1. The condition of the negative plates was the same as cell #1.

Cell #3 failed at 380 cycles. Cause of failure was shorting. Silver migrated through two layers of separators, meeting some zinc penetration. The negative plates had approximately 30% of the active material washed out.

Cell #4 failed at 704 cycles. Cause of failure was complete penetration of silver through all four layers of cellophane. The negative plates had approximately 40% of the active material washed out.

Cell #5 failed at 310 cycles. Cause of failure was a ruptured container. The condition of the negative plates was good, although there was some treeing on the edges of the plates. The silvor had penetrated three layers of cellophane.

Cell #6 failed at 962 cycles. Cause of failure was the same as cell #4. The negative plates had approximately 50% of the active material washed out.

Cell #7 failed at 442 cycles. Causo of failure was a ruptured container.

Cell #8 failed at 637 cycles. Cause of failure appeared to be excessive loss of negative active material. Approximately 60% washing occurred. Silver had penetrated two layers of separator material.

Cell #9 failed at 192 cycles. Cause of failure was a ruptured container.

Cell #10 failed at 442 cycles. Cause of failure was a ruptured container.

Cell #11 failed at 442 cycles. Cause of failure was a ruptured container.

Cell #12 failed at 649 cycles. Cause of failure was silver penetration through six layers of cellophane. The negative active material was about 30% washed out.

Cell #13 failed at 380 cycles. Cause of failure was a ruptured container.

Cell #14 failed at 86 cycles. Cause of failure was a ruptured container.

Cell #15 failed at 720 cycles. Cause of failure was shorting due to silver penetration through two layers of separator. The negative plates were in excellent condition.

Cell #16 failed at 382 cycles. Cause of failure was shorting caused by silver penetration through two layers of separator material. The negative plates were about 50% washed out.

Cell #17 failed at 297 cycles. Cause of failure was shorting due to silver penetration through two layers of separators. The negative plate active material was about 40% washed out.

Cell #18 failed at 297 cycles. Cause of failure and condition of the negative plates were the same as cell #17.

Cell #19 failed at 555 cycles. Cause of failure was shorting due to silver penetration. The negative plates were approximately 50% washed out.

Cell #20 failed at 600 cycles. Cause of failure was shorting due to silver penetration. The negative plates were approximately 50% washed out.

Cell #21 failed at 637 cycles. Cause of failure was the same as for cell #20.

Cell #22 failed at 480 cycles. Cause of failure was excessive washing of negative material. Approximately 60% of the material washed out.

Cell #23 failed at 100 cycles. Cause of failure was a ruptured cell container.

Cell #24 failed at 543 cycles. Cause of failure was excessive washing of negative material. Approximately 60% of the material washed out.

Cell #25 failed at 703 cycles. Cause of failure was excessive washing of negative material. Approximately 60% of the material washed out.

Cell #26 failed at 100 cycles. Cause of failure was a ruptured container.

Cell #27 failed at 703 cycles. Cause of failure was washing of the negative material. Approximately 50% of the material washed out.

Fig. 10 shows end of discharge voltages and pressures for cells #1 through 9 at 100 cycle intervals.

Fig. 11 shows end of discharge voltages and pressures for cells #10 through 18 at 100 cycle intervals.

Fig. 12 shows end of discharge voltage and pressure for cells #19 through 27 at 100 cycle intervals.

The following figures show silver content in Mg/in^2 of separator material for the indicated cells:

Fig. 13	Cells #1 through #6
Fig. 14	Cells #7 through #12
Fig. 15	Cells #13 through #21
Fig. 16	Cells #22 through #27
Fig. 17	Shows initial capacity runs of the cells in this group.
Fig. 18	Shows number of cycles delivered by cells in this group.

Group 2:

These cells will be discussed in the order of the temperature cycle rather than in numerical order.

30°F Temperature Cycle

Cells #34 and 35 failed at 200 cycles. Cause of failure was apparently that the cells would not recharge fast enough in 85 minutes at low temperatures. Upon removal to room temperature both these cells delivered 583 cycles. Ultimate cause of failure was negative material washing, (60%).

Cell #36 failed at 122 cycles. Cause of failure was ruptured container.

Cell #43, 44 and 45 failed at 122 cycles because of lack of recharge capability. These cells were removed to room temperature and delivered 314, 224, 173 cycles, respectively. The ultimate cause of failure in all cases was excessive washing of the negative active material, (60%).

Cells #52, 53 and 54 failed at 47 cycles because of lack of recharge capability. These cells recovered at room temperature and delivered 200 cycles. The ultimate cause of failure was excessive washing of negative active material, (60%).

Room Temperature Cycle:

Cells #28, 29 and 30 failed at 466, 465 and 551 cycles, respectively. Cause of failure in all cases was excessive washing of negative active material, (60%).

Cells #37, 38 and 39 failed at 302, 344 and 302 cycles, respectively. Cause of failure was excessive washing of negative active material, (60%).

Cells #46, 47 and 48 failed at 200 cycles each. Cause of failure was excessive washing of negative active material (60%).

100°F Temperature Cycle:

Cells #31, 32 and 33 failed at 583, 415 and 574 cycles, respectively. Cause of failure was excessive washing of negative active material.

Cells #40, 41 and 42 failed at 400, 368 and 302 cycles, respectively. Cause of failure in cell #42 was a ruptured container. Cause of failure in the other cells was washing of negative active material, (60%).

Cells #49, 50 and 51 failed at 200 cycles. Cause of failure was excessive washing of negative active material (60%).

The following figures show end of discharge voltages and pressures for the indicated cells:

Fig. 19 Cells #34, 35, 36, 43, 44, 45, 52, 53, 54

Fig. 20 Cells #28, 29, 30, 37, 38, 39, 46, 47, 48

Fig. 21 Cells #31, 32, 33, 40, 41, 42, 49, 50, 51

The following figures show silver content in Mg/in^2 of separator material for the indicated cells:

Fig. 22	Cells #28 through #33
Fig. 23	Cells #34 through #39
Fig. 24	Cells #40 through #45
Fig. 25	Cells #46 through #51
Fig. 26	Cells #52 through #54
Fig. 27	Shows initial capacity runs of Group 2 cells
Fig. 28	Shows number of cycles obtained by Group 2 cells.

Group 3:

Cells #55 and 56 failed at 152 cycles. Cause of failure seemed to be the inability of the negative plates to function in restricted electrolyte.

Cell #57 failed at 462 cycles. Cause of failure was washing of the negative active material, (60%).

Cell #58, 59, 60 and 61 failed at 547, 400, 560, 560 cycles, respectively. Cause of failure was ruptured containers. The negative plates did show 40% to 50% washing.

Cell 362 failed at 4 cycles due to a ruptured container.

Fig. 29 shows the end of discharge voltage and pressure for cells #55 through #62.

Fig. 30 shows the silver content in Mg/in^2 of separator material for cells #55 through #62.

Fig. 31 shows initial capacity runs of Group 3 cells.

Fig. 32 shows number of cycles obtained by cells in this group.

Group 4:

Cells #63 through #78 are still on life cycle test. In this group cells #68, 69 and 70 made up the three cell battery that underwent environmental testing. The following outline describes the test procedure and results of the environmental tests performed.

1. Vibration

a. Requirement:

The 3-cell battery sample shall be subjected to a vibration test in accordance with Mil-E-5272C, Procedure XIV, Para. 4.7.14 and work statement PR-92008 of Delco-Remy Proposal DRD-102, listed under Phase II, which specifies a limit of vibration intensity of 10 g throughout the vibration test and the total test time to be 6 hours.

b. Equipment:

Vibration System Ling Calidyne Model CP 3/4, S/N 26

Accelerometer, Endevco, Model 2213 S/N 4800

Accelerometer Amplifier, Endevco Model 2614 S/N 1867

DC Voltmeter Weston Model 901 S/N 11323

DC Ammeter Weston Model 901 S/N 13639

Strip Chart Recorder, Varian Model G-22 S/N 291

c. Procedure:

The battery sample was securely clamped to the vibration exciter by means of a test fixture which could secure the sample along each of 3 mutually perpendicular axes. The sample was subjected to a variable frequency vibration scan for resonance in which the frequency was varied from 5 to 20 cps at an amplitude of $\pm$ 1.0 g or 0.20 in. double amplitude, whichever was the limiting value. At the conclusion of the resonance vibration scan, the sample was subjected to cycling vibration which consisted of vibrating the sample while varying the frequency from 20 to 2000 cps and back to 20 cps in a period of 1 hour. The frequency was varied logarithmically. The amplitude of vibration was maintained at $\pm$ 10 g or 0.050 in. double amplitude, whichever was the limiting value. The cycling vibration was conducted for a period of 2 hours along each of 3 mutually perpendicular axes (total vibration time - 6 hours).

Throughout the vibration tests the battery sample was electrically operated. At the start of vibration cycling along each axis, the battery was discharged for 35 min. at 9 amperes and then charged for 85 min. at 3.7 amperes. Throughout the vibration test in all 3 axes, a strip chart recorded a permanent record of the battery voltage.

d. Results:

There was no apparent damage to the battery during or after the vibration test as determined by the fact that the cell voltages returned to normal open circuit readings. There were no resonant frequencies noted during the scan for resonance in any axis. Fig. 33 shows the charge, discharge curves during the vibration test. Figures 34, 35 and 36 show positions of sample during test.

2. Shock

a. Requirement:

The 3-cell battery sample shall be subjected to a shock test which shall consist of a total of 18 shocks at 40 g intensity and 11 ± 1 milliseconds duration. This test shall be performed in accordance with specification Mil-E-5272C, Procedure V, Para. 4.15.5.1, and modified by work statement PR-92008 of Delco-Remy Proposal DRD-102, listed under Phase II.

b. Equipment:

Shock Machine, Barry Varipulse, Model 16805 S/N 004

DC Voltmeter, Weston Model 901 S/N 11323

DC Ammeter, Weston Model 901 S/N 13639

Strip Chart Recorder, Varian Model G-22 S/N 291

c. Procedure:

The battery sample was securely clamped to the shock machine test platform by means of a clamp which could securely fasten the sample in any of 6 directions along 3 mutually perpendicular planes. The sample was subjected to a total of 18 shock impacts, 3 impacts along each direction of 3 mutually perpendicular axes of the specimen. The shock impacts consisted of a half-sine wave form of 40 g peak intensity, and with a time duration of 11 ± 1 milliseconds. The battery sample was discharged at the rate of 9 amperes during this test. The sample was visually examined during and after this environment.

d. Results:

There was no apparent damage to the sample during or after the shock test. Fig. 37 shows the discharge curve during the shock test. Figures 38, 39 and 40 show positions of sample during test.

3. Acceleration

a. Requirement:

The 3-cell battery sample shall be subjected to an acceleration test in accordance with specification Mil-E-5272C, Procedure III, Para. 4.16.3 and modified by work statement PR-92008 of Delco-Remy Proposal DRD-102 listed under Phase II.

b. Equipment:

Precision Accelerator, Delco-Remy Accelerometer Calibrator Model

DC Voltmeter, Weston Model 901, S/N 11323

DC Ammeter, Weston Model 901 S/N 13639

Strip Chart Recorder, Varian Model G-22 S/N 291

c. Procedure:

The battery sample was secured to the acceleration machine by means of a clamping fixture. The sample was subjected to the specified acceleration in each of 6 directions, that is, along both directions of 3 mutually perpendicular axes. Figs. 41, 42 and 43 show the 3-cell battery sample mounted in the accelerator.

The intensity of acceleration was 18 g, and the acceleration was maintained at this level for 3 minutes in each direction of applied force. During the each acceleration application, the battery was discharged at the rate of 9.0 amperes and the output voltage was continuously monitored and recorded. The sample was thoroughly examined after each acceleration application.

d. Results:

There was no apparent damage to the battery sample during or after the acceleration test as determined by the fact that cell voltages returned to normal open circuit readings. Fig. 37 shows the discharge curve during the acceleration test.

4. Pressure

a. Requirement:

The 3-cell battery sample shall be subjected to an absolute pressure approaching 10^{-2}mm of mercury for a period of 6 hours per work statement PR-92008 of Delco-Remy Proposal DRD-102 listed under Phase II.

b. Equipment:

Vacuum Pump, Welch Duo Seal S/N 6843-2

Bell Jar and Base- Central Scientific 9 in. dia.

McLeod Gauge - General Electric S/N 3569

DC Voltmeter - Weston Model 901 S/N 11323

DC Ammeter - Weston Model 901 S/N 13639

Strip Chart Recorder - Varian Model G-22 S/N 291

c. Procedure:

The battery sample was placed in its normal position within the bell jar enclosure after electrical connections had been secured. The electrical connections permitted the battery to be charged and discharged while maintained at a low absolute pressure.

The ambient pressure surrounding the test battery sample was reduced to 10^{-2}mm of mercury within 30 minutes and maintained for a period of 18 hours at this pressure. The external circuit was open during this period. At the start of the electrical operation, the pressure had attained 5.5 x 10^{-3}mm of mercury and ranged to 7.0 x 10^{-3} mm of mercury throughout the 6 hour test duration.

The electrical operation consisted of discharging the battery sample at a rate of 9.0 amperes for 35 minutes after which the battery was charged at a rate of 3.7 amperes for 85 minutes. Three complete cycles of this electrical operation were conducted during this test. The battery was continuously monitored electrically and inspected visually during and after this exposure. A helium leak test was performed on the sample after removal from the bell jar chamber to check leak rate.

d. Results:

There was no apparent damage to the sample as a result of the low pressure test as determined by the fact that cell voltages returned to normal open circuit readings. There was no visible signs of leakage of any type. The leak rate of the sample, when checked following this test, was below the detection threshold (less than 1×10^{-8} cc/sec). Fig. 44 shows charge and discharge curves during pressure test.

Fig. 45 shows position of sample during test.

Fig. 46 shows end of discharge voltages at 100 cycle intervals reached thus far for cells #63 through #78.

Fig. 47 shows initial capacity runs for cells in this group.

Fig. 48 shows number of cycles obtained thus far by cells in Group 4.

Fig. 49 shows typical charge and discharge current-time curves used in the cycle program for the cells in Group 1, 2, 3 and 4.

Cells #79 through #86 have just completed activation and are commencing life cycle tests.

Fig. 50 shows the initial capacity runs of cells in this group.

A summary of all cell data is recorded in Test Summary sheets 1, 2 and 3.

DISCUSSION

Test Cell Design:

Cells tested in Groups 1, 2, 3 and 4 were designed to check out the variables listed in the Test Procedure with a more-or-less arbitrarily selected nominal capacity (25 ampere-hours), plate number (13), plate thickness (0.020" positives and 0.040" negatives) and area (10 sq. in.).

Twenty-five ampere hours is large enough for problems of scale-up in size to be felt so a good approximation of the final cell design to meet the ampere hour requirement (20 amperes for 35 minutes with an 85 minute recharge) could be made.

It was desirable to keep the number of plates to a practical minimum to reduce the total weight and thickness of separation necessary. It is known that the watt hour per unit weight and volume yield of secondary batteries will increase as number of plates per cell is reduced because the separator thickness term is a not-inconsequential contribution to cell weight and volume where cycling life is desired. (Interim Report No. 1, Delco-Remy Project No. 4260-K, "The Effects of Plate Thickness and Electrolyte Concentration on Energy Yield of Secondary Silver Oxide-Zinc Cells at Various Discharge Rates," July 5, 1961). The major reason for the separator thickness contribution is silver penetration of the separator material and where failure would be limited by this factor cycle life would be strictly a matter of separator thickness.

On the other hand, high-rate performance is generally improved by designing for more and thinner plates, and the two hour cycle time involved in this proposal may be considered to be a high rate situation. The terminology "high rate performance" includes rechargeability of the cell also. It is also possible, as will be discussed, that thinner plates lead to longer cycle life.

Substantially then the design tested represents an attempt at compromising the known design factors to obtain higher energy per unit weight and volume yields in the absence of any detailed knowledge as to how the design parameters would affect life, except for the accumulated knowledge about silver penetration of separators.

Minimum Separation:

From previous testing (Phase I, Technical Report), it is well-known that one layer of separation of the best available materials will allow less than 100 cycles before shorting due to silver and/or zinc penetration. From the results of testing of Group 1 cells, #1 through #12 where various numbers of layers of FSC and cellophane were used, life is increased to 300 - 900 cycles by adding additional layers of separation.

Use of Dynel Next to Positive Plate:

From the Phase I Technical Report and additional data obtained during this phase, it was learned that the use of a thin layer of porous but inert material, such as dynel, next to the positive plate reduces silver penetration. It is evident from testing of cells #22 through #27 that the use of dynel does extend cycling life, although the results do not allow a quantitative measure of additional life due to this cause because the nature of failure changed. Permion 300, a new type of ion-exchange membrane, has a similar effect (cells #59 through #62).

Use of Polypor:

Polypor, from Phase I testing and additional work in these tests, is no more effective in stopping silver penetration than an equivalent thickness of cellophane or FSC and consequently is regarded as having no additional beneficial properties.

Negative Plate Additives:

Solka Floc, a fine fibrous inert material, was added to the negative mix in an effort to reduce negative plate washing (cells #16, #17, and #18). While these cells failed due to shorting, there was no evidence that Solka Floc was effective in retaining zinc.

Polyethylene oxide showed capability of retaining zinc as did the use of polyvinyl alcohol. Both these addition agents also seemed to increase time to shorting failure, probably because they help keep the zinc in place.

Negative Plate Washing:

With increase in separator thickness, negative plate washing became the chief cause of failure where additives to negative material were not used or were ineffective. The use of PVA has resulted in reducing negative plate washing and cycle life for this design has achieved 600 cycles consistently (cells #63 through #70). These cells are still cycling.

The use of excess zinc is also being tested (cells #71 through #78). These have achieved 400 cycles and are still on test.

Temperature:

Cells will not cycle at 0°F at discharge depths as low as 21% due to lack of rechargeability. Some life is obtained at 30°F at 21% depth of discharge, but early failure occurs because of lack of rechargeability. At room temperature and 100°F., cells accept charge and failure is due to other causes.

Depth of Discharge:

It is evident that increasing the depth of discharge decreases the cycle life where negative plate washing is the cause of failure. Other types of batteries, i.e., lead-acid and nickel-cadmium, also exhibit shortened life due to increased depth of discharge.

Current Density:

There is some evidence that distributing current over a larger number of plates per cell will be effective in increasing life. Cells A, B and C, although of a different ampere-hour capacity (48), yielded 1760 cycles at 21% depth of discharge with very little evidence of negative plate deterioration. The obvious cause is reduction of current density per plate, although other contributing causes may be present. The final series of cells (#79 through #86) should give additional information on this point.

While cycle life may be improved by going to thinner plates, on the basis of present knowledge it seems that this is likely to be at the expense of reduced performance on a weight and volume basis. Other benefits are expected to accrue, however, from reduction in plate thickness, specifically better rechargeability and increased cold performance.

When separation and negative plate additives are checked out, the question of optimum design for best cycle life and energy performance needs evaluation.

RECOMMENDATIONS

It has been demonstrated that a silver oxide-zinc cell can be effectively sealed and deliver at least 500 cycles according to the Purpose of Test.

It is recommended that approval be given to commence Item III of Contract AF 33(600)-41600 which covers the construction and testing of prototype batteries.

It is further recommended that additional cell studies be continued on some other program in an effort to develop more efficient binders to retard negative active material washing which is a large factor in cell failure in this cycle schedule.

Also, the testing of new separator materials of the ion exchange type (Permion 300) and others should be incorporated in cell studies in an effort to reduce the number of separators now required to enable higher yields of energy per unit weight and volume.

It is also recommended that charge acceptance be studied to enable deeper discharges and higher energy yields to be obtained.

APPENDIX A

TABLES, SUMMARY SHEETS AND ILLUSTRATIONS

TABLE 1 - CELL CONSTRUCTION DETAILS: SEPARATOR AND NEGATIVE PLATE VARIATIONS

Electrolyte 40% - KOH Zinc Saturated

Cell #	Separator	a.h. Cap.	Positive Plate	Negative Plate	Depth of Discharge	Cycle Temp.
A B C	Five layers FSC	48	.010" Ag. 22 plates	.020" ZnO + 1% HgO 23 plates	21%	R.T.
1 2 3	Two layers FSC	25	.020" Ag. 6 plates	.040" ZnO + 1% HgO 7 plates	21%	R.T.
4 5 6	Four layers cellophane	"	"	"	"	"
7 8 9	Three layers FSC	"	"	"	"	"
10 11 12	Six layers cellophane	"	"	"	"	"
13 14 15	Two layers FSC	"	"	.035" ZnO + 1% HgO + polyethylene oxide used as binder	"	"
16 17 18	Two layers FSC	"	"	.035" ZnO + 1% HgO + solka floc used as expander material	"	"
19 20 21	Two layers FSC	"	"	.035" ZnO + 1% HgO + PVA used as binding paste	"	"
22 23 24	One layer Dynel • Two layers FSC One around (FSC) negative, one Dynel & one FSC around positive	"	"	.035" ZnO + 1% HgO	"	"
25 26 27	One layer Dynel Three layers FSC Two FSC around negative, one Dynel & one FSC around positive.	25	"	"	"	"

TABLE 2 - TEMPERATURE AND CURRENT DENSITY TEST VARIATIONS

All Cells Contain 40% KOH and Separators as Follows From the Positive Plate: 1 Layer Dynel, a Layer Polypor and 3 layers FSC - Discharge C = 9.0 amps, recharge at constant potential of 1.97 vpc constant resistance.

Cell #	Positive Plate	Negative Plate	A.H. Cap.	Current Density	% Depth Discharge	Cycle Temp.
28 29 30	.020# Ag 6 plates	.040" ZnO + 1% HgO 7 plates	25	.070 amp/in²	21%	R.T.
31 32 33	"	"	"	.070 amp/in²	21%	100°F.
34 35 36	"	"	"	.070 amp/in²	21%	30°F.
37 38 39	"	"	18	.095 amp/in²	29%	R.T.
40 41 42	"	"	"	.095 amp/in²	"	100°F.
43 44 45	"	"	"	.095 amp/in²	"	30°F.
46 47 48	"	"	13	.125 amp/in²	40.5%	R.T.
49 50 51	"	"	"	.125 amp/in²	"	100°F.
52 53 54	"	"	"	.125 amp/in²	"	30°F.

TABLE 3 - CELL CONSTRUCTION DETAILS: ADDITIONAL

SEPARATOR AND NEGATIVE PLATE VARIATIONS

25 a.h. Cells, Cycled at R. T. to 21% of Nominal Capacity in 40% KOH - Discharge C = 9.0 amps - Constant Resistance, Recharge Constant Potential of 1.97 vps - Current Density = .070 amp/in^2

Cell #	Separator	Positive Plate	Negative Plate
55	2 layers FSC	.020" Ag. 6 plates	.040" ZnO + HgO + Polyethylene Oxide as Binder 7 plates
56	2 layers FSC	"	"
57	1 layer Dynel 3 layers FSC	"	.040" ZnO + 1% HgO
58	"	"	"
59	1 layer Permion 300 and 3 layers FSC	"	"
60	"	"	"
61	"	"	"
62	1 layer Dynel 4 layers FSC	.020" Ag. 6 plates	.040" ZnO + 1% HgO + PVA as Binder 7 plates

TABLE 4 - CELL CONSTRUCTION DETAILS: MOLDED NYLON CONTAINERS AND COVERS: NEGATIVE PLATE VARIATIONS

25 a.h. Cells in Molded Nylon Containers and Covers Cycled at R.T. to 21% of Nominal Capacity in 40% KOH. Current Density = .070 amps/in^2 Discharge = 9.0 amps; Constant Resistance, Recharge Constant Potential of 1.97 vpc.

Cell #	Separator	Positive Plate	Negative Plate
63	1 layer Dynel 4 layers FSC	.020" Ag. 6 plates	.040" ZnO + 1% HgO + PVA as Binder 7 plates
64	"	"	"
65	"	"	"
66	"	"	"
67	"	"	"
68	"	"	"
69	"	"	"
70	"	"	"
71	"	"	.035" ZnO + 1% HgO Excess ZnO
72	"	"	"
73	"	"	"
74	"	"	"
75	"	"	"
76	"	"	"
77	"	"	"
78	"	"	"

TABLE 5 - CELL CONSTRUCTION DETAILS: ADDITIONAL SEPARATOR AND NEGATIVE PLATE VARIATIONS

All Cells Are of Nominal 37 a.h. Activated in 40% KOH. Discharge C = 20 Amperes, Constant Resistance, Recharge at Constant Voltage of 1.97 vpc. Current Density = .052 amps/in^2.

Cell #	Positive Plate	Negative Plate	Separation	Cycle Temp.
79	.010" Ag. 19 plates	.020" ZnO + 1% HgO 20 plates Without PVA Binder	1 layer Dynel 3 layers FSC	R.T.
80	"	"	"	"
81	"	With PVA Binder	"	"
82	"	"	"	"
83	"	"	1 layer Permion 300 3 layers FSC	"
84	"	"	"	"
85	"	Without PVA Binder	"	"
86	"	"	"	"

48 a.h. Cells A, B, C Contain .010" Positive Plates; Remaining 25 a.h. Cells Con

Cell #	Cycles	Cycle Temp.	Current Density	% Depth Discharge	Separators	Negative Plate Process
A	1760	R.T.	.043 a/in^2	21%	5 layers FSC	ZnO + 1% HgO Mix .020"
B	1760	"	"	"	"	"
C	1760	"	"	"	"	"
1	297	"	.070 a/in^2	"	2 layers FSC	ZnO + 1% HgO Mix .040"
2	442	"	"	"	"	"
3	380	"	"	"	"	"
4	704	"	"	"	4 layers cellophane	"
5	310	"	"	"	"	"
6	962	"	"	"	"	"
7	442	"	"	"	3 layers FSC	"
8	637	"	"	"	"	"
9	192	"	"	"	"	"
10	442	"	"	"	6 layers Cellophane	"
11	442	"	"	"	"	"
12	649	"	"	"	"	"
13	380	"	"	"	2 layers FSC	ZnO + 1% HgO + Polyethyle
14	86	"	"	"	"	"
15	720	"	"	"	"	"
16	382	"	"	"	2 layers FSC	ZnO + 1% HgO + Solka Floc
17	297	"	"	"	"	"
18	297	"	"	"	"	"
19	555	"	"	"	2 layers FSC	ZnO + 1% HgO + PVA Mix
20	600	"	"	"	"	"
21	637	"	"	"	"	"
22	480	"	"	"	1 layer Dynel, 2 layers FSC	ZnO + 1% HgO Mix
23	100	"	"	"	"	"
24	543	"	"	"	"	"
25	703	"	"	"	1 layer Dynel, 3 layers FSC	"
26	100	"	"	"	"	"
27	703	"	"	"	"	"
28	466	"	"	"	1 layer Dynel, 1 layer Polypor, 3 layers FSC	"
29	465	"	"	"	"	"
30	551	"	"	"	"	"
31	583	100°F	"	"	"	"
32	415	"	"	"	"	"
33	574	"	"	"	"	"

1

TEST SUMMARY SHEET 1 TEST COMPLETION OCTOBER, 1961.

.010" Positive Plates; Remaining 25 a.h. Cells Contain .020" Positive Plates. All Cells activated in 40% KOH - Zincate

parators	Negative Plate Process	Cause of Failure	Cell #
ayers FSC	ZnO + 1% HgO Mix .020"	Corrosion of Positive Plate Lugs	A
	"	"	B
	"	"	C
ayers FSC	ZnO + 1% HgO Mix .040"	Shorts - silver migration through separators	1
	"	"	2
	"	"	3
ayers cellophane	"	"	4
	"	Ruptured Container	5
	"	Shorts - silver migration through separators	6
ayers FSC	"	Ruptured Container	7
	"	Excessive washing of negative material	8
	"	Ruptured Container	9
ayers Cellophane	"	"	10
	"	"	11
	"	Shorts - silver penetration	12
ayers FSC	ZnO + 1% HgO + Polyethylene Oxide Mix	Ruptured Container	13
	"	"	14
	"	Shorts - silver penetration	15
ayers FSC	ZnO + 1% HgO + Solka Floc Mix	"	16
	"	"	17
	"	"	18
ayers FSC	ZnO + 1% HgO + PVA Mix	"	19
	"	"	20
	"	"	21
ayer Dynel, 2 layers FSC	ZnO + 1% HgO Mix	Excessive washing of negative material	22
	"	Ruptured Container	23
	"	Excessive washing of negative material	24
ayer Dynel, 3 layers FSC	"	"	25
	"	Ruptured Container	26
	"	Excessive washing of negative material	27
ayer Dynel, 1 layer ypor, 3 layers FSC	"	"	28
	"	"	29
	"	"	30
	"	"	31
	"	"	32
	"	"	33

All Cells Containing .020" Positive Plates, Activated in

Cell #	Cycles	Cycle Temp.	Current Density	% Depth Discharge	Separators	Negative Plate Process
34	200	30°F.	.070 a/in^2	21%	1 layer Dynel, 1 layer Polypor, 3 layers FSC	ZnO + 1% HgO Mix .040"
35	200	"	"	"	"	"
36	122	"	"	"	"	"
37	302	R.T.	.095 a/in^2	29%	"	"
38	344	"	"	"	"	"
39	302	"	"	"	"	"
40	400	100°F	"	"	"	"
41	368	"	"	"	"	"
42	302	"	"	"	"	"
43	122	30°F.	"	"	"	"
44	122	"	"	"	"	"
45	122	"	"	"	"	"
46	200	R.T.	.125 a/in^2	40.5%	"	"
47	200	"	"	"	"	"
48	200	"	"	"	"	"
49	200	100°F	"	"	"	"
50	200	"	"	"	"	"
51	200	"	"	"	"	"
52	47	30°F	"	"	"	"
53	47	"	"	"	"	"
54	47	"	"	"	"	"
55	152	R.T.	.070 a/in^2	21%	2 layers FSC	ZnO + 1% HgO Polyethylen Oxide Mix
56	152	"	"	"	"	"
57	462	"	"	"	1 layer Dynel, 3 layers FSC	ZnO + 1% HgO Mix
58	547	"	"	"	"	"
59	400	"	"	"	1 layer Permeon 300, 3 layers FSC	"
60	560	"	"	"	"	"
61	560	"	"	"	"	"
62	4	"	"	"	"	"
63	600	"	"	"	1 layer Dynel, 4 layers FSC	ZnO + 1% HgO, PVA Mix
64	600	"	"	"	"	"
65	600	"	"	"	"	"
66	600	"	"	"	"	"
67	600	"	"	"	"	"
68	600	"	"	"	"	"

1

TEST SUMMARY SHEET 2 TEST COMPLETION OCTOBER, 1961

ells Containing .020" Positive Plates, Activated in 40% KOH - Zincate

eparators	Negative Plate Process	a.h. Cap.	Cause of Failure	Cell #
layer Dynel, 1 layer olypor, 3 layers FSC	ZnO + 1% HgO Mix .040"	25	Cells unable to accept recharge	34
	"	"	"	35
	"	"	"	36
	"	18	Excessive washing of negative material	37
	"	"	"	38
	"	"	"	39
	"	"	"	40
	"	"	"	41
	"	"	Ruptured container	42
	"	"	Cells unable to accept recharge	43
	"	"	"	44
	"	"	"	45
	"	13	Excessive washing of negative material	46
	"	"	"	47
	"	"	"	48
	"	"	"	49
	"	"	"	50
	"	"	"	51
	"	"	Cells unable to accept recharge	52
	"	"	"	53
	"	"	"	54
layers FSC	ZnO + 1% HgO Polyethylene Oxide Mix	25	Dry cells	55
	"	"	"	56
layer Dynel, 3 layers SC	ZnO + 1% HgO Mix	"	Excessive washing of negative material	57
	"	"	Ruptured containers	58
layer Permeon 300, 3 ayers FSC	"	"	"	59
	"	"	"	60
	"	"	"	61
	"	"	"	62
layer Dynel, 4 layers SC	ZnO + 1% HgO, PVA Mix	"	Still cycling	63
	"	"	"	64
	"	"	"	65
	"	"	"	66
	"	"	"	67
	"	"	"	68

All Cells Activated in 40% KO

Cell "	Cycles	Cycle Temp.	a.h. Cap.	Current Density	% Depth Discharge	Separators	Negativ
69	600	R.T.	25	.070 a/in^2	21%	1 layer Dynel, 4 layers FSC	ZnO + 1
70	600	"	"	"	"	"	"
71	400	"	"	"	"	"	ZnO + 1 ZnO, No
72	400	"	"	"	"	"	"
73	400	"	"	"	"	"	"
74	400	"	"	"	"	"	"
75	400	"	"	"	"	"	"
76	400	"	"	"	"	"	"
77	400	"	"	"	"	"	"
78	400	"	"	"	"	"	"
79	1	"	37	.052 a/in^2	24%	1 layer Dynel, 3 layers	ZnO + 1% .020" n
80	1	"	"	"	"	"	"
81	1	"	"	"	"	"	ZnO + 1%
82	1	"	"	"	"	"	"
83	1	"	"	"	"	1 layer Permeon 300, 3 layers FSC	"
84	1	"	"	"	"	"	"
85	1	"	"	"	"	"	ZnO + 1%
86	1	"	"	"	"	"	"

1

TEST SUMMARY SHEET 3 TEST NOT COMPLETED

All Cells Activated in 40% KOH - Zincate

% Depth Discharge	Separators	Negative Plate Process	Status	Cell #
1%	1 layer Dynel, 4 layers FSC	ZnO + 1% HgO with PVA in mix	Still Cycling	69
	"	"	"	70
	"	ZnO + 1% HgO with excess ZnO, No PVA	"	71
	"	"	"	72
	"	"	"	73
	"	"	"	74
	"	"	"	75
	"	"	"	76
	"	"	"	77
	"	"	"	78
4%	1 layer Dynel, 3 layers	ZnO + 1% HgO .010" positive .020" negative	"	79
	"	"	"	80
	"	ZnO + 1% HgO with PVA in mix	"	81
	"	"	"	82
	1 layer Permeon 300, 3 layers FSC	"	"	83
	"	"	"	84
	"	ZnO + 1% HgO	"	85
	"	"	"	86

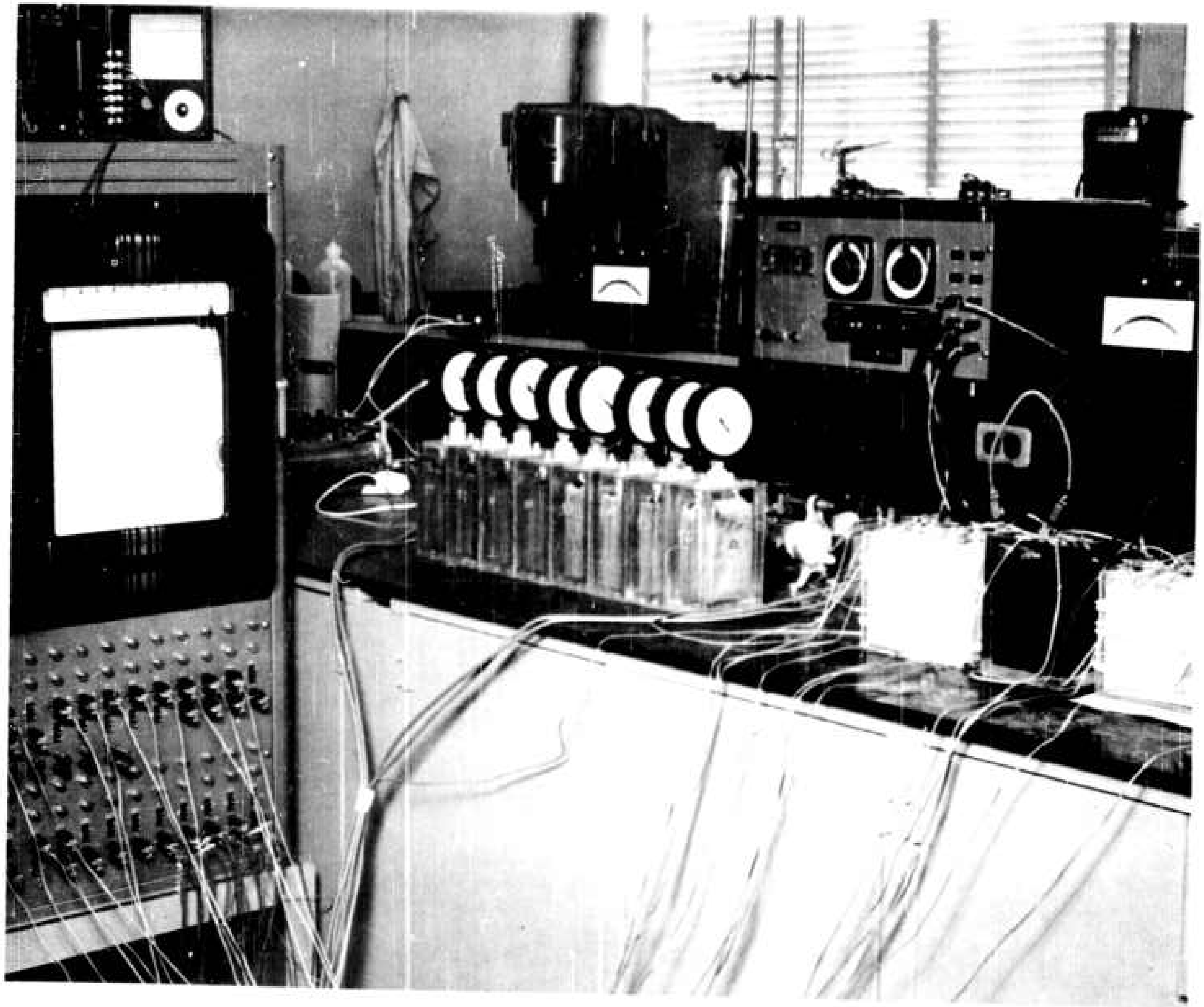


FIGURE 1

RECORDING VOLTMETER, BATTERY TIMER AND CELLS UNDERGOING CYCLE LIFE

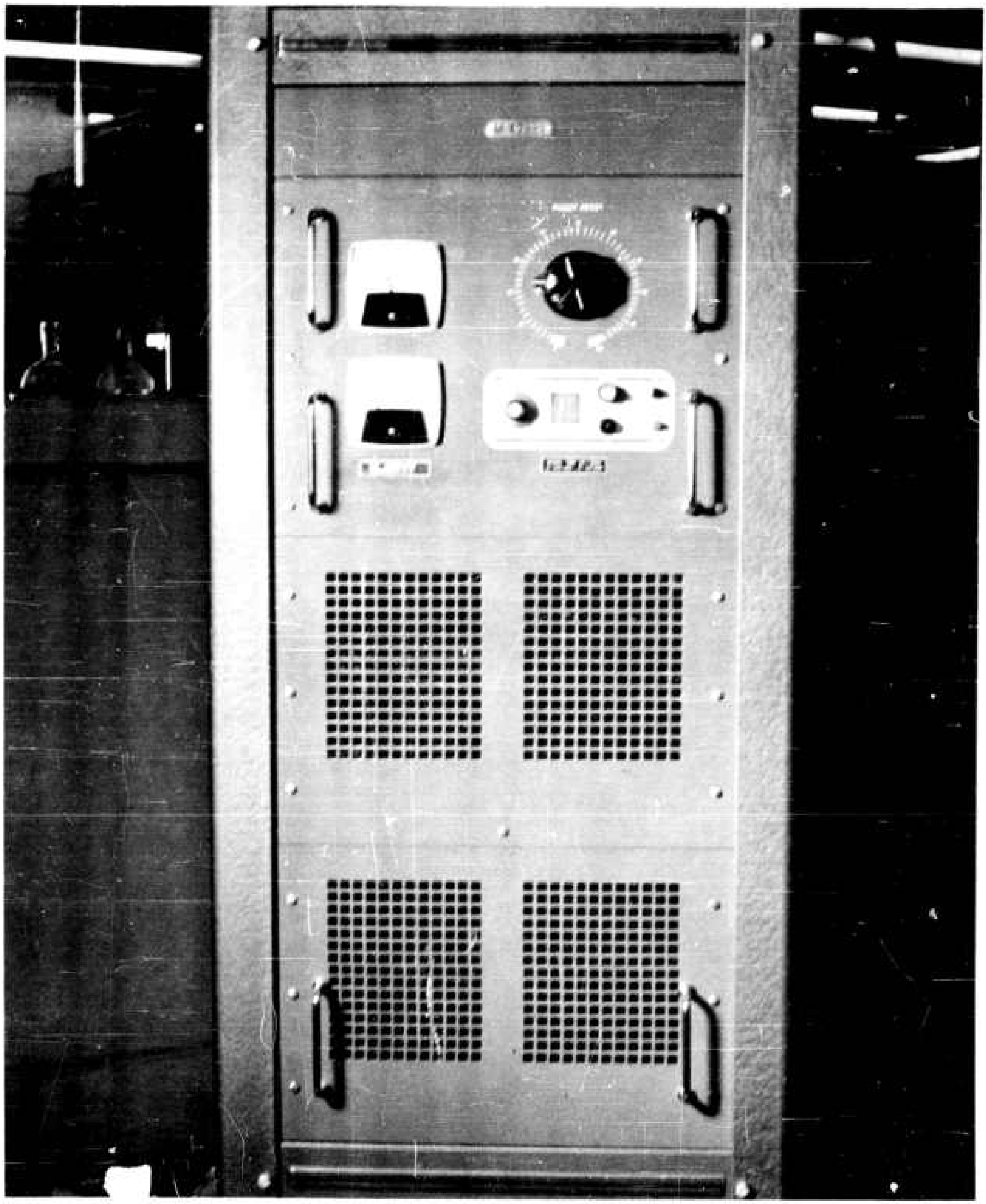


FIGURE 2

CONSTANT POTENTIAL POWER SUPPLY UNIT

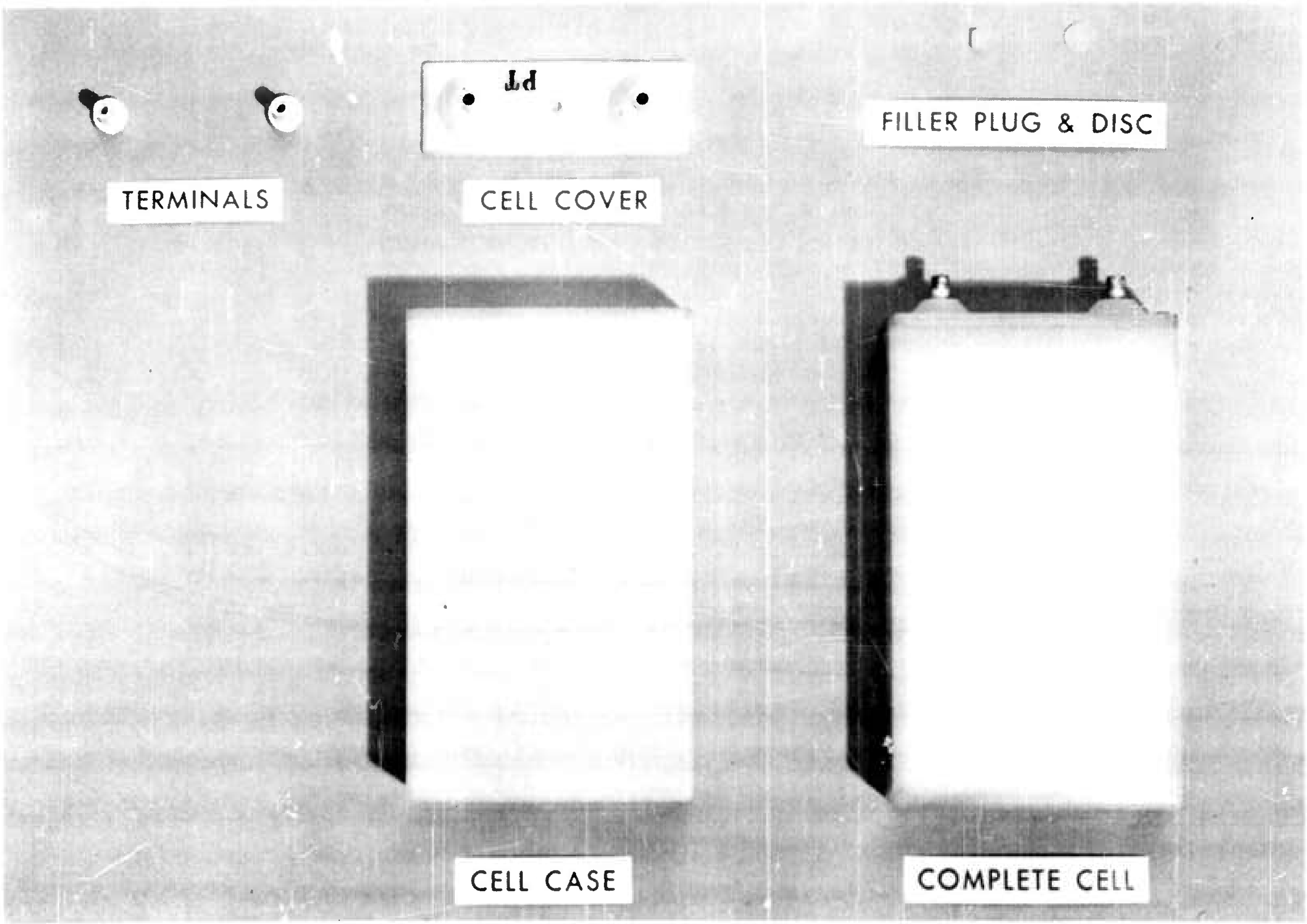


FIGURE 3

TERMINALS AND MOLDED PARTS OF THE CELL

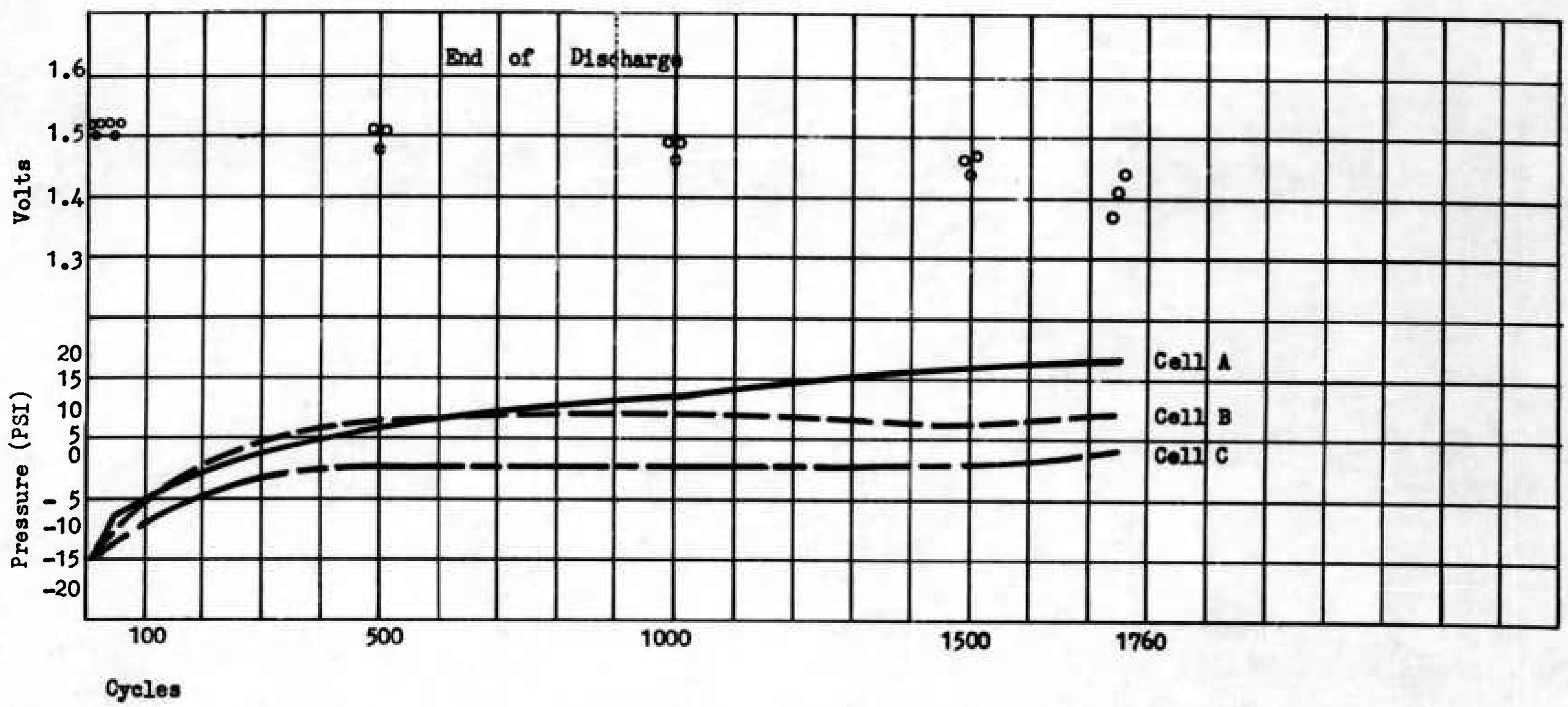


FIGURE 4

END OF DISCHARGE VOLTAGE AND PRESSURE FOR SEALED BATTERY OF THREE CELLS. POINTS, READING FROM LEFT TO RIGHT, INDICATE CELLS #A, B, C, RESPECTIVELY.

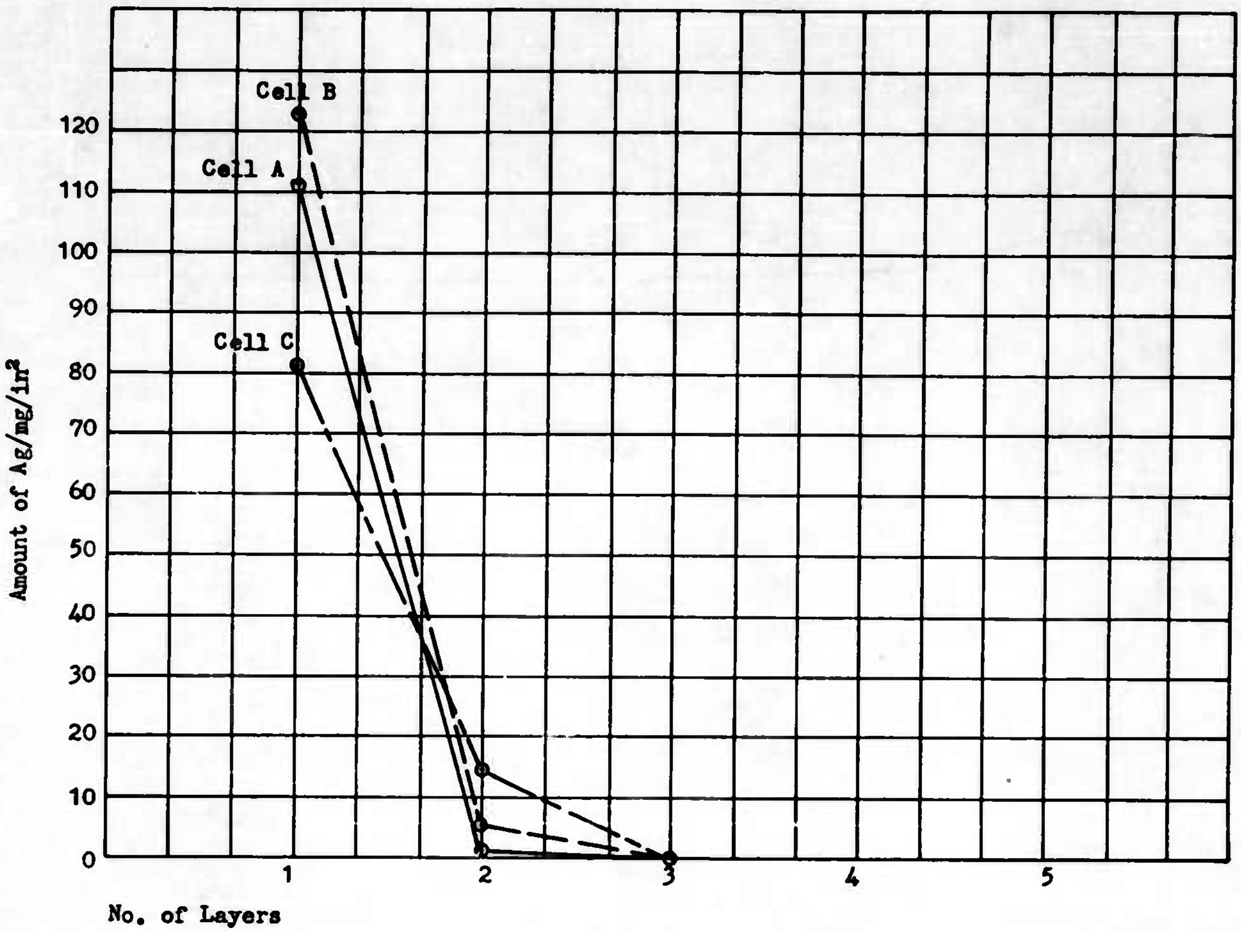


FIGURE 5

SILVER CONTENT IN SEPARATOR

AFTER 1760 CYCLES IN EACH OF THREE CELLS

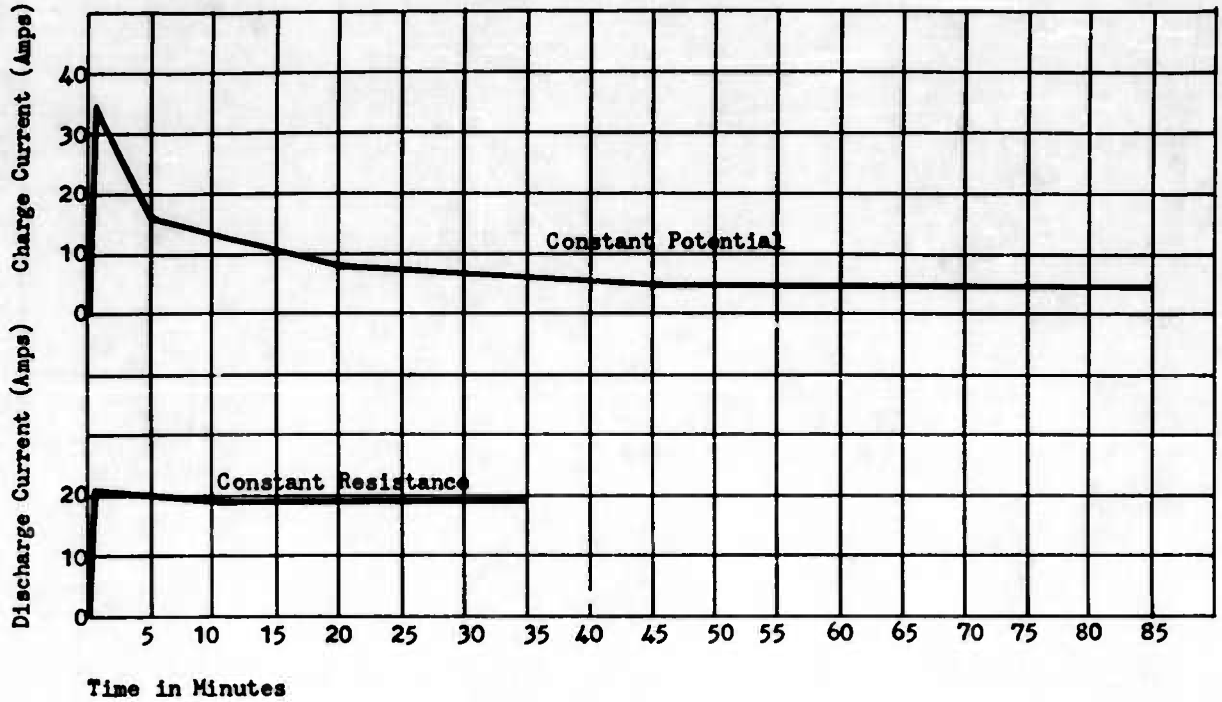


FIGURE 6

TYPICAL CHARGE AND DISCHARGE CURVES OF CELL OPERATING

FOR 1760 CYCLES

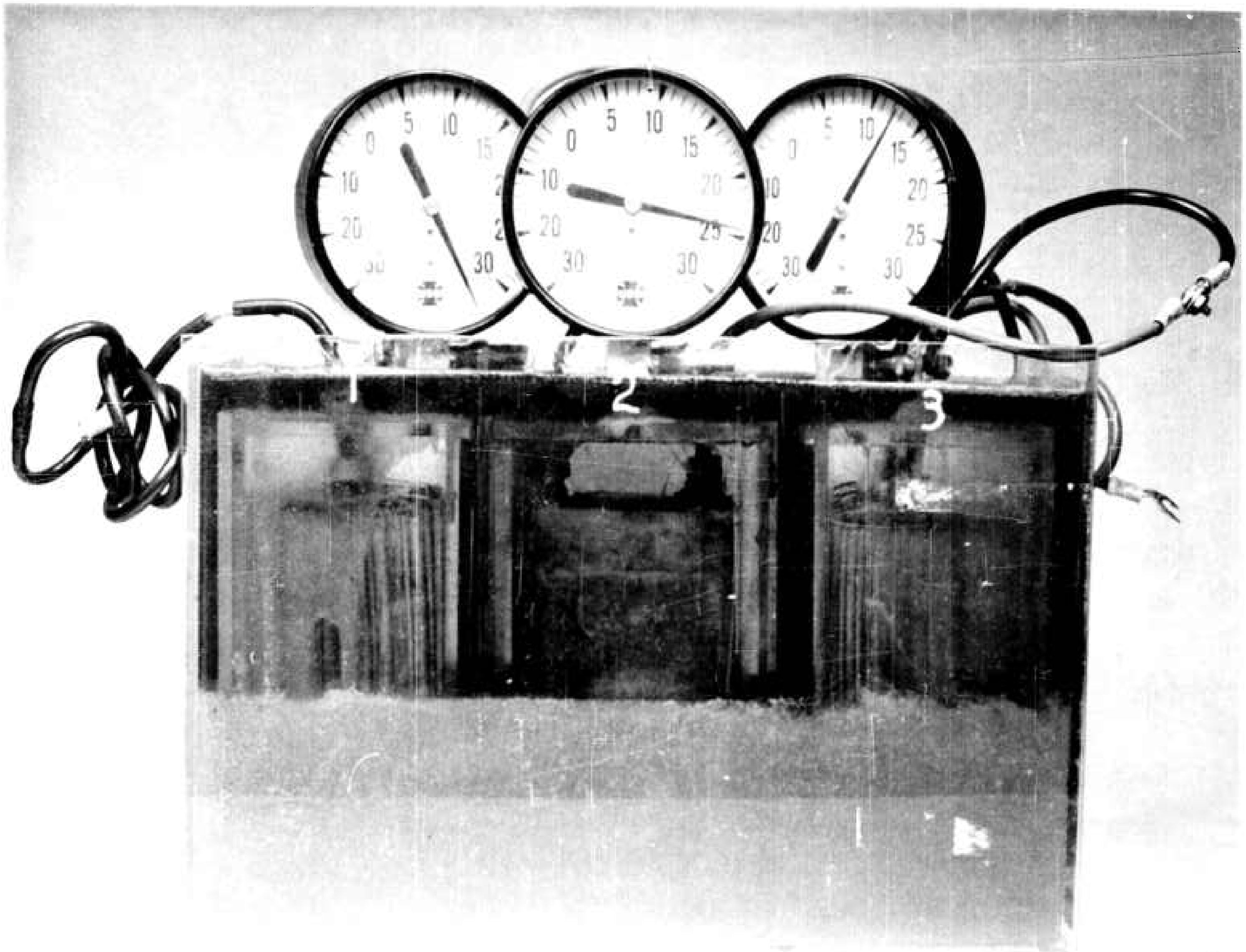
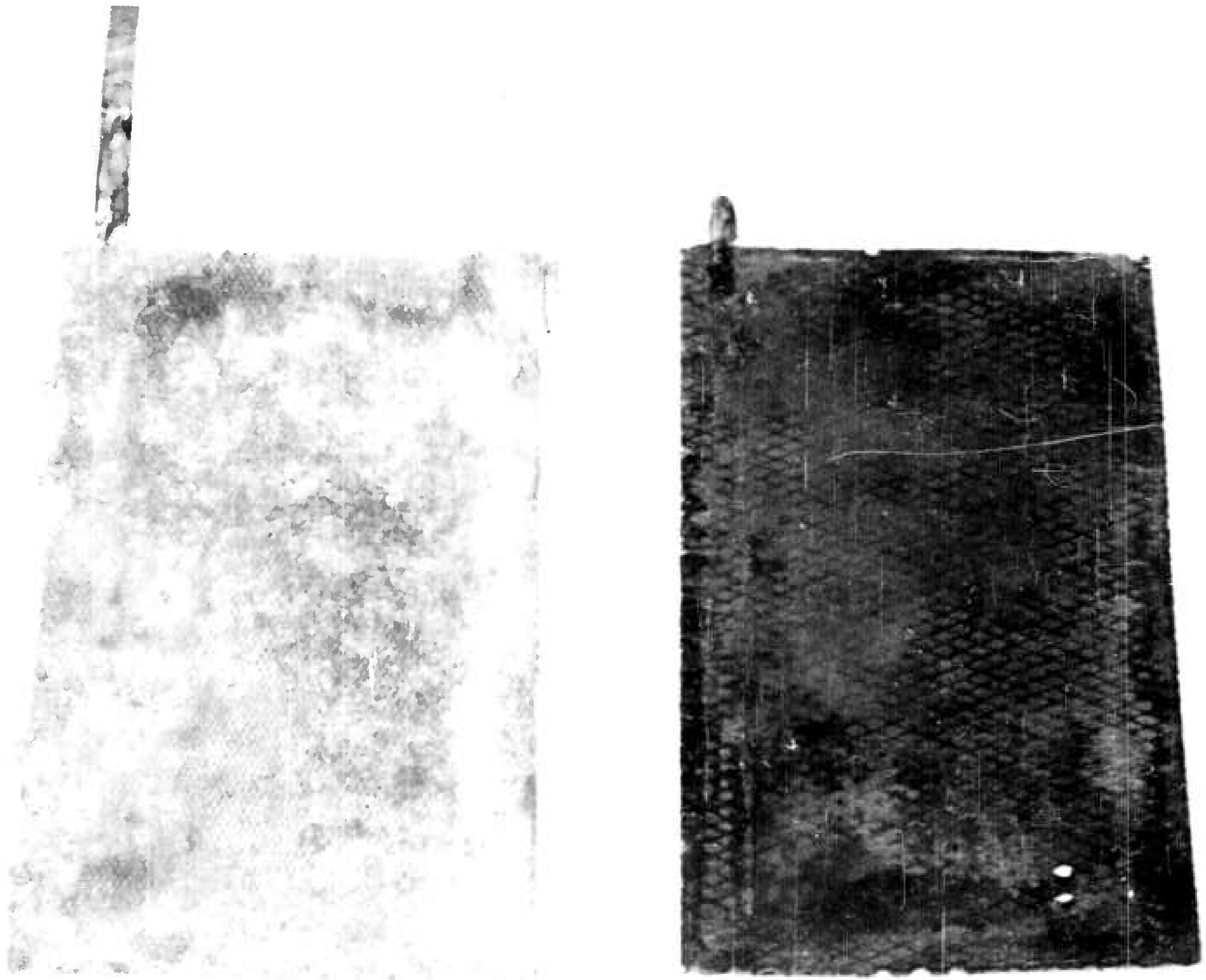


FIGURE 7

SEALED BATTERY OF CELLS A, B AND C



NEGATIVE PLATE POSITIVE PLATE

FIGURE 8

POSITIVE AND NEGATIVE PLATE SAMPLE FROM CELLS A, B AND C

1st Layer 2nd Layer 3rd Layer

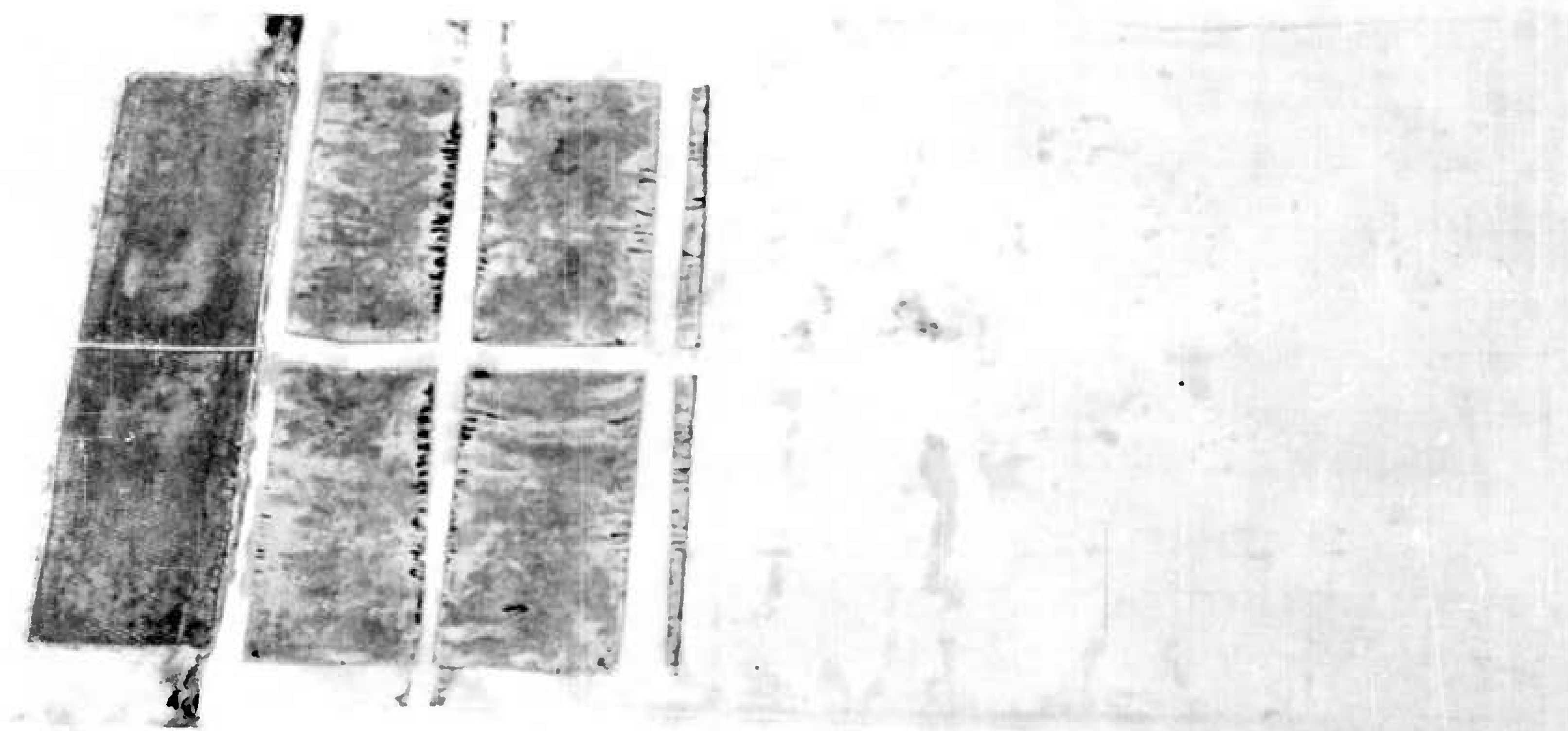


FIGURE 9

SEPARATOR SAMPLE FROM CELLS A, B AND C

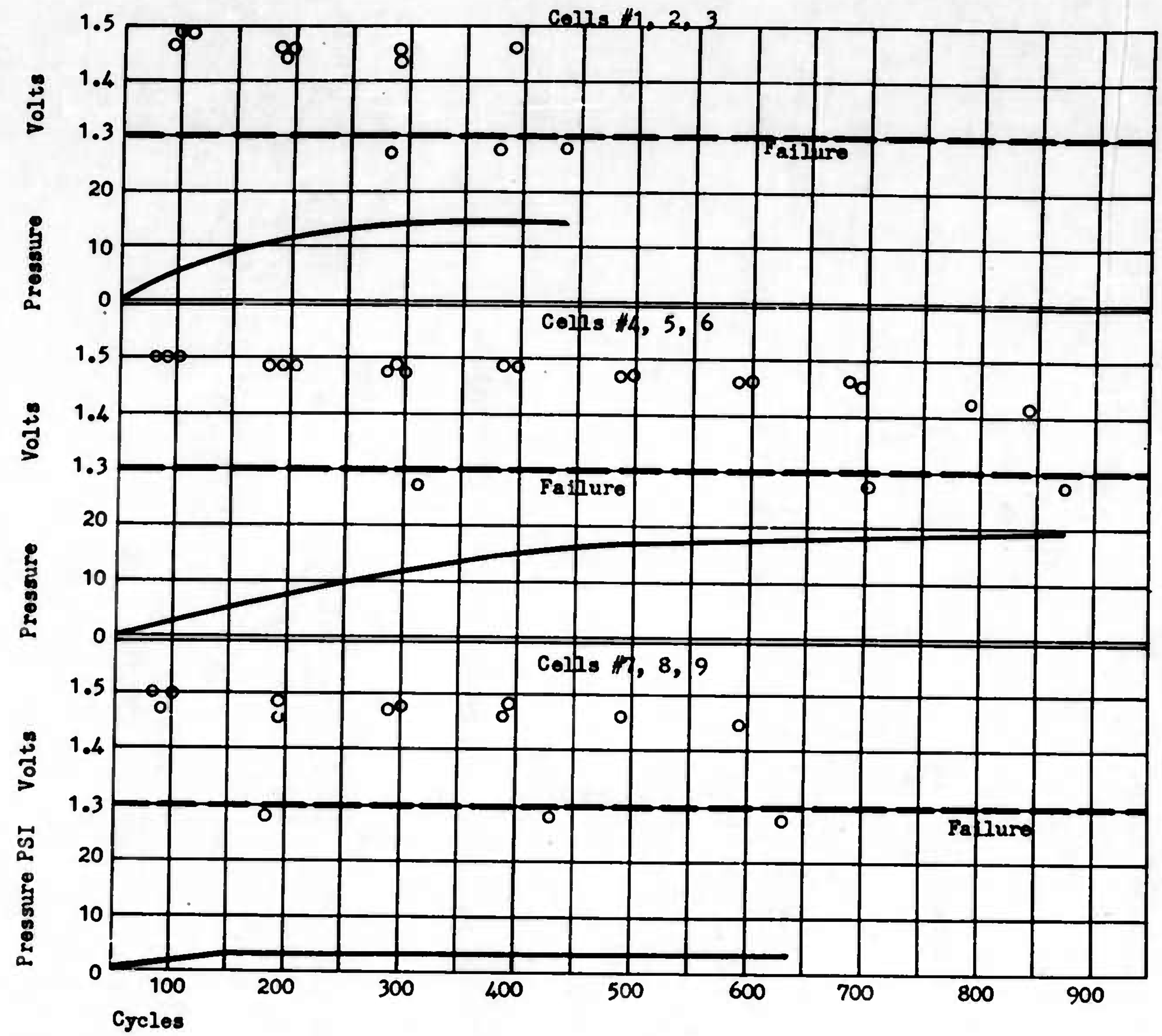


FIGURE 10

END OF DISCHARGE VOLTAGE AT EACH 100 CYCLE MARK, AND AVERAGE PRESSURE OF THREE CELLS IN EACH THREE-CELL GROUP FOR CELLS #1 THROUGH #9

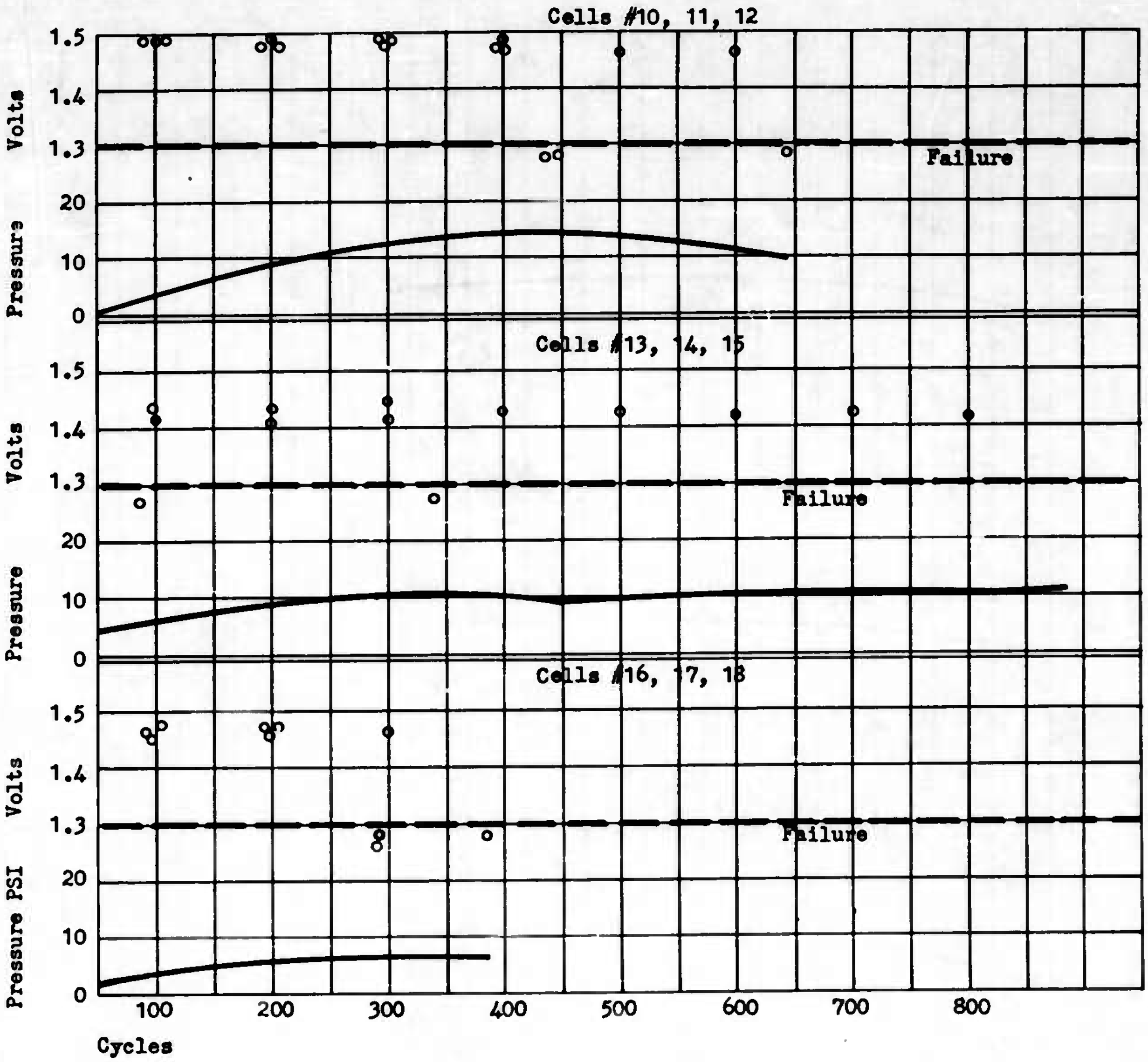


FIGURE 11

END OF DISCHARGE VOLTS AND PRESSURES
Cells #10 Through #18

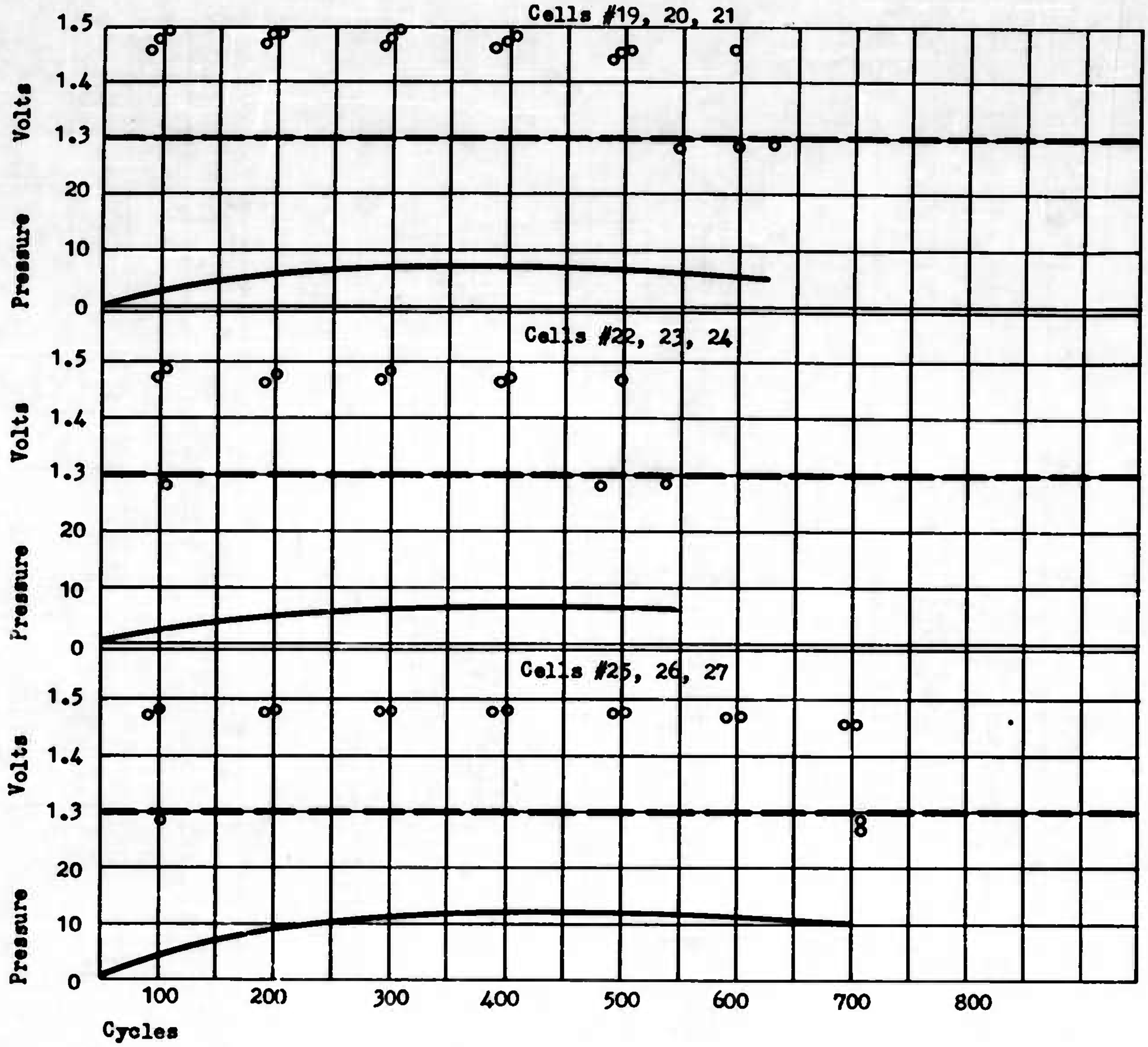


FIGURE 12

END OF DISCHARGE VOLTS AND PRESSURES

Cells #19 Through #27

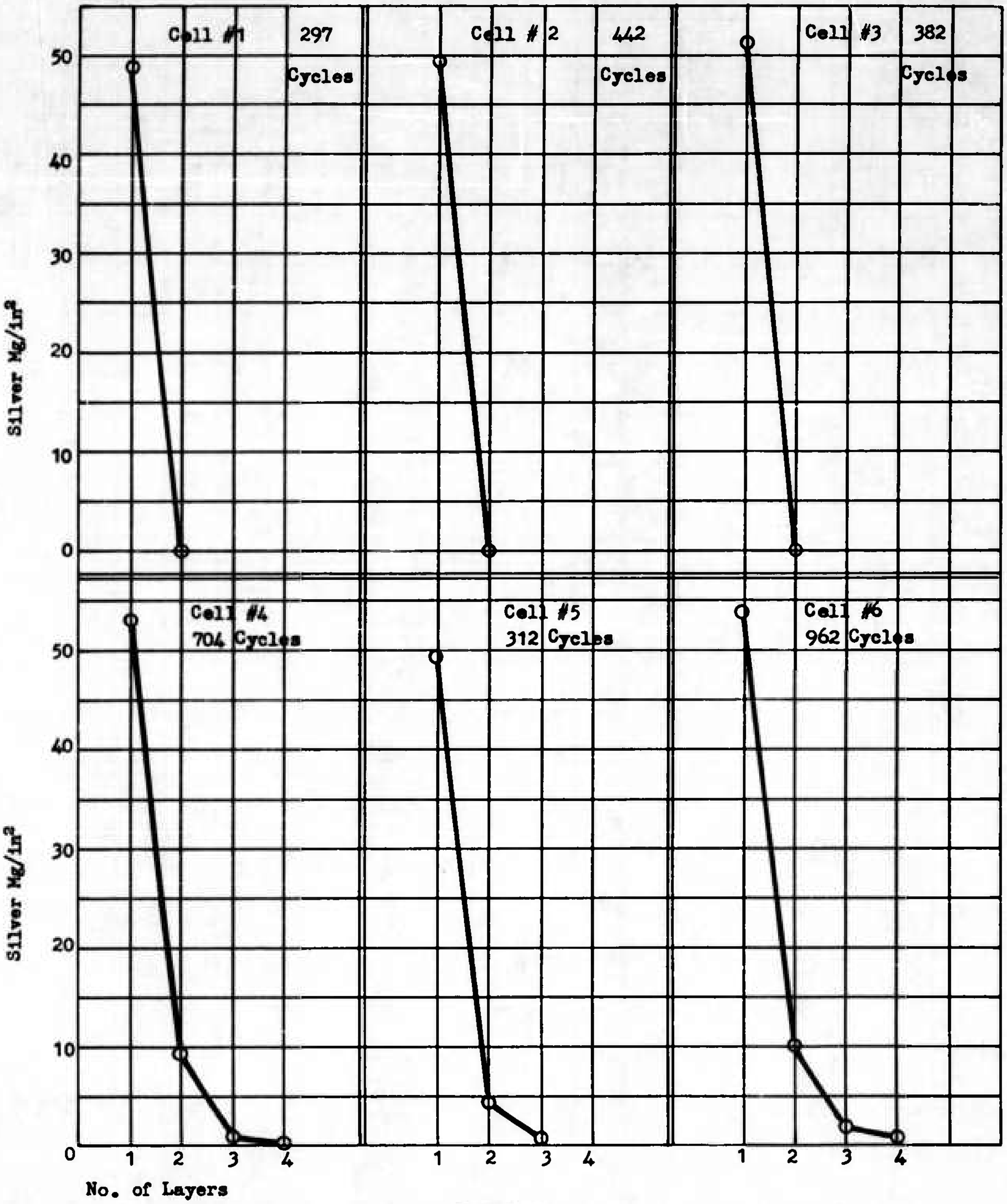


FIGURE 13

SILVER CONTENT IN Mg/in^2 IN SEPARATORS OF CELLS #1 THROUGH #6

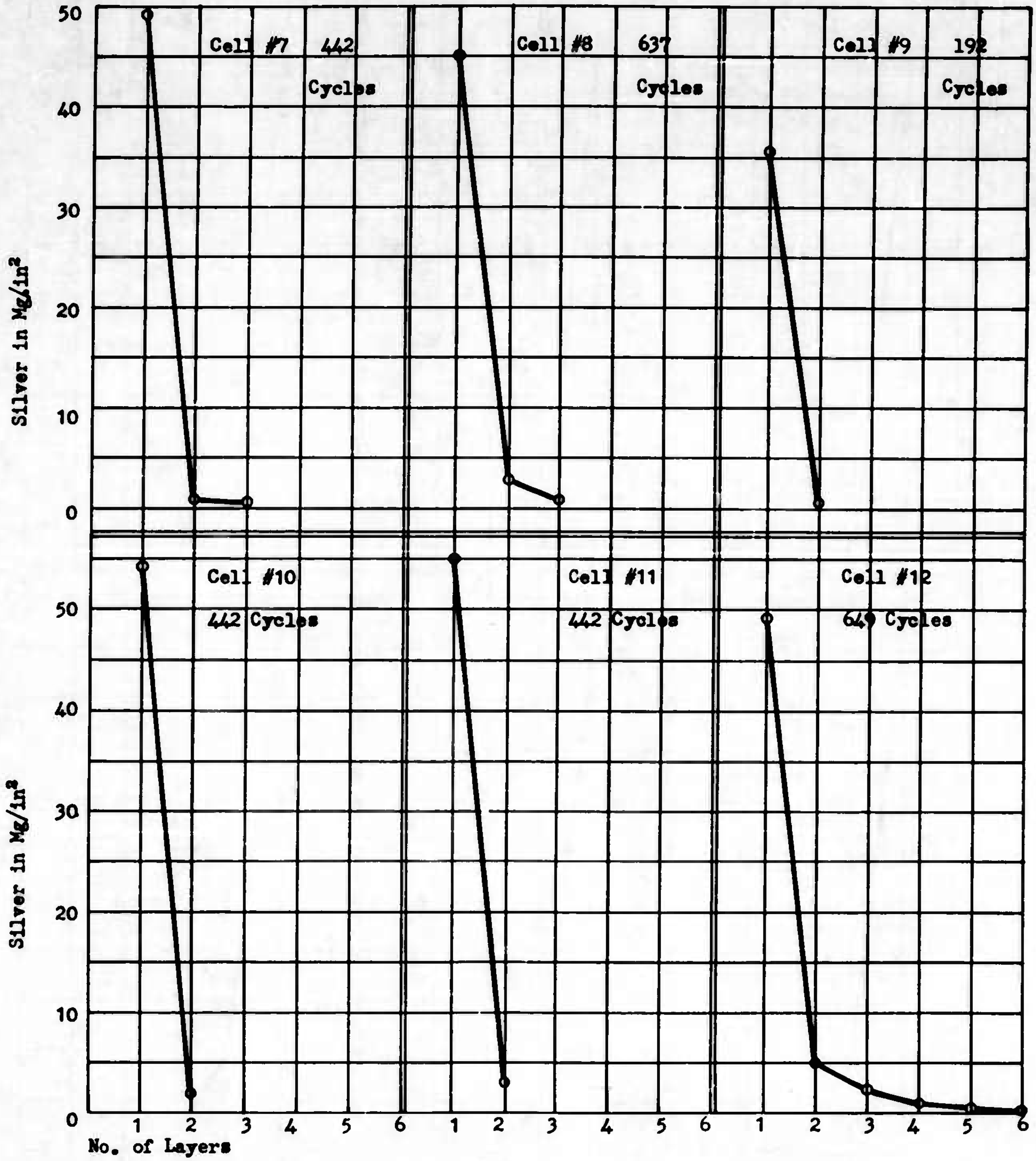


FIGURE 14

SILVER CONTENT IN Mg/in^2 IN SEPARATORS OF CELLS #7 THROUGH #12

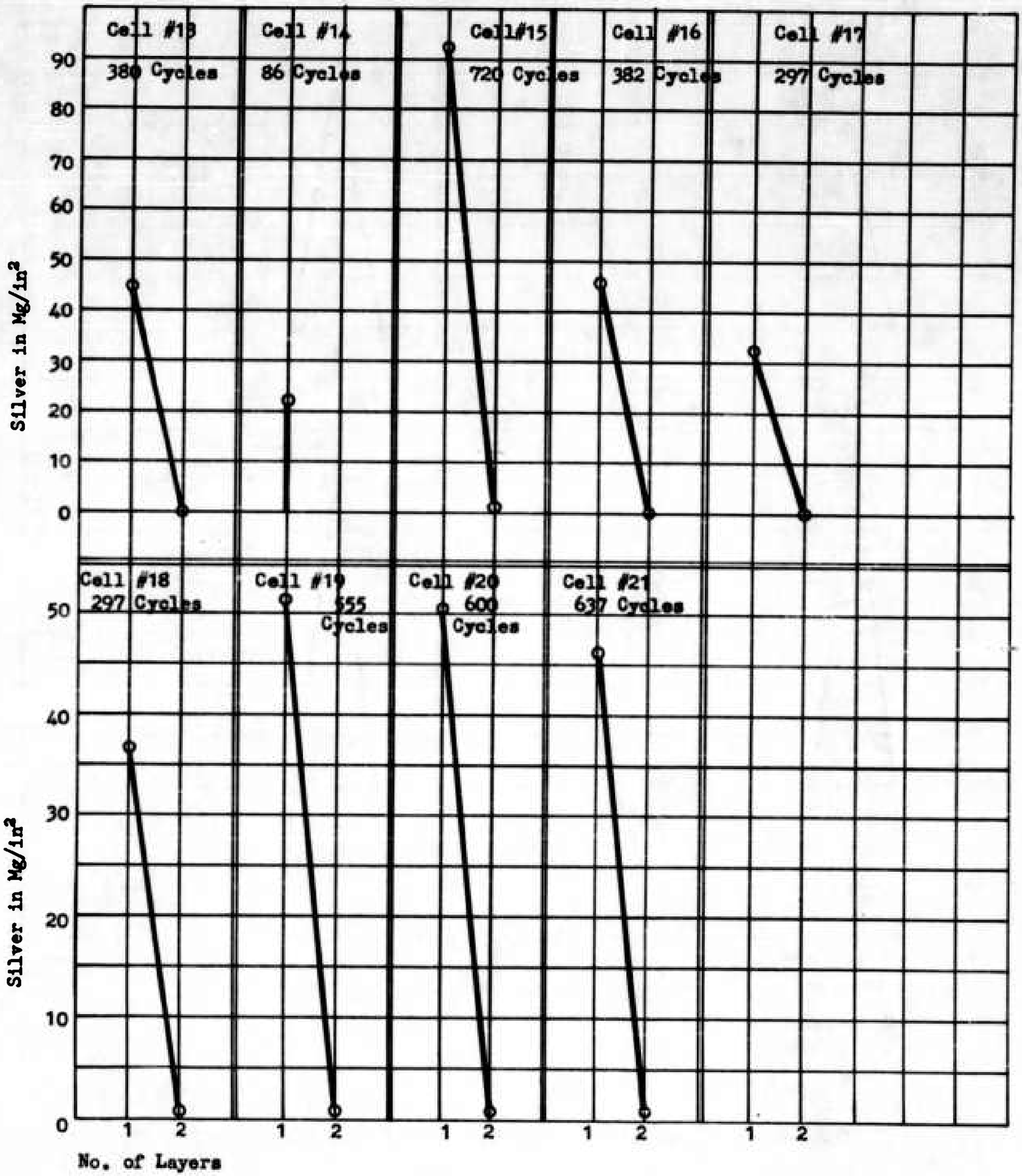


FIGURE 15

SILVER CONTENT IN Mg/in^2 IN SEPARATORS OF CELLS #13 THROUGH #21

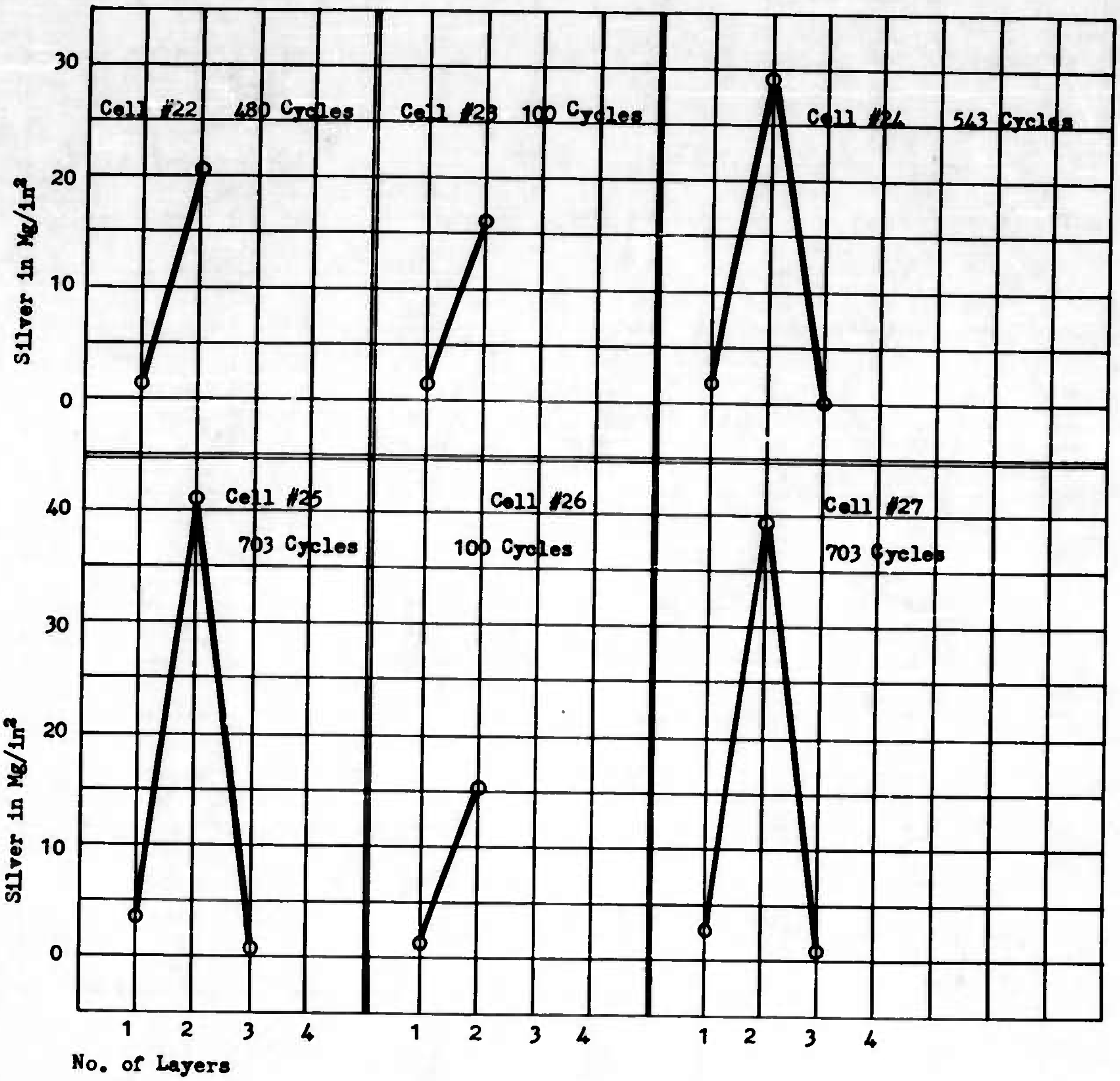


FIGURE 16

SILVER CONTENT IN Mg/in^2 IN SEPARATORS OF CELLS #22 THROUGH #27

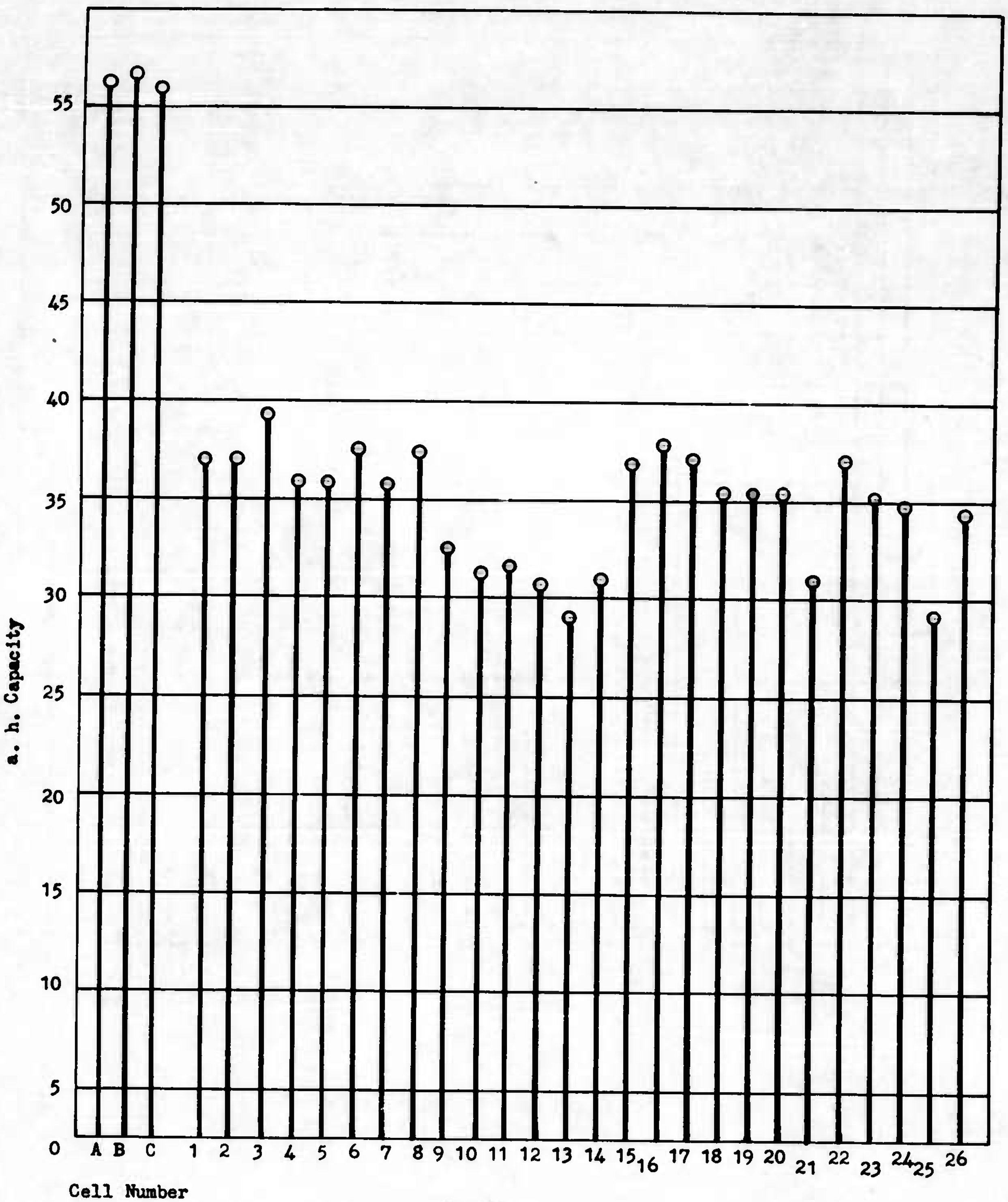


FIGURE 17

GROUP 1 - AMPERE HOUR CAPACITY
OF FIRST CYCLE OF CELLS A, B, C, RATED AT 48 a.h. AND 27 CELLS, RATED AT 25 a.h. DISCHARGE AT 20 AMPS FOR CELLS A, B, C, AT 9 AMPS FOR ALL OTHER CELLS, OUT VOLTAGE TO 1.00 vpc

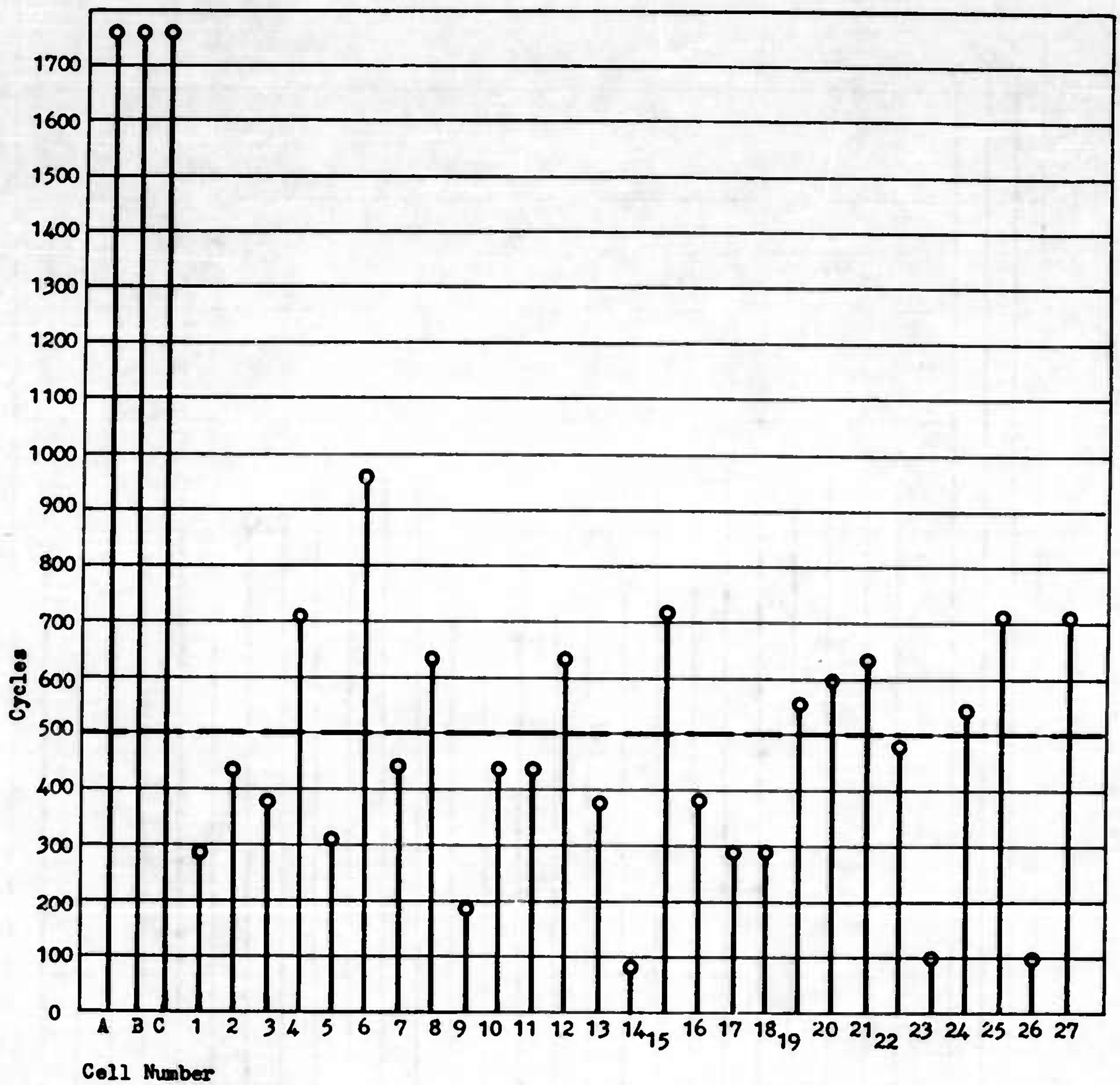


FIGURE 18

NUMBER OF CYCLES OBTAINED BY GROUP 1 CELLS

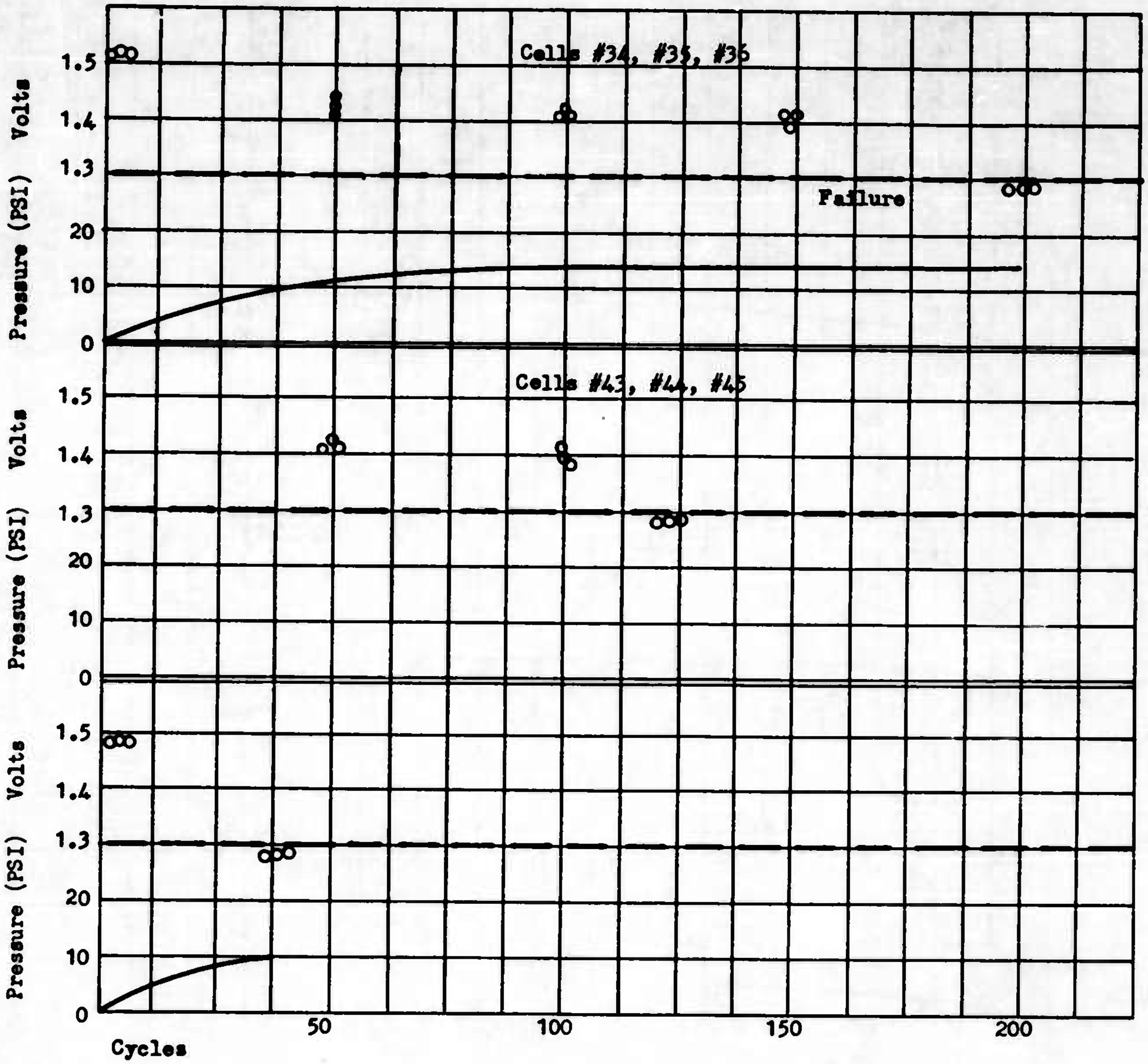


FIGURE 19

END OF DISCHARGE VOLTAGES AND PRESSURES
AT EACH 50 CYCLE INTERVAL AT 30° F FOR INDICATED CELLS

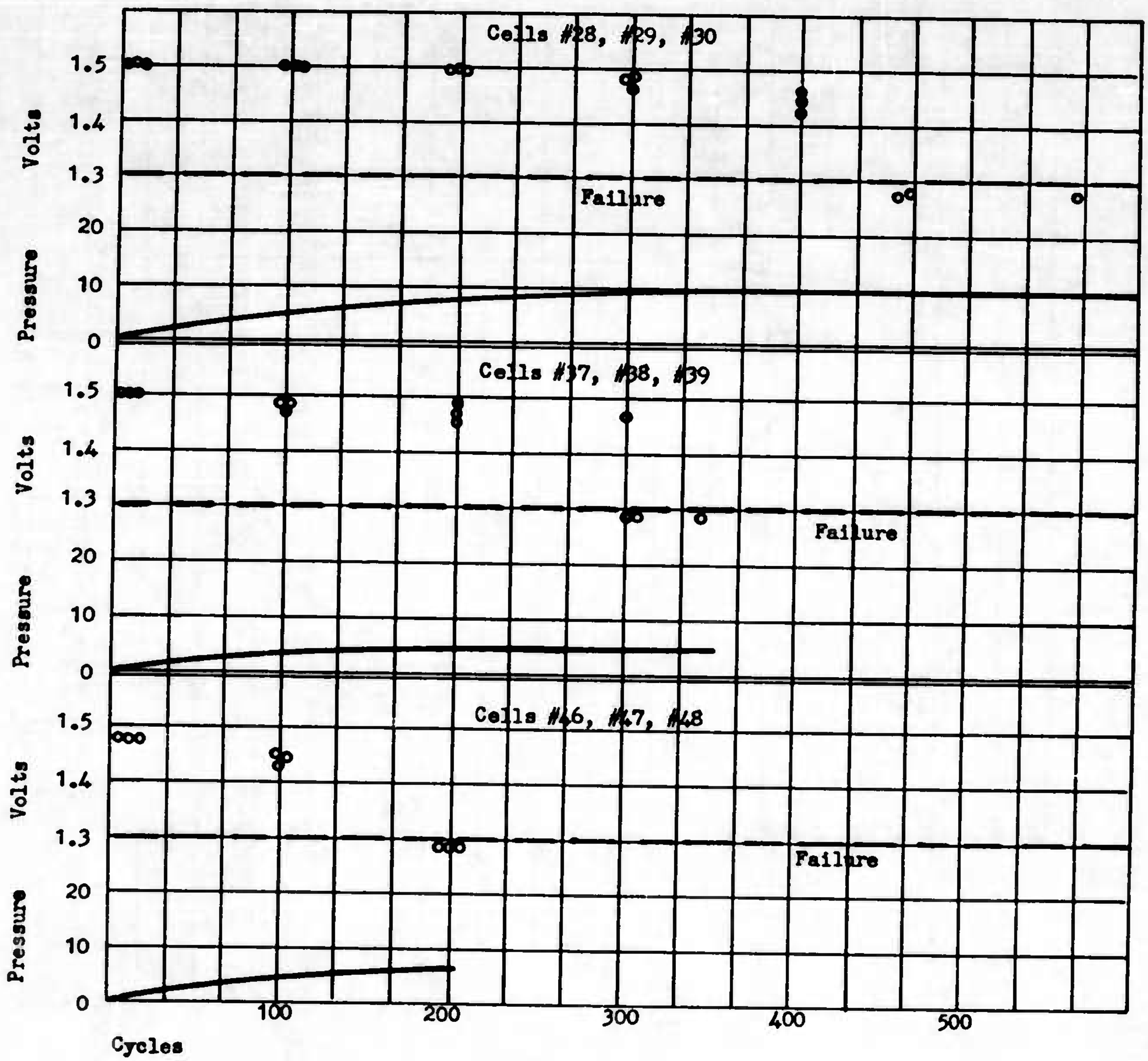


FIGURE 20

END OF DISCHARGE VOLTAGES AND PRESSURES AT EACH 100 CYCLE INTERVAL AT ROOM TEMPERATURE FOR INDICATED CELLS

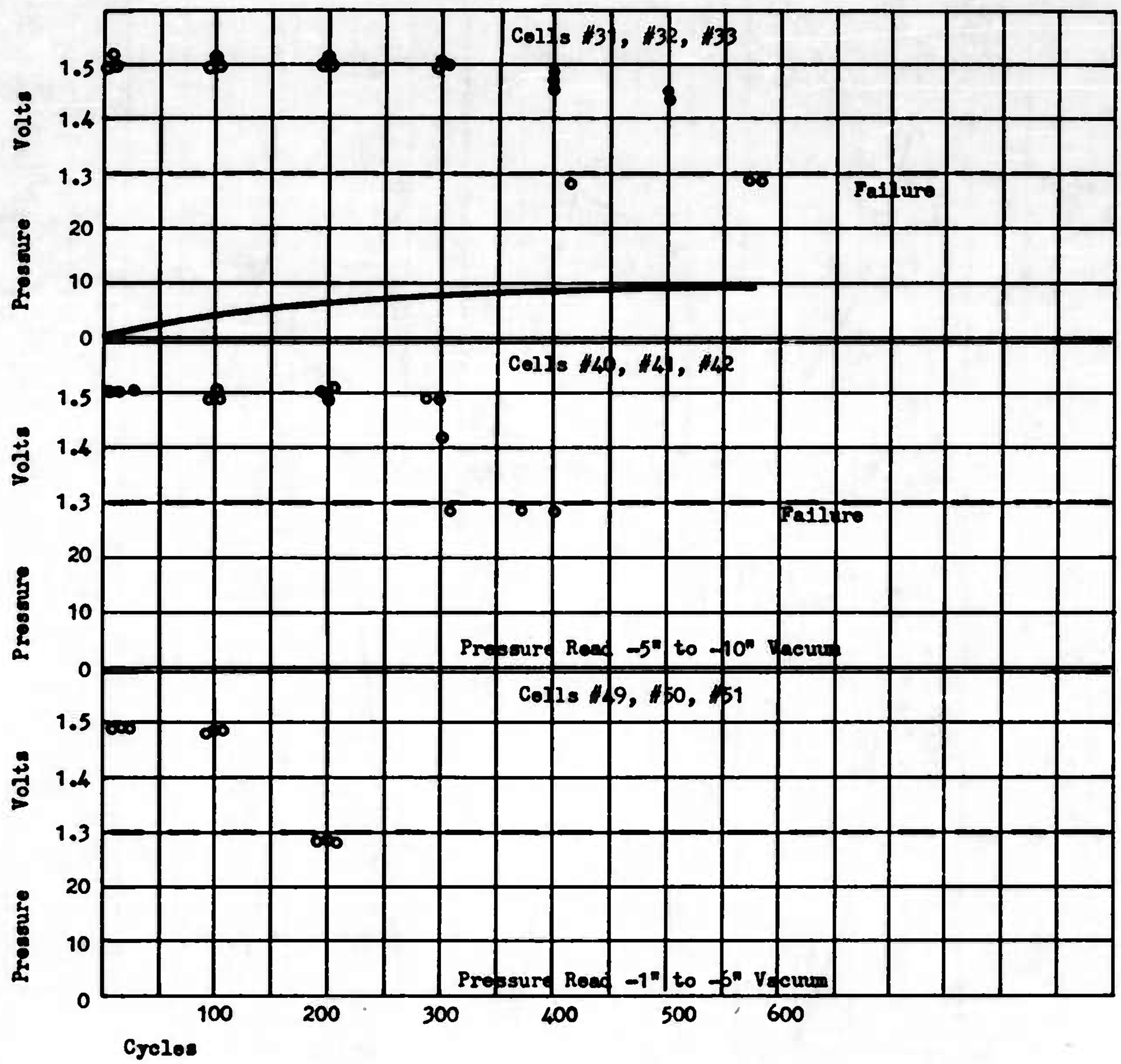


FIGURE 21

END OF DISCHARGE VOLTAGES AND PRESSURES AT EACH 100 CYCLE INTERVAL AT 100° F FOR INDICATED CELLS

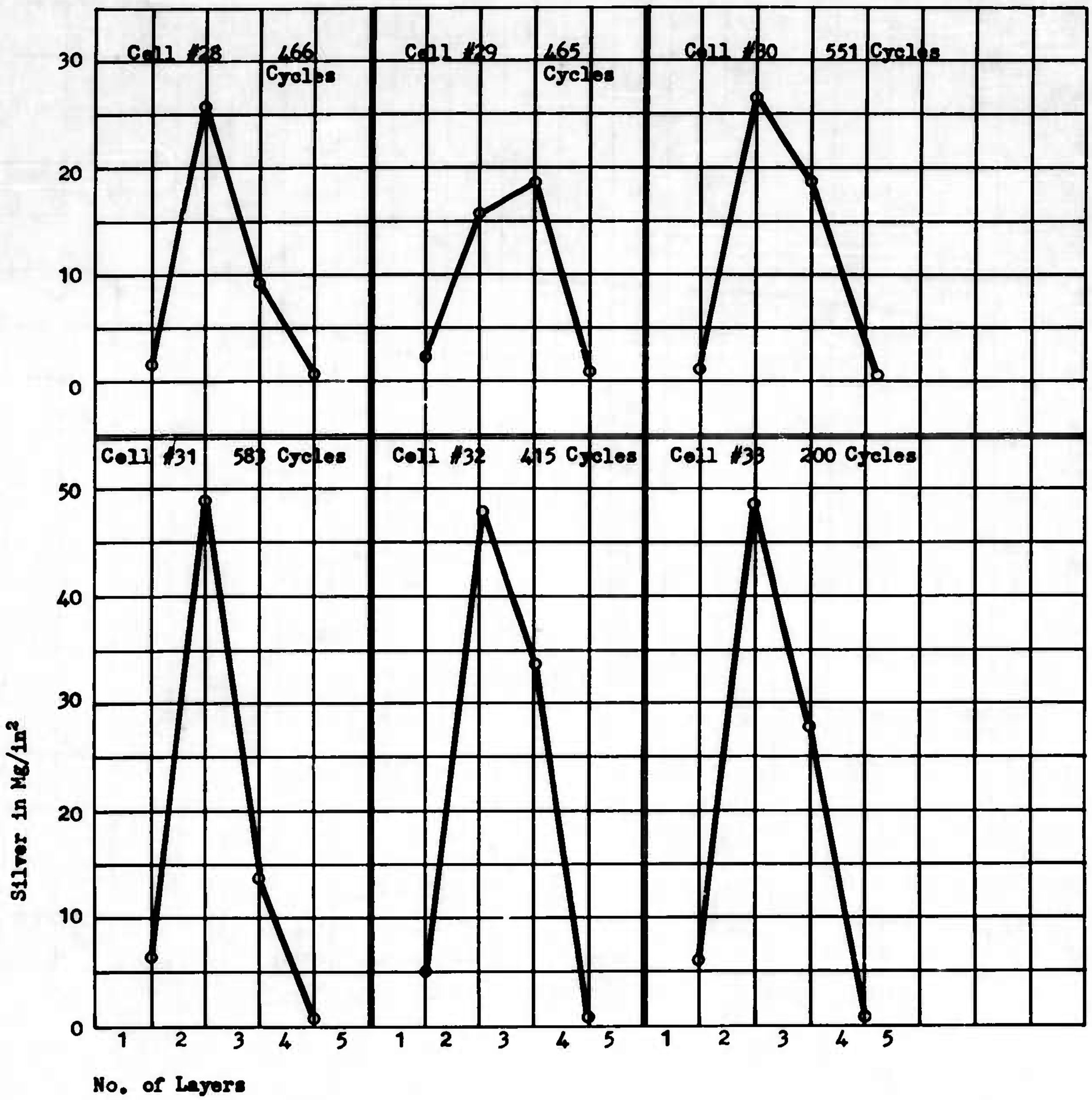


FIGURE 22

SILVER CONTENT IN Mg/in^2 IN SEPARATORS OF CELLS #28 THROUGH #33

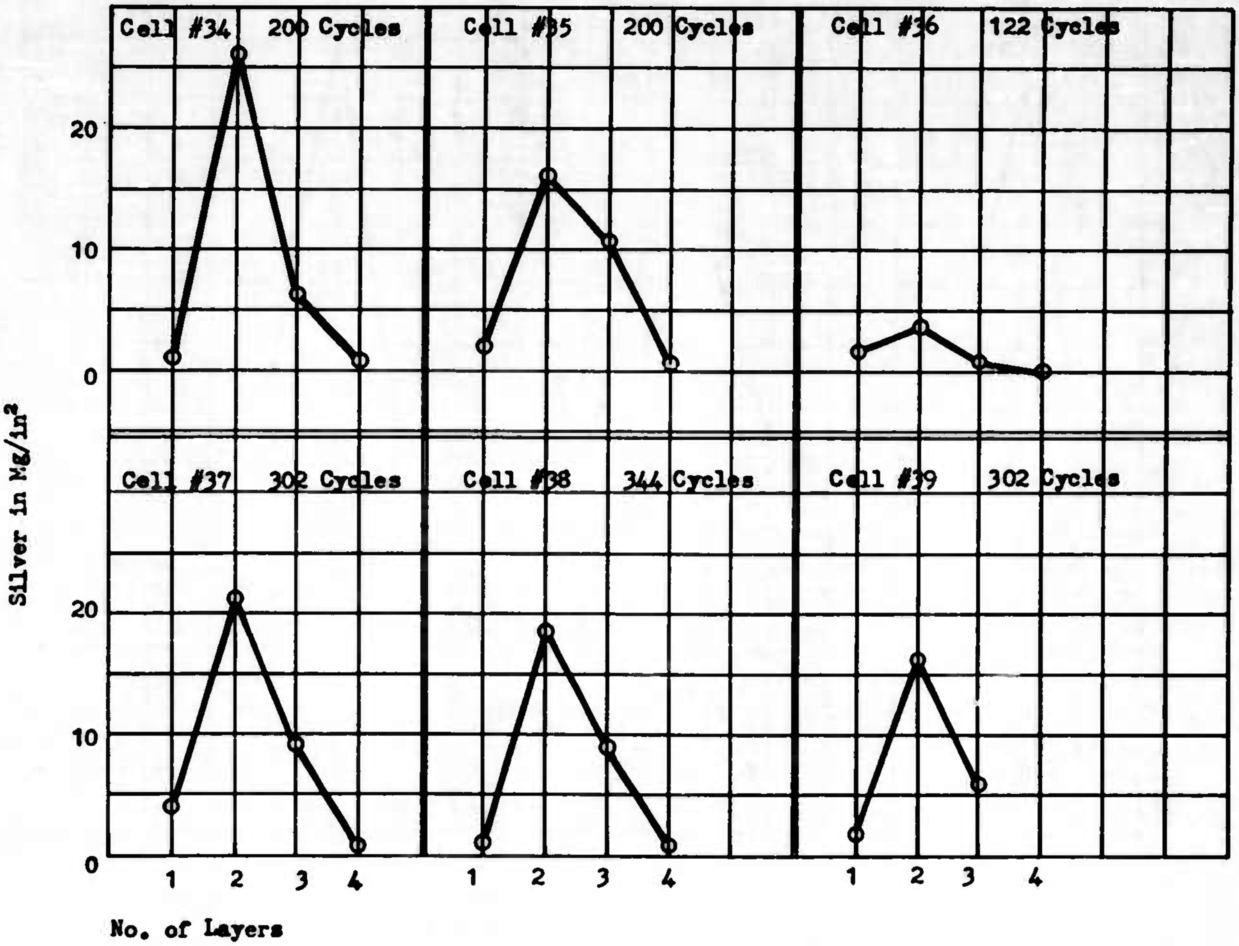


FIGURE 23

SILVER CONTENT IN Mg/in^2 IN SEPARATORS

OF CELLS #34 THROUGH #39

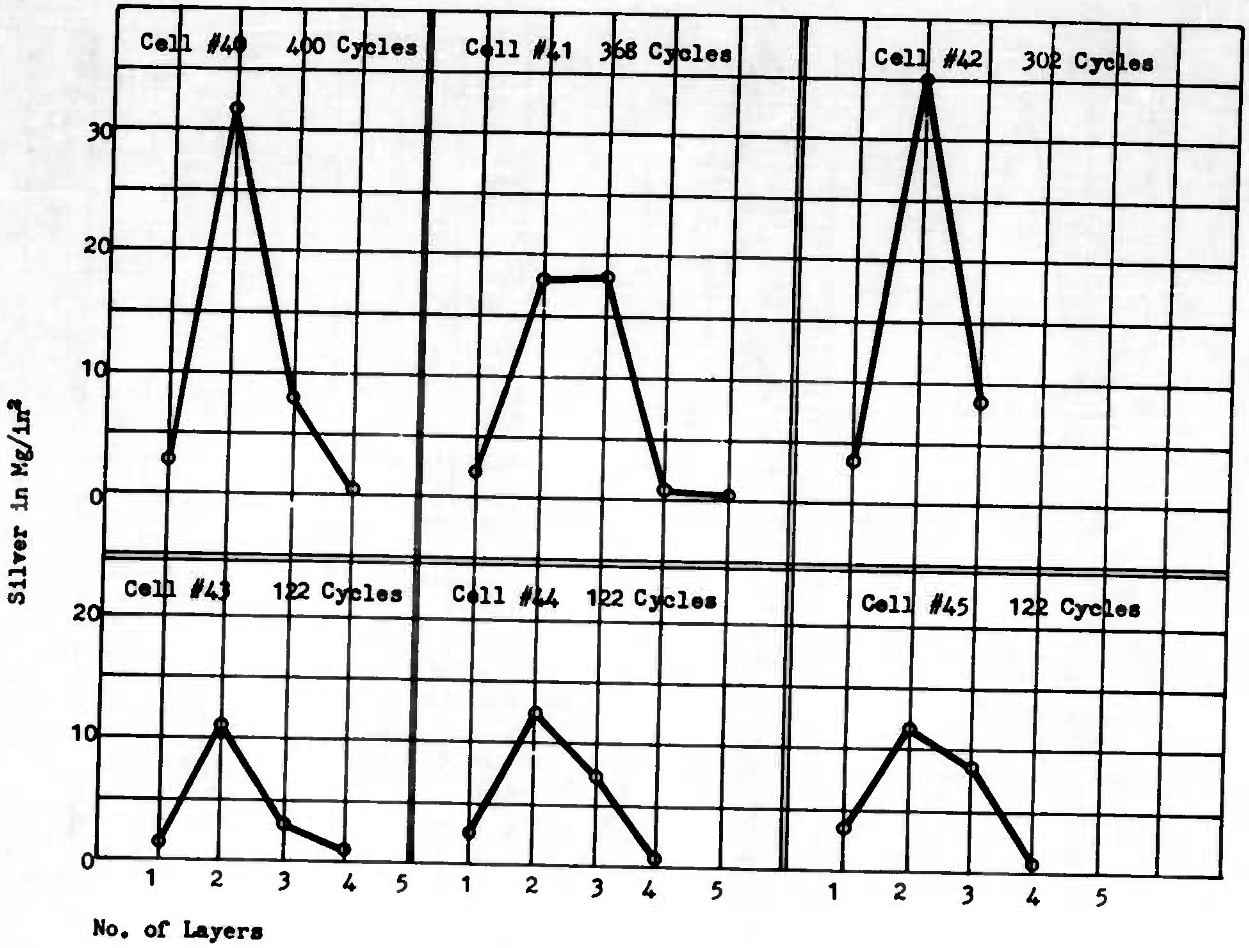


FIGURE 24

SILVER CONTENT IN Mg/in^2 IN SEPARATORS

OF CELLS #40 THROUGH #45

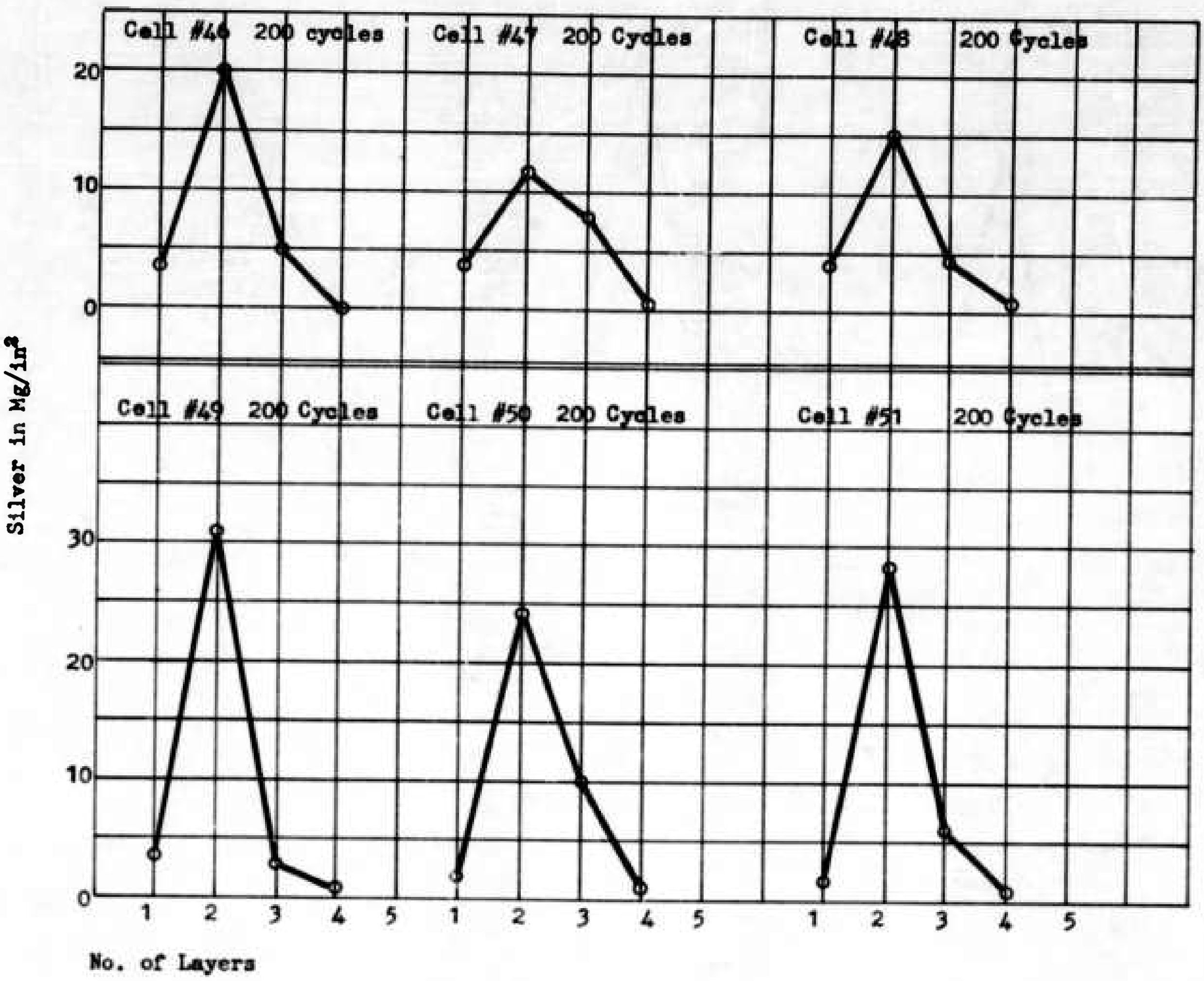


FIGURE 25

SILVER CONTENT IN Mg/in^2 IN

SEPARATORS OF CELLS #46 THROUGH #51

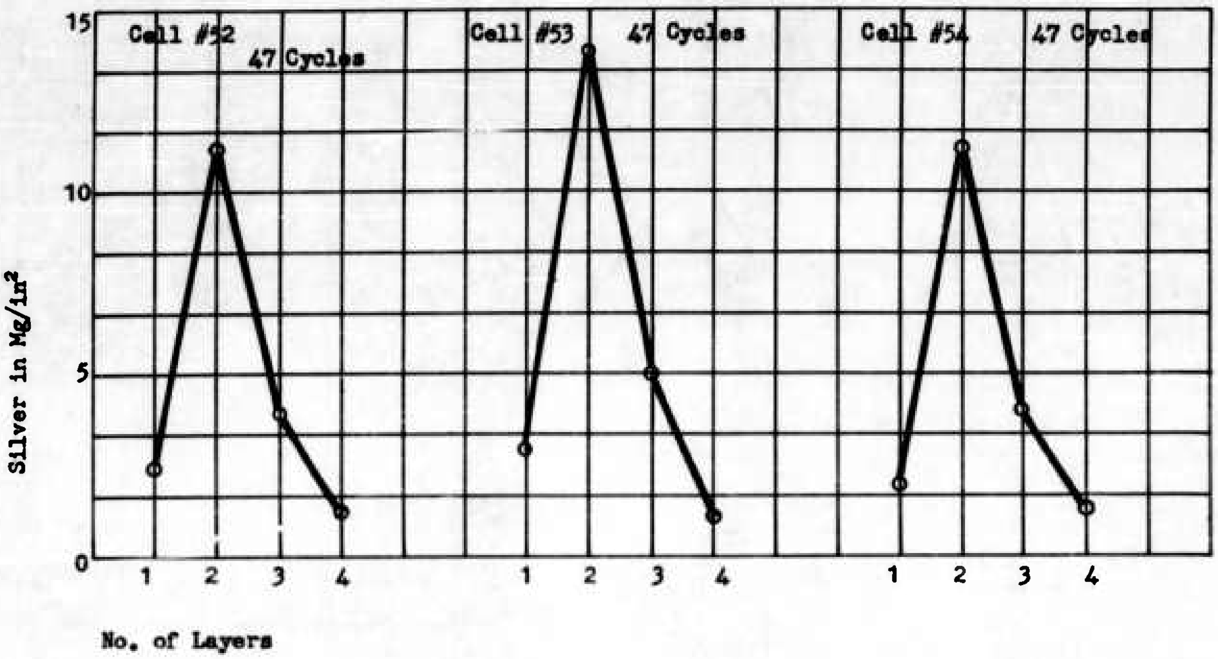


FIGURE 26

SILVER CONTENT IN Mg/in^2

SEPARATORS OF CELLS

#52 THROUGH #54

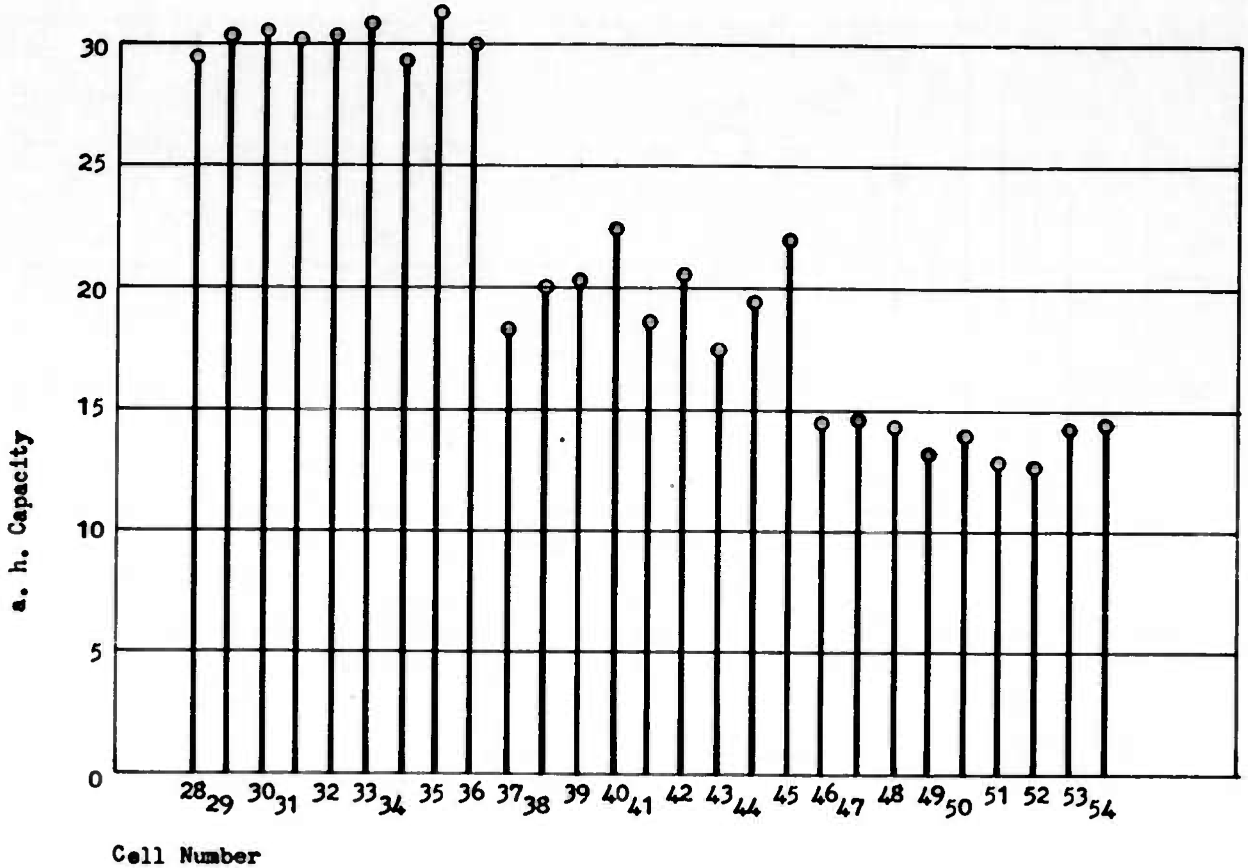


FIGURE 27

GROUP 2

AMPERE HOUR CAPACITY OF FIRST CYCLE

Cells #28 to #36 Rated at 25 a.h.

Cells #37 to #45 Rated at 18 a.h.

Cells #46 to #54 Rated at 13 a.h.

Discharge C = 9.0 Amps to 1.00 vpc

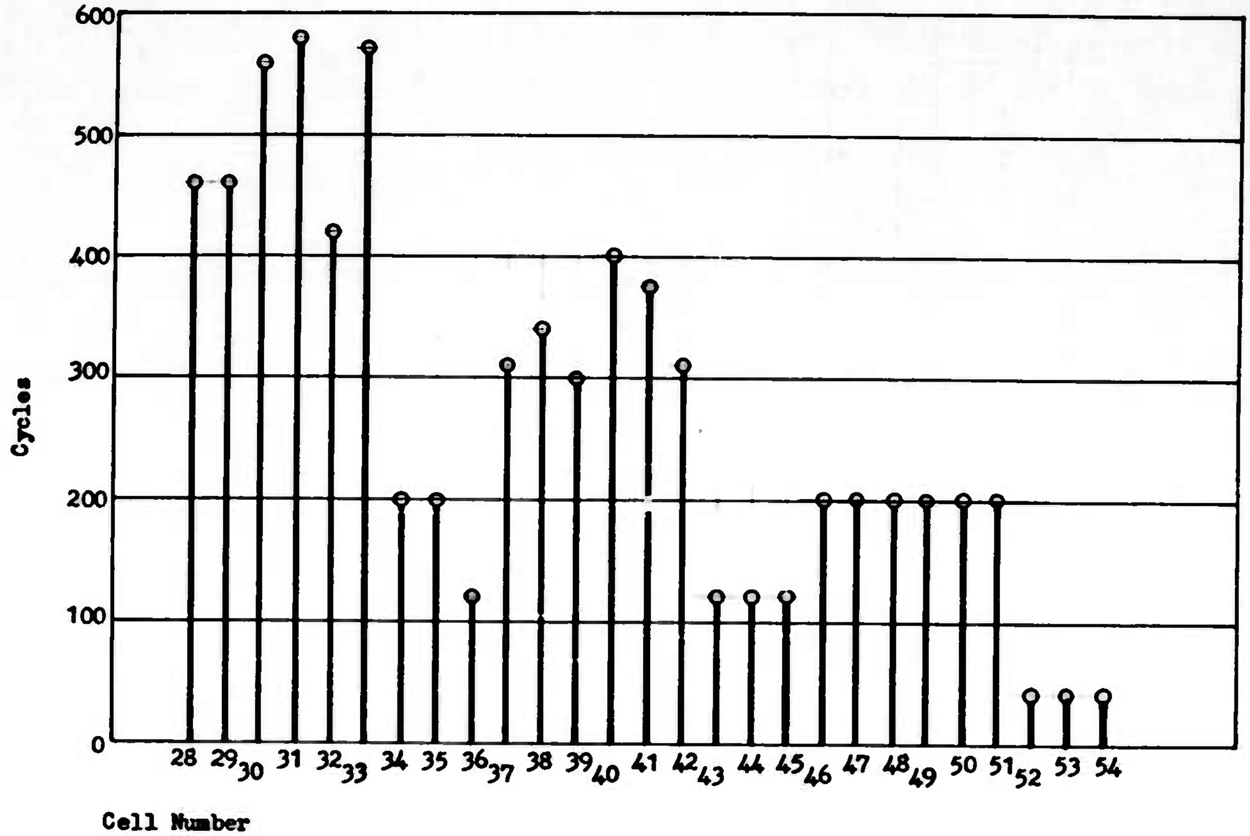


FIGURE 28

NUMBER OF CYCLES

OBTAINED BY GROUP

2 CELLS

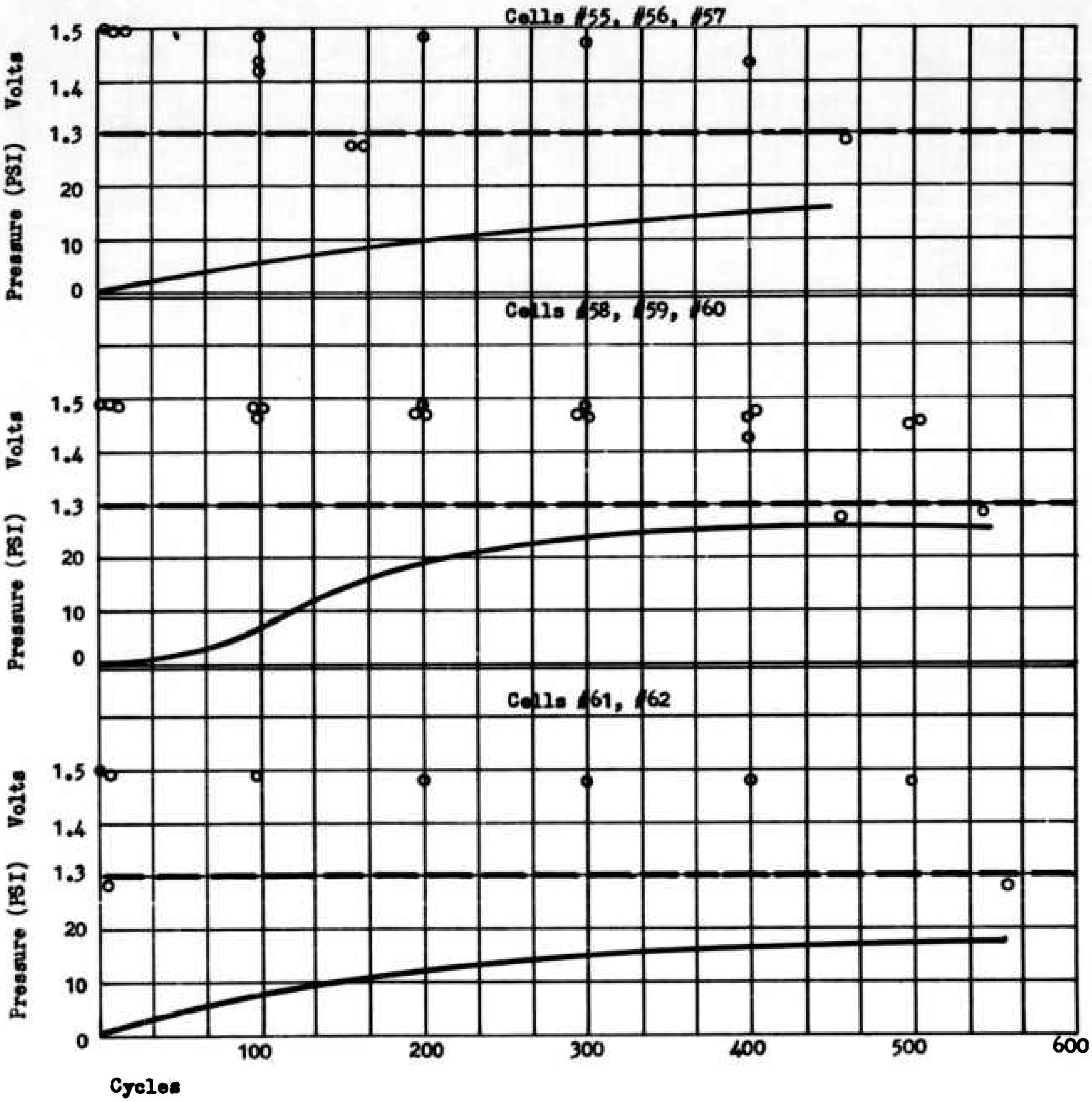


FIGURE 29

END OF DISCHARGE VOLTAGE AND PRESSURE AT

EACH 100 CYCLE INTERVAL AT ROOM TEMPERATURE

FOR THE INDICATED CELLS

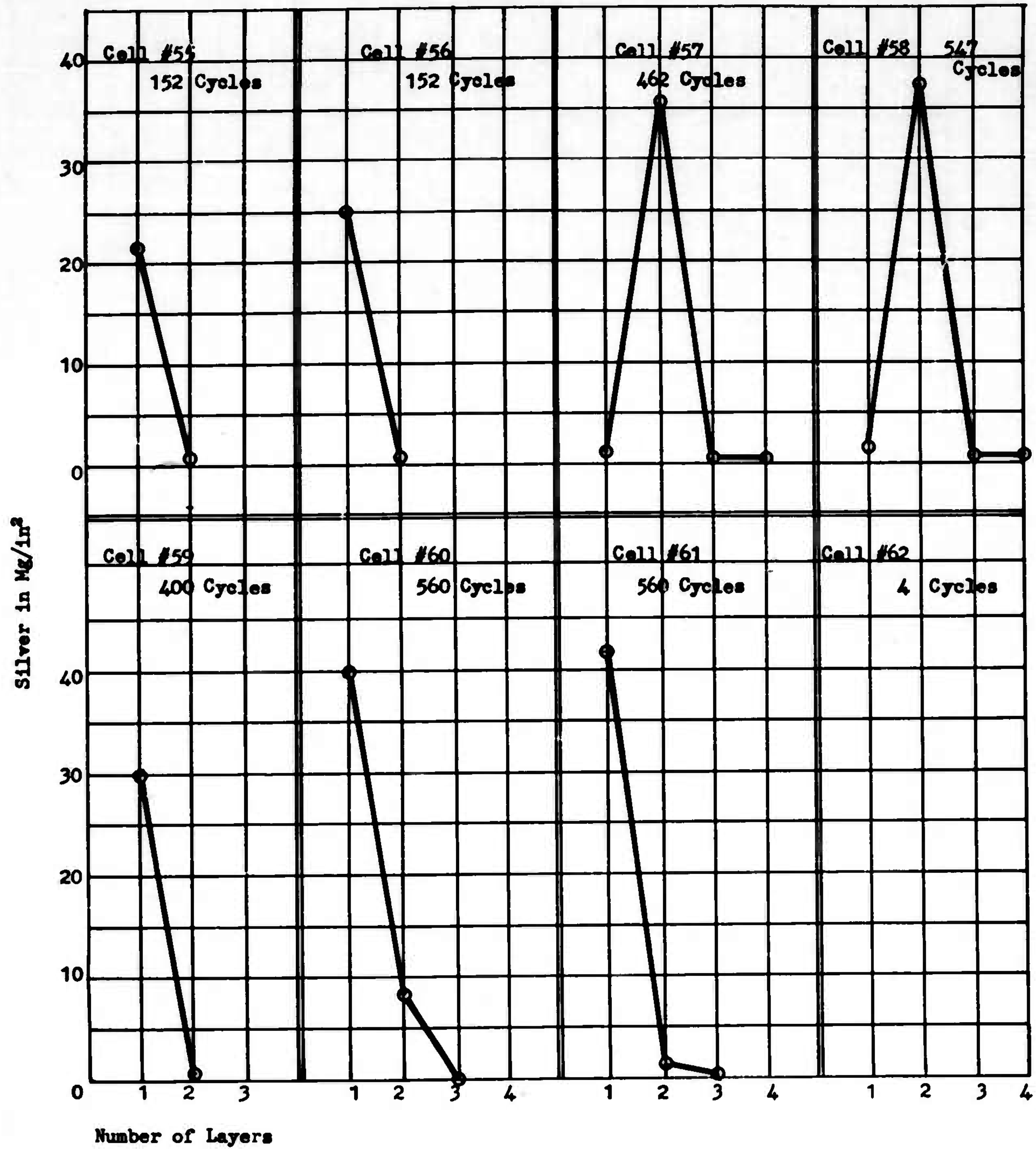


FIGURE 30

SILVER CONTENT IN Mg/in² IN SEPARATORS OF CELLS #55 THROUGH #62

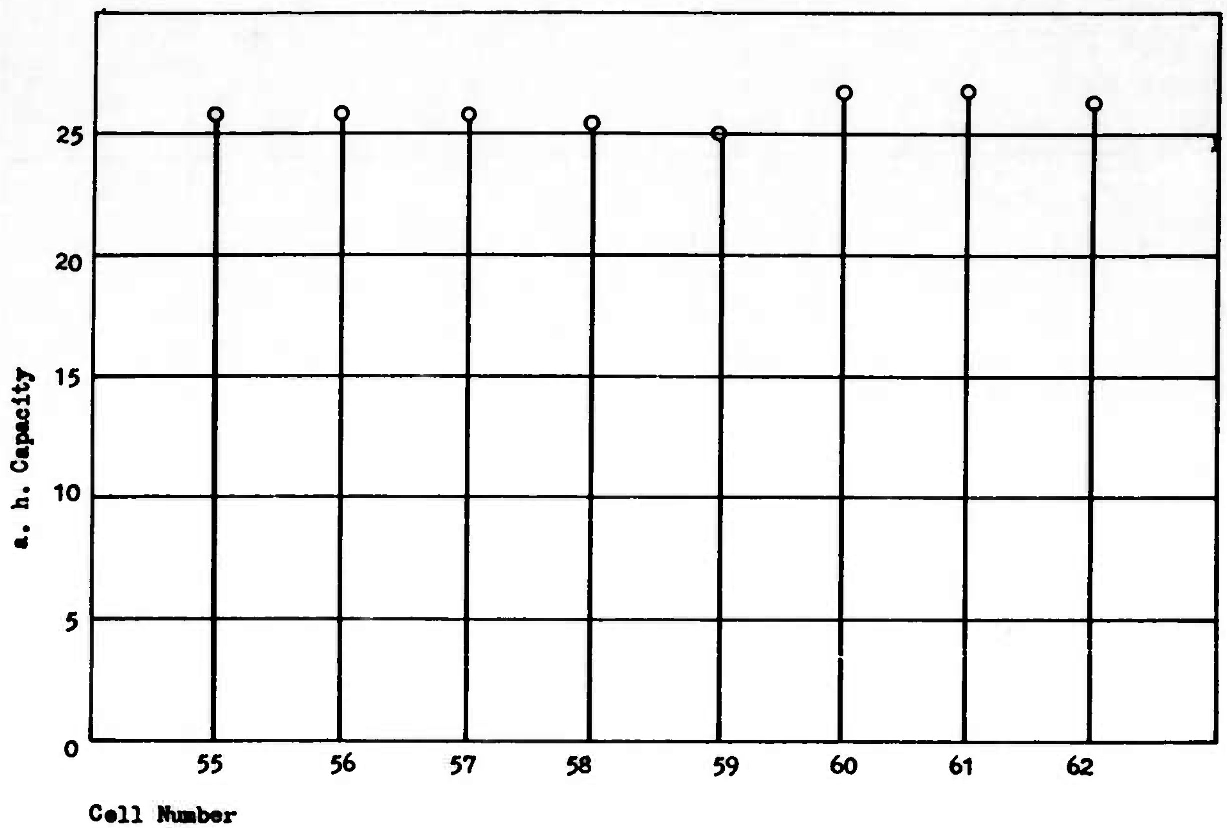


FIGURE 31

GROUP 3

AMPERE HOUR CAPACITY OF FIRST CYCLE FOR CELLS #55 THROUGH #62

DISCHARGE C = 9.0 AMP. TO 1.00 vpc

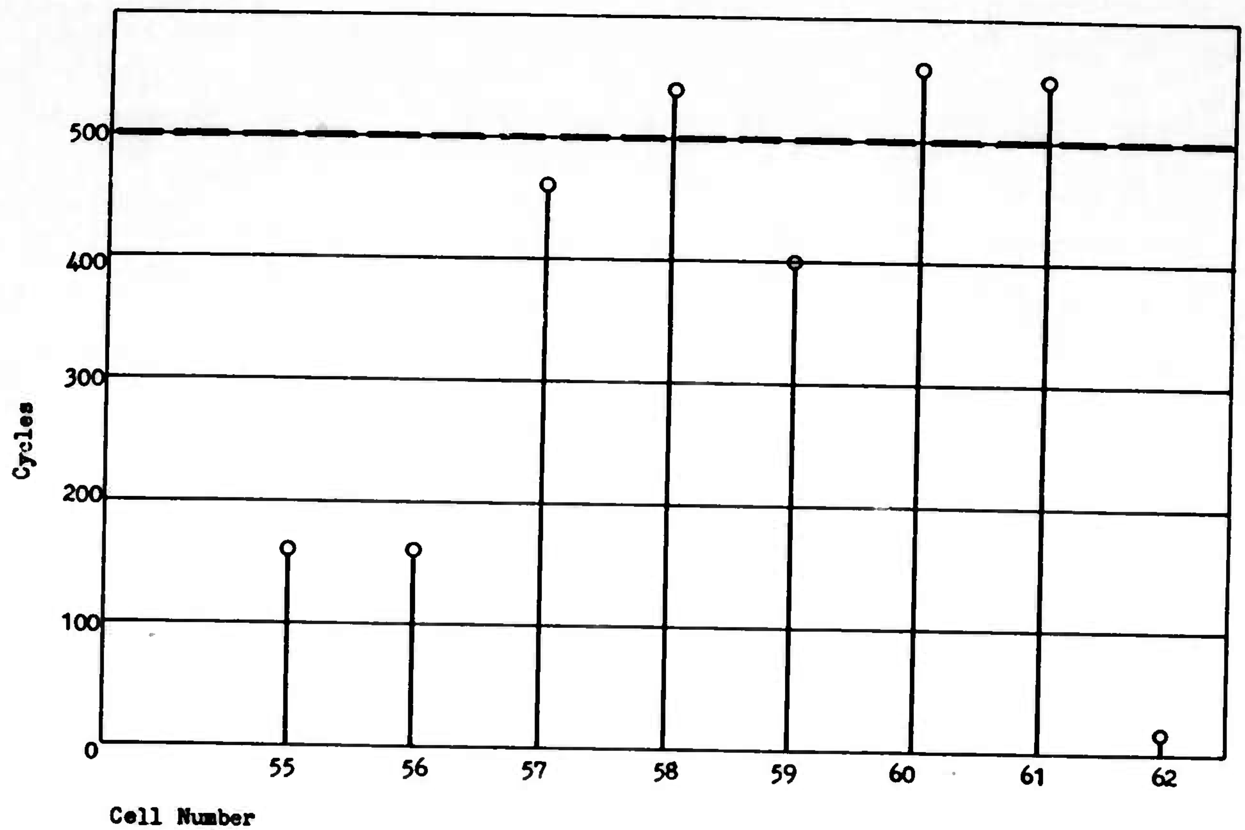


FIGURE 32

NUMBER OF CYCLES OBTAINED BY GROUP 3 CELLS

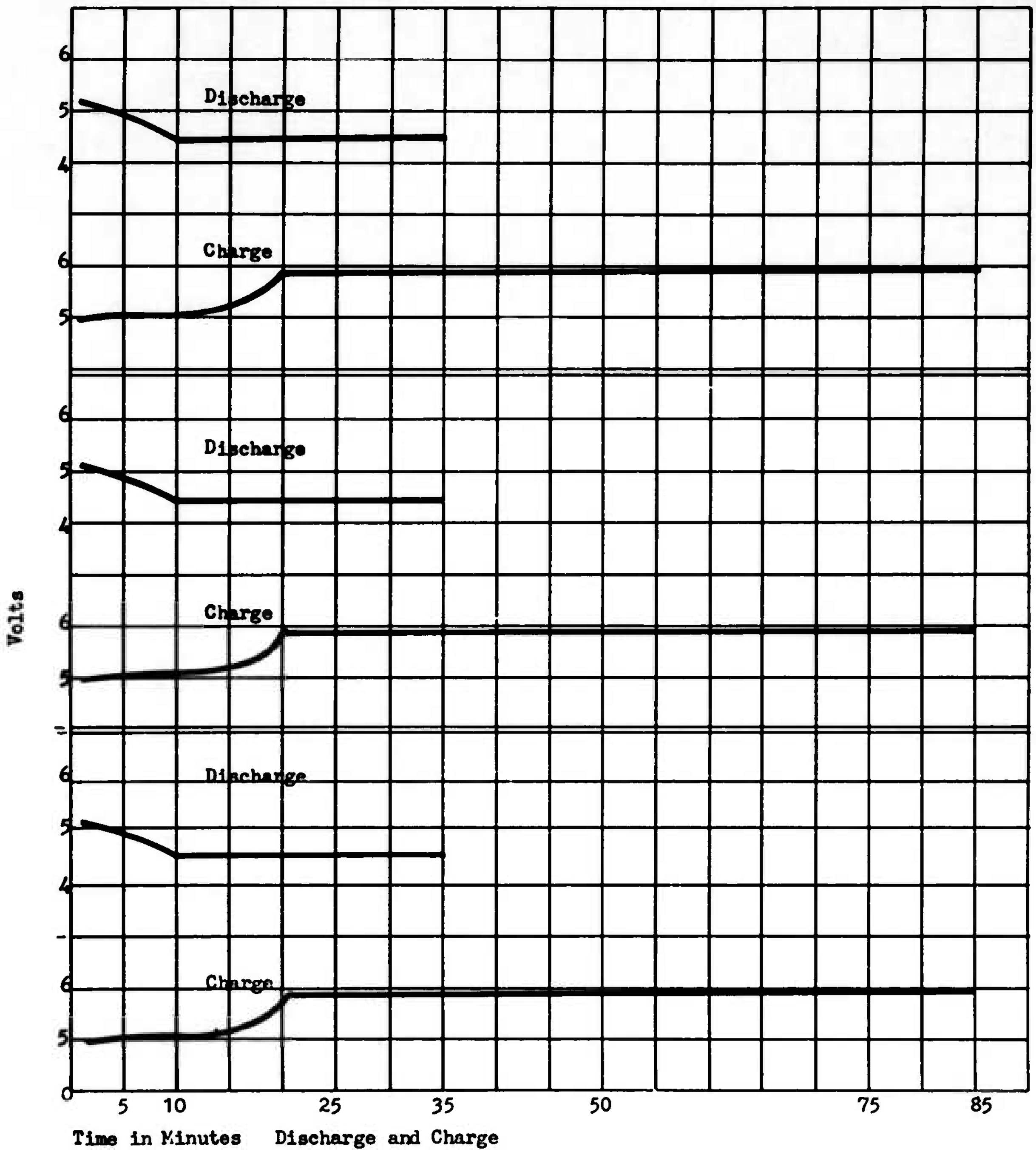


FIGURE 33

SEALED 3-CELL UNIT VIBRATION 3 CYCLES

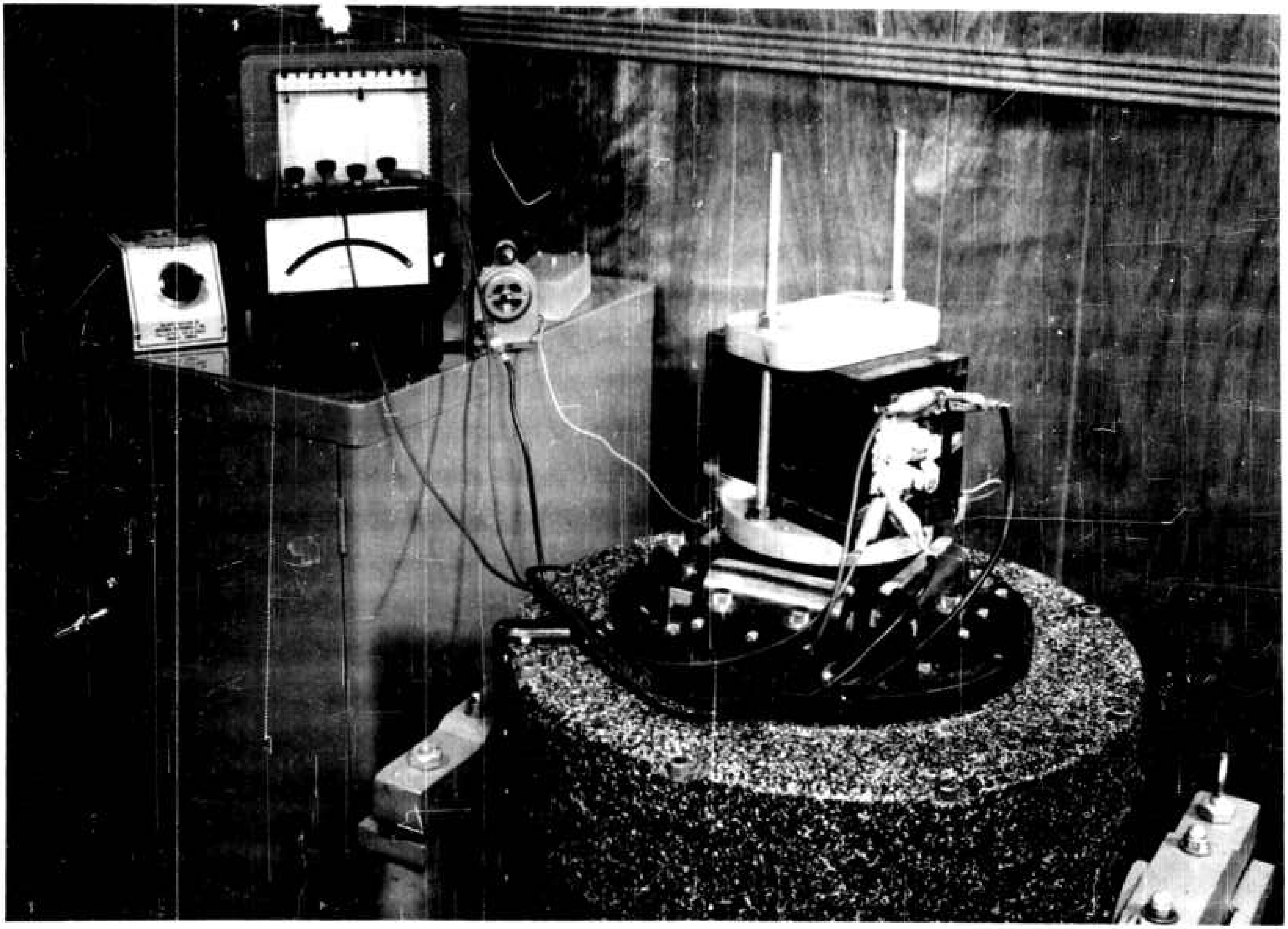


FIGURE 34

VIBRATION OF PLANE #1 OF 3-SEALED CELLS

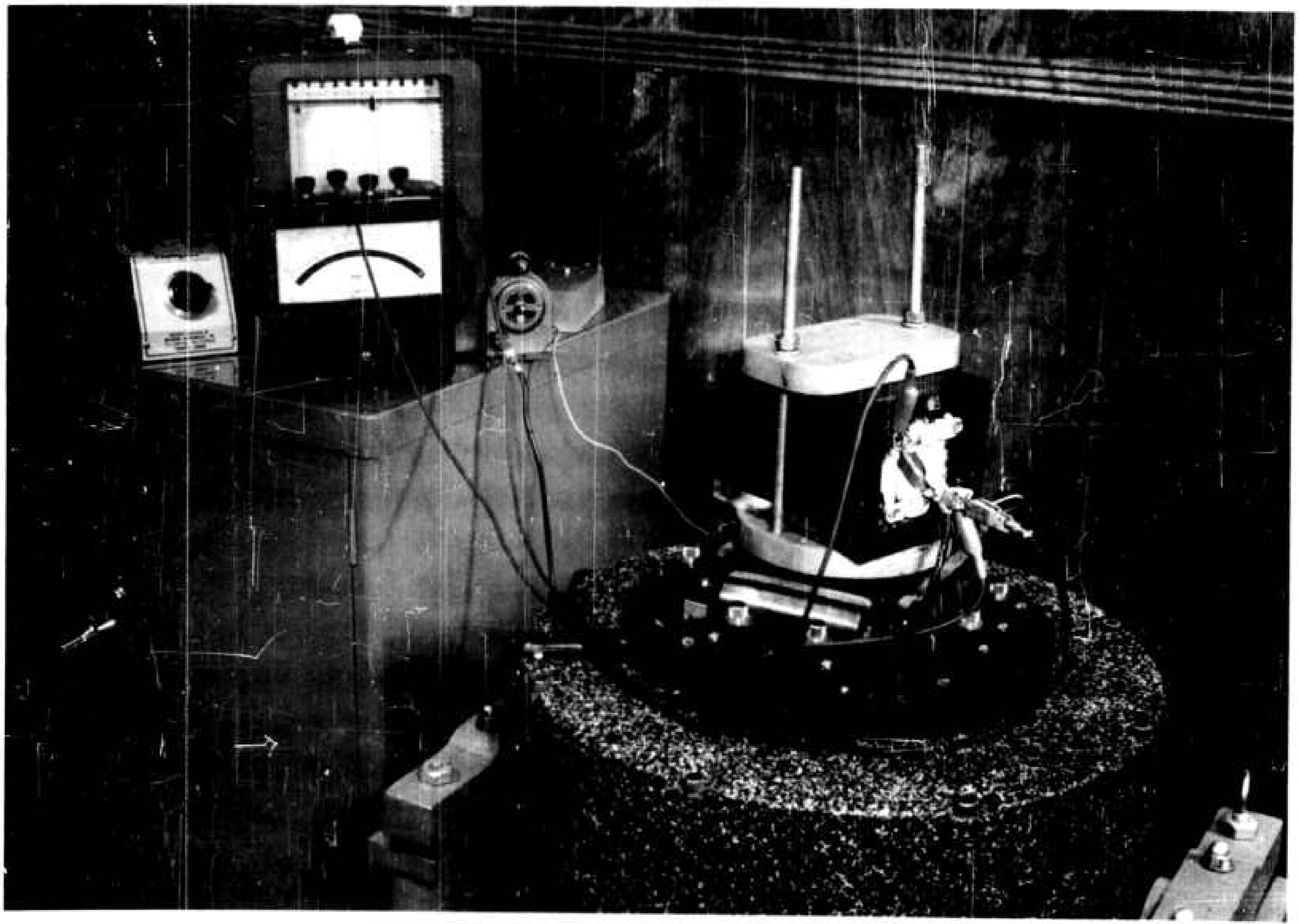


FIGURE 35

VIBRATION OF PLANE #2 OF 3-SEALED CELLS

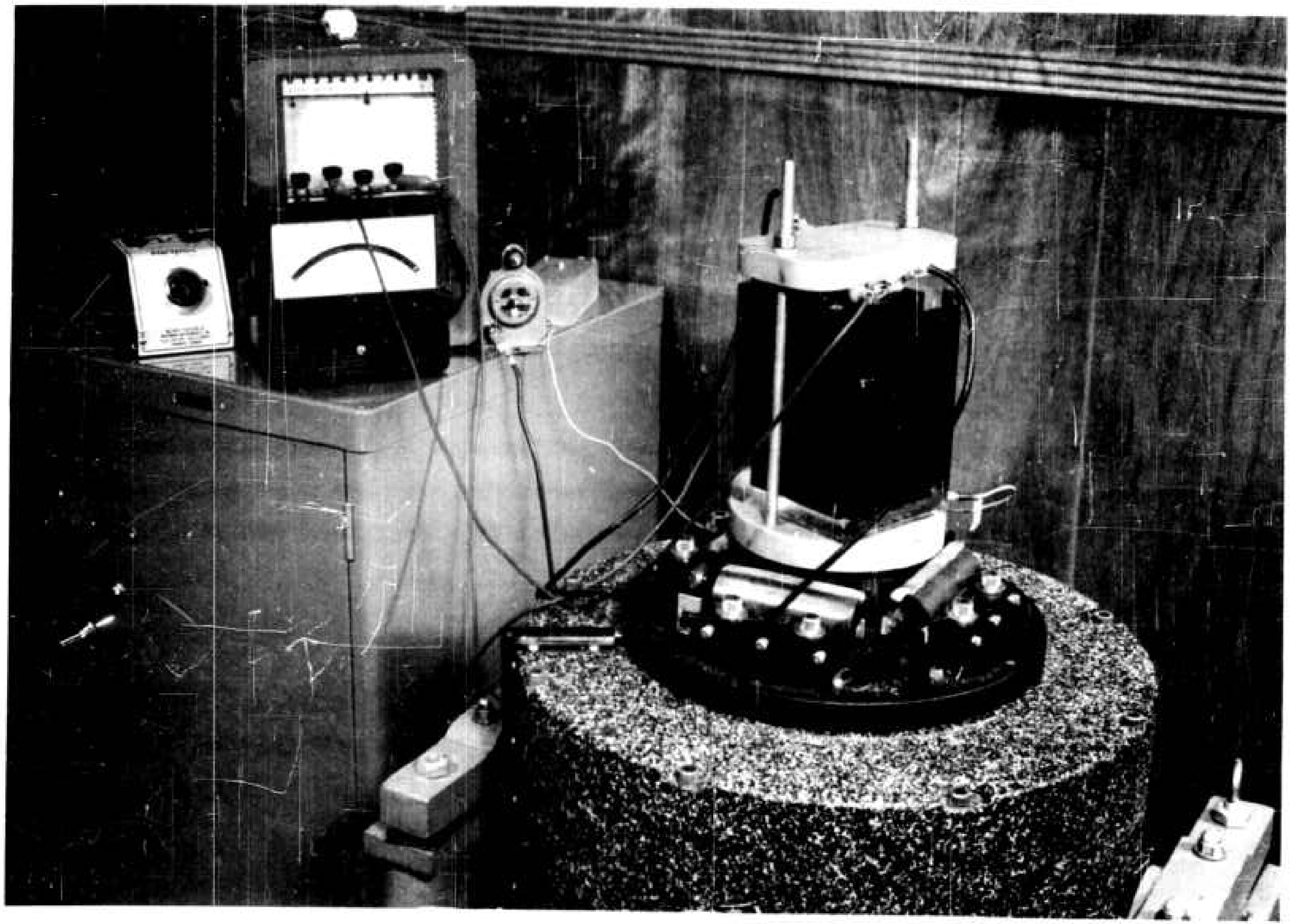


FIGURE 36

VIBRATION OF PLANE #3 OF 3-SEALED CELLS

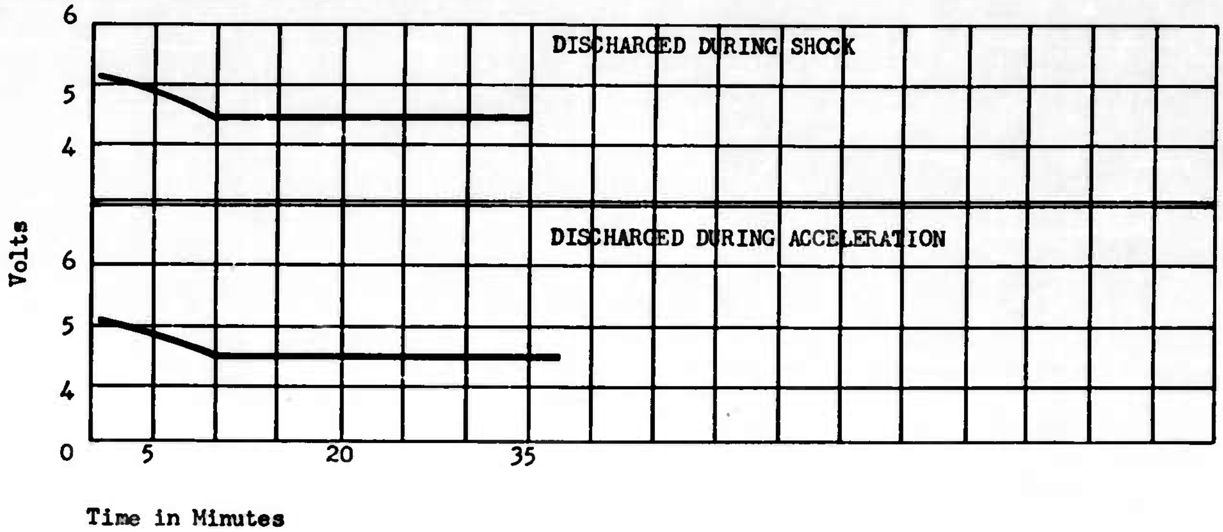


FIGURE 37

SEALED 3-CELL UNIT

DISCHARGED AS SHOWN

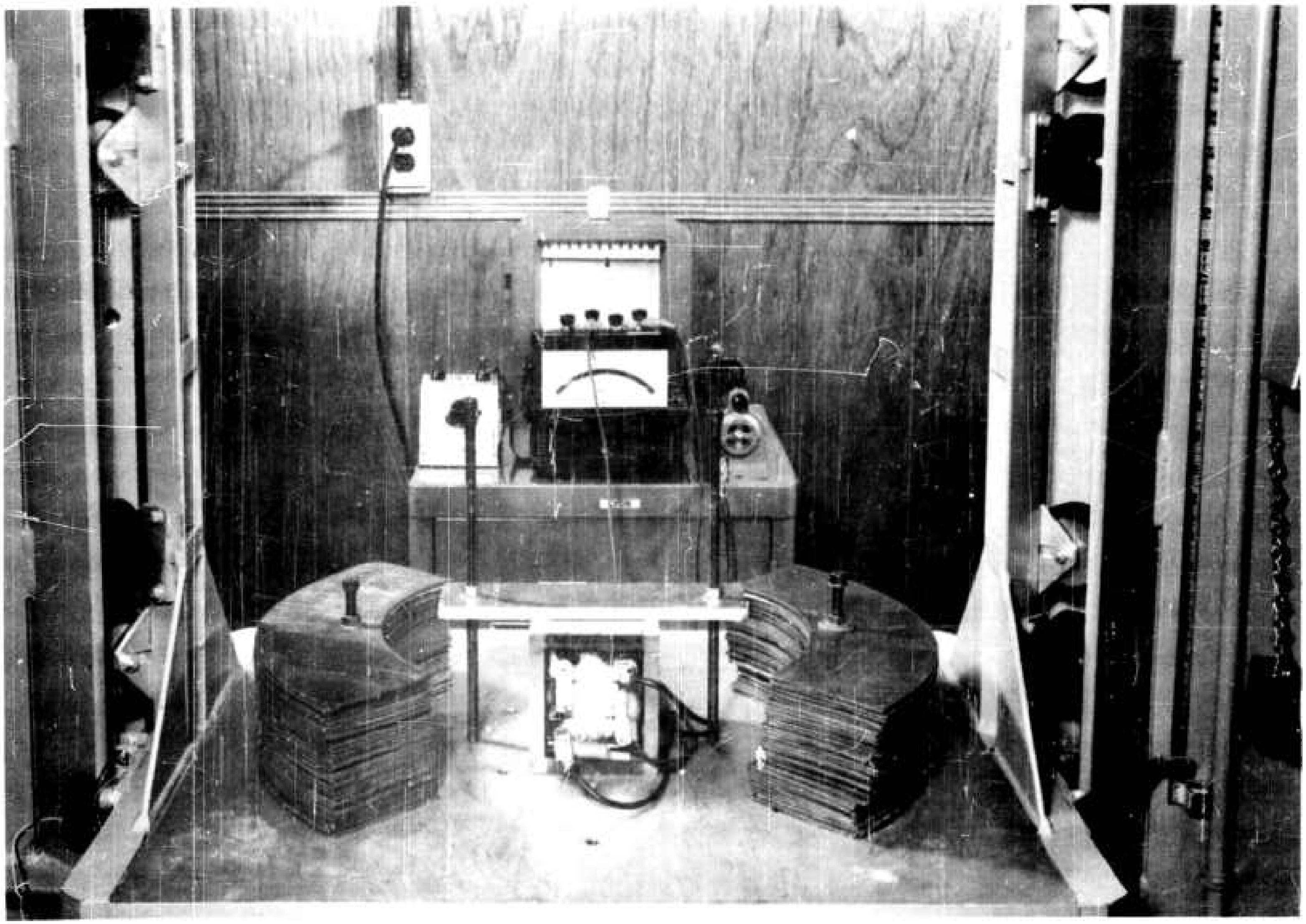


FIGURE 38

SHOCK OF PLANE #1 OF 3-SEALED CELLS

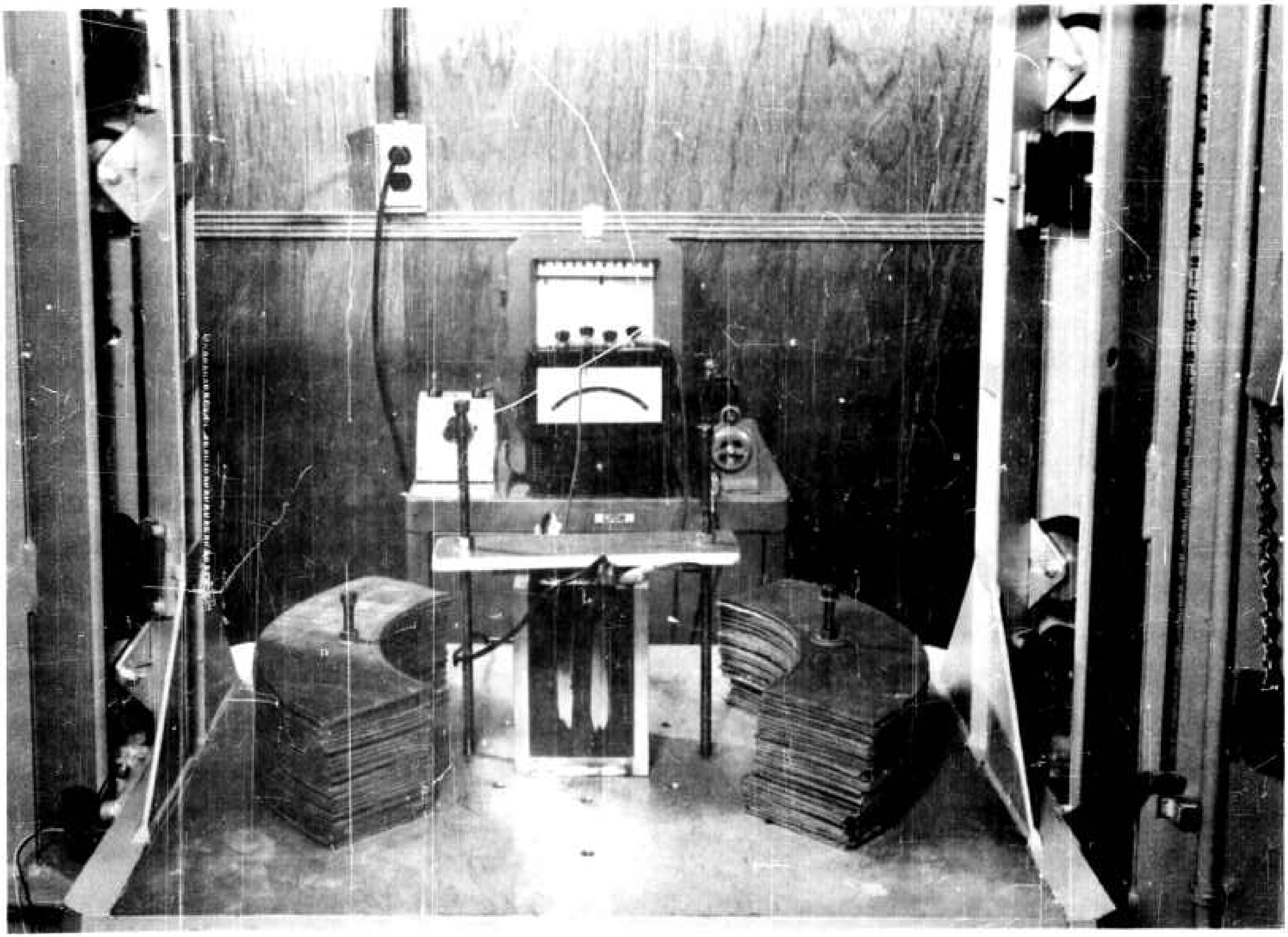


FIGURE 39

SHOCK OF PLANE #2 OF 3-SEALED CELLS

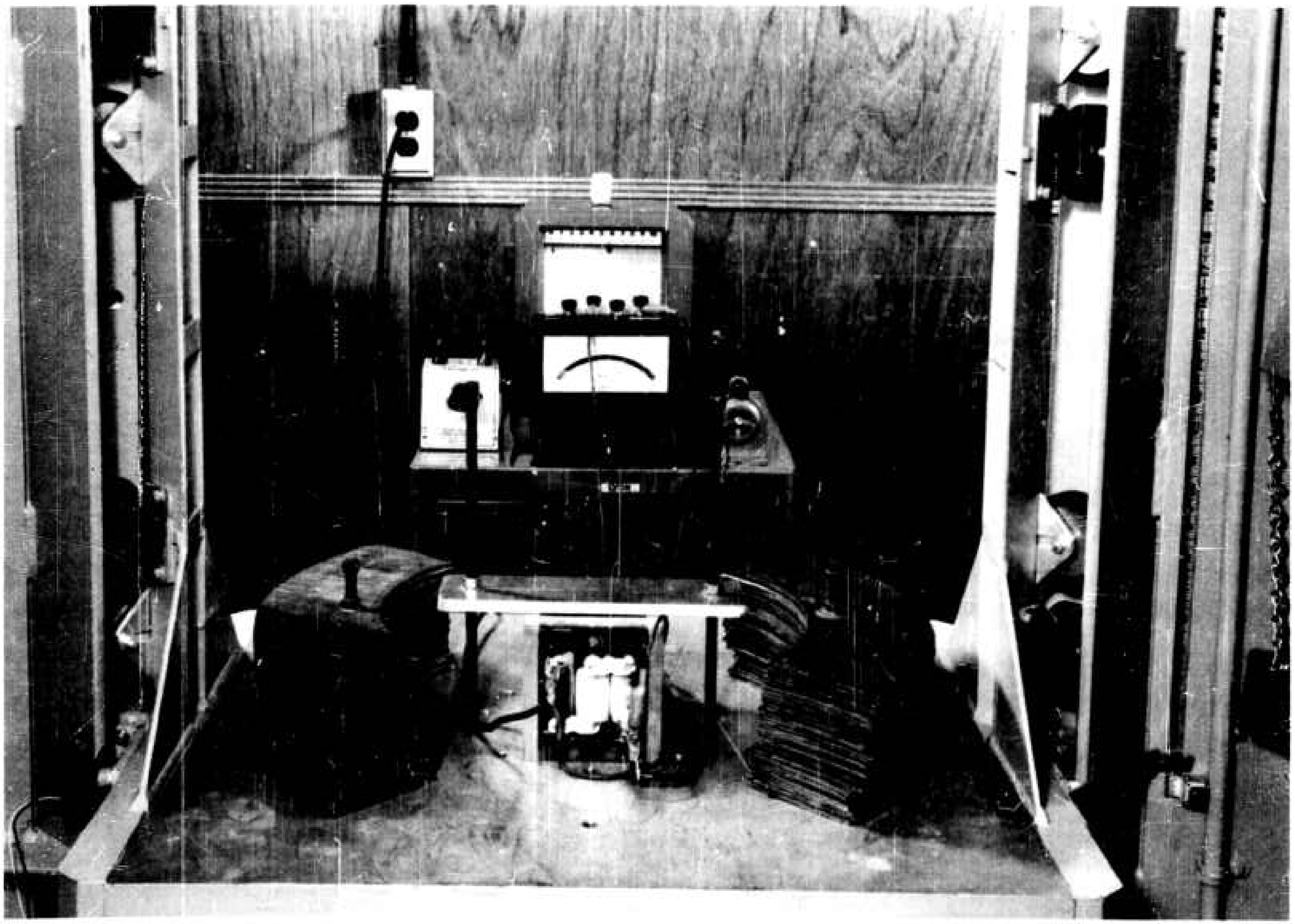


FIGURE 40

SHOCK OF PLANE #3 OF 3-SEALED CELLS

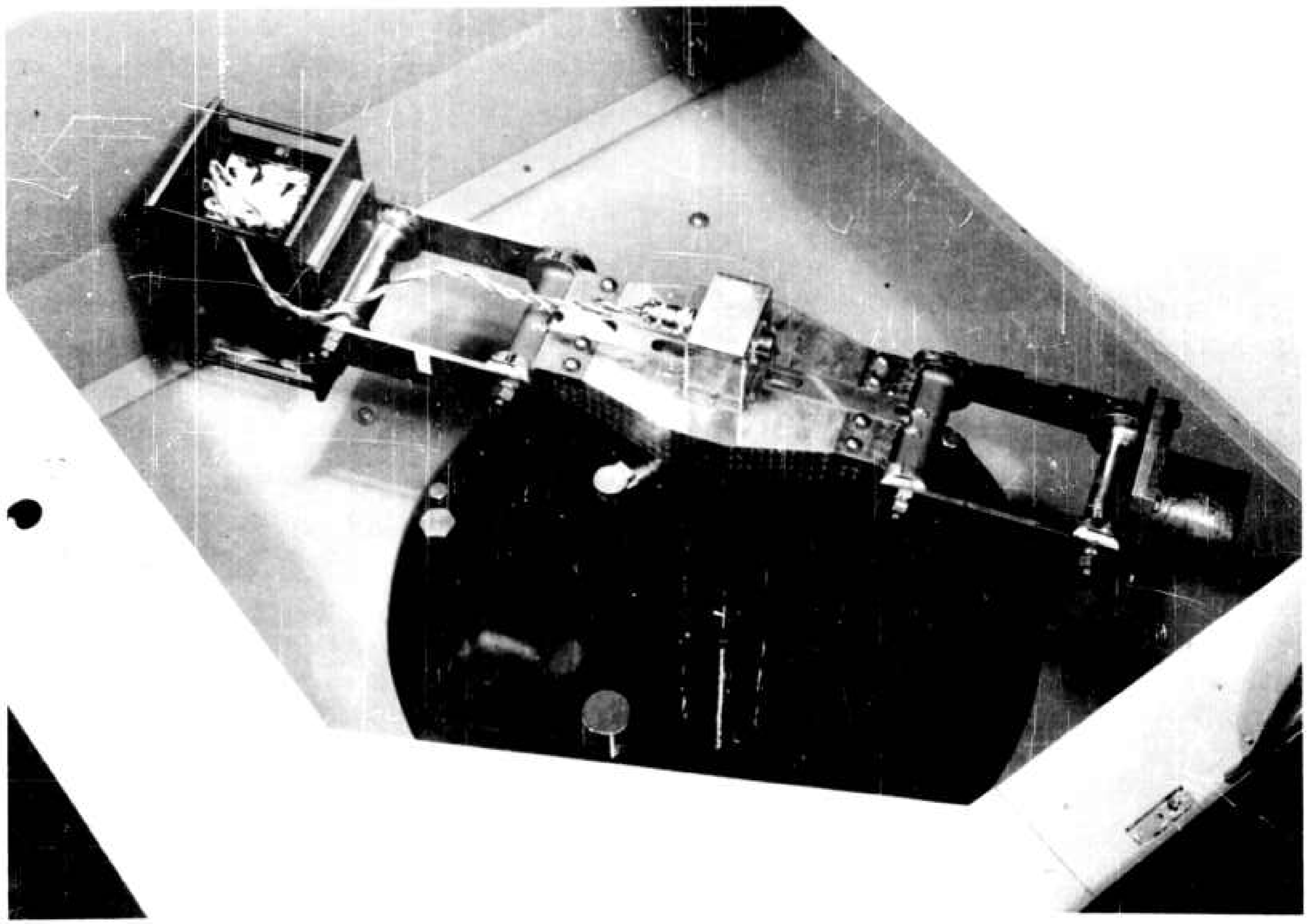


FIGURE 41

ACCELERATION IN PLANE #1 OF 3-SEALED CELLS

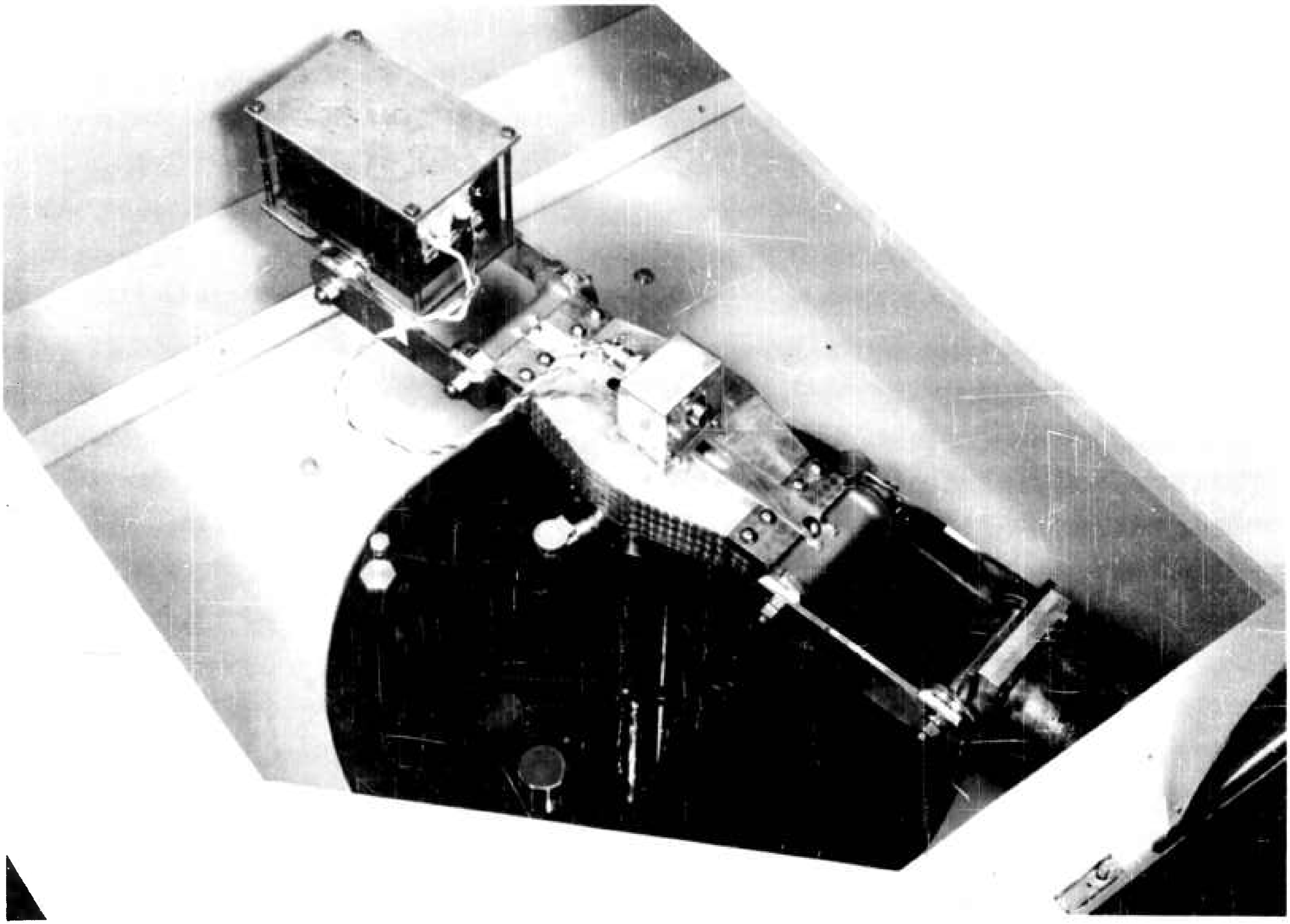


FIGURE 42

ACCELERATION OF PLANE #2 OF 3-SEALED CELLS

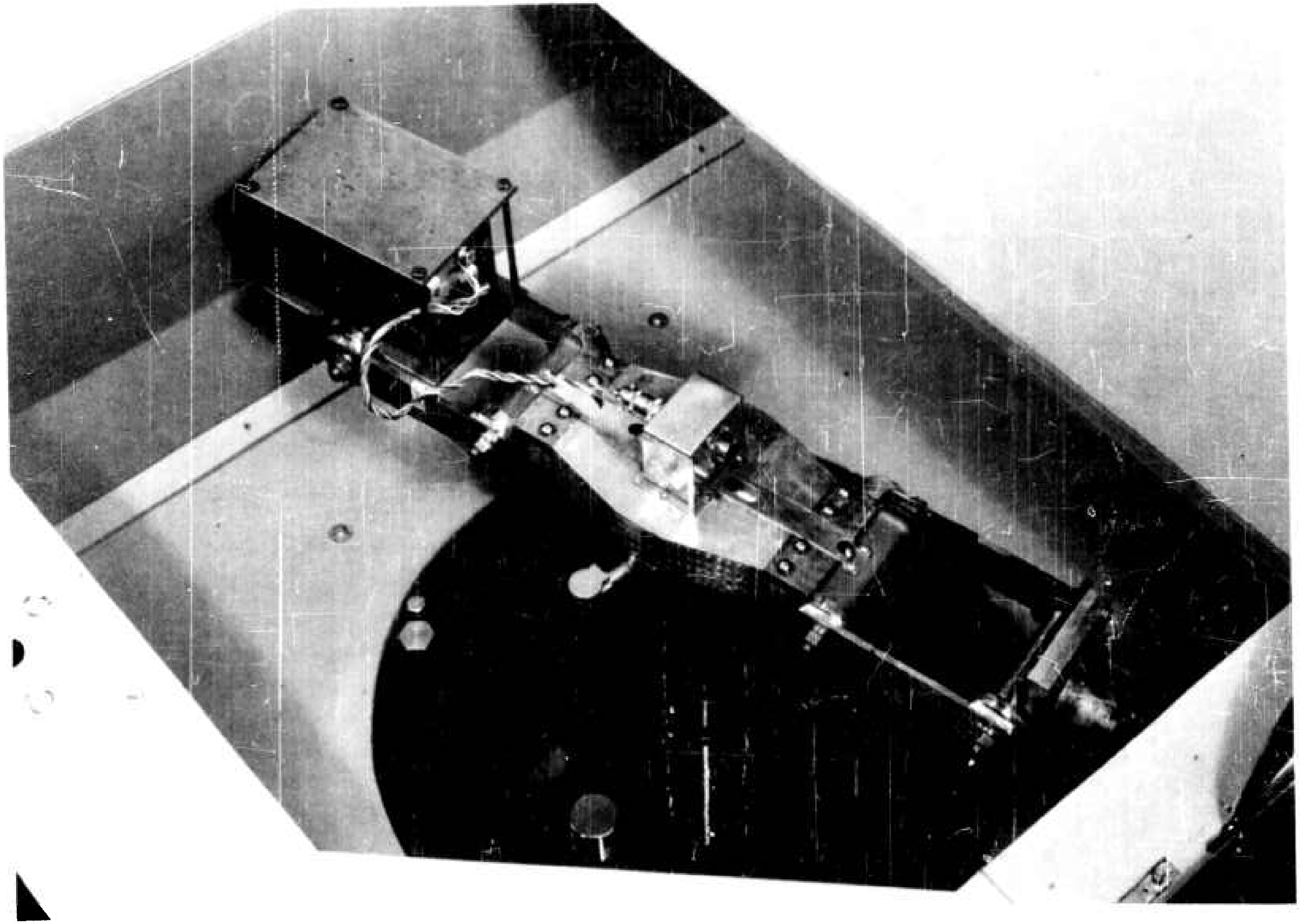


FIGURE 43
ACCELERATION OF PLANE #3 OF 3-SEALED CELLS

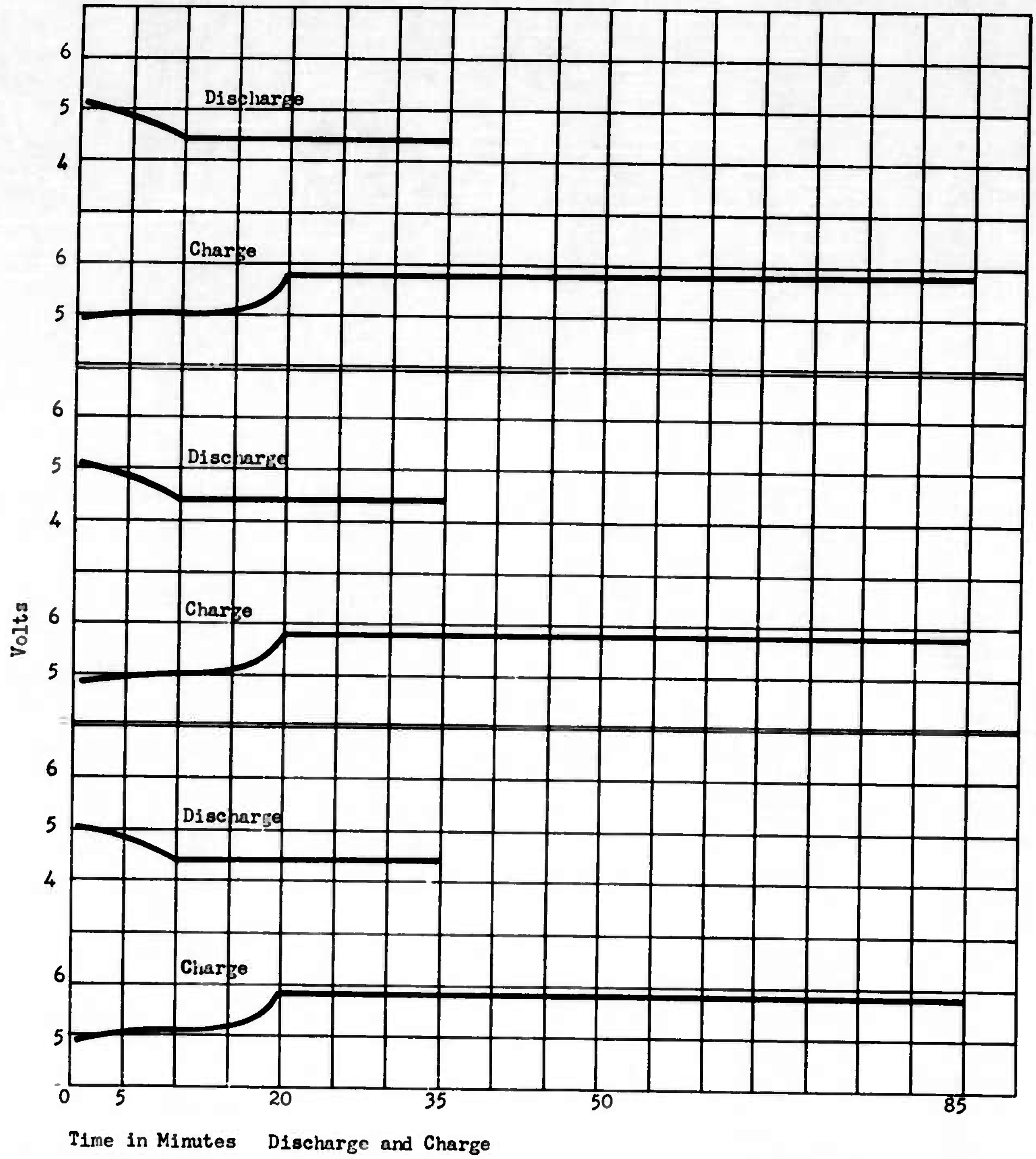


FIGURE 44

SEALED 3-CELL UNIT PRESSURE TEST 3 CYCLES

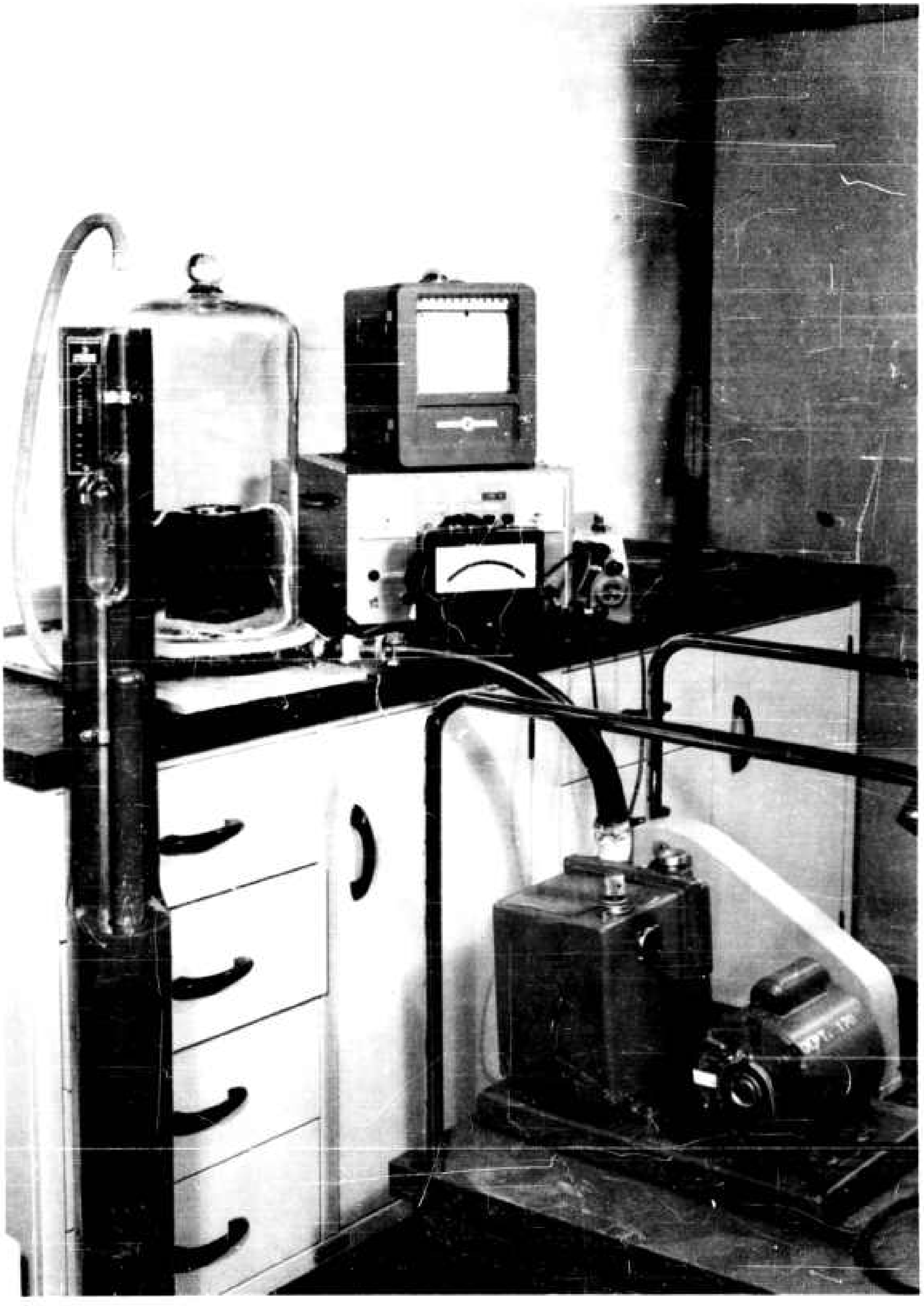


FIGURE 45

PRESSURE TEST OF 3-SEALED CELLS

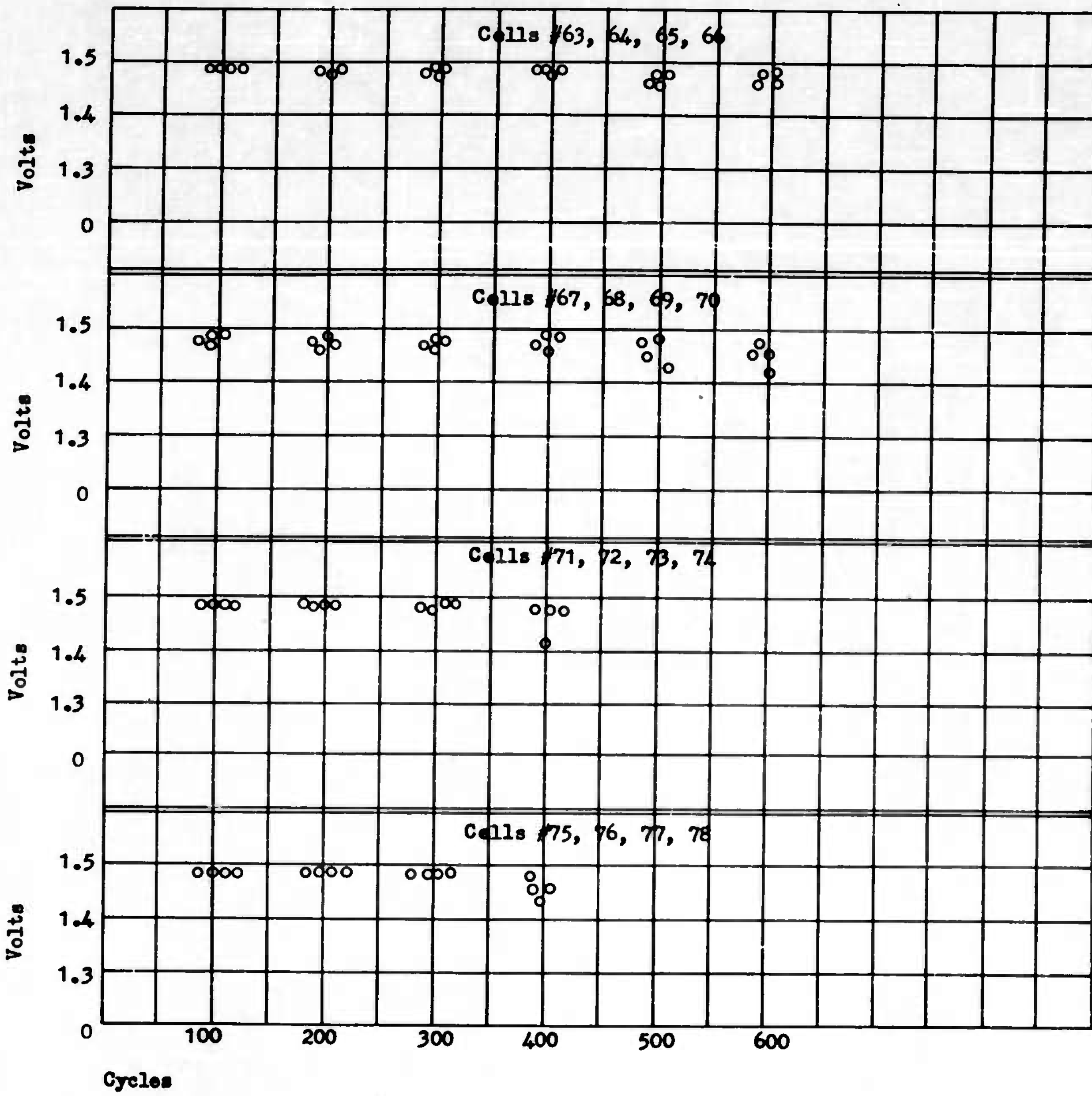


FIGURE 46

END OF DISCHARGE VOLTAGE FOR CELLS #63 THROUGH #78

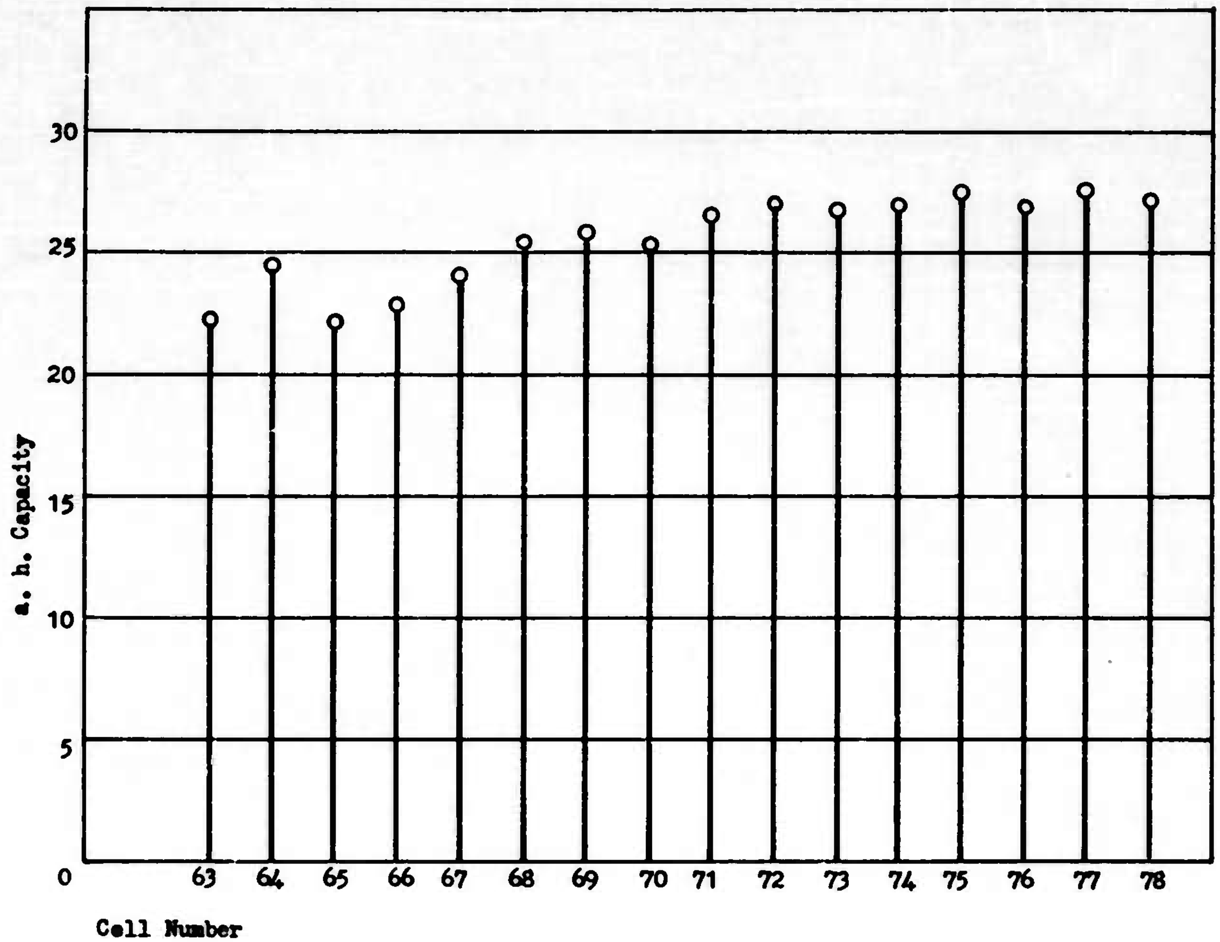


FIGURE 47

GROUP 4

AMPERE HOUR CAPACITY OF FIRST CYCLE FOR CELLS #63 THROUGH #78

DISCHARGE = 9.0 AMPS TO 1.00 vpc

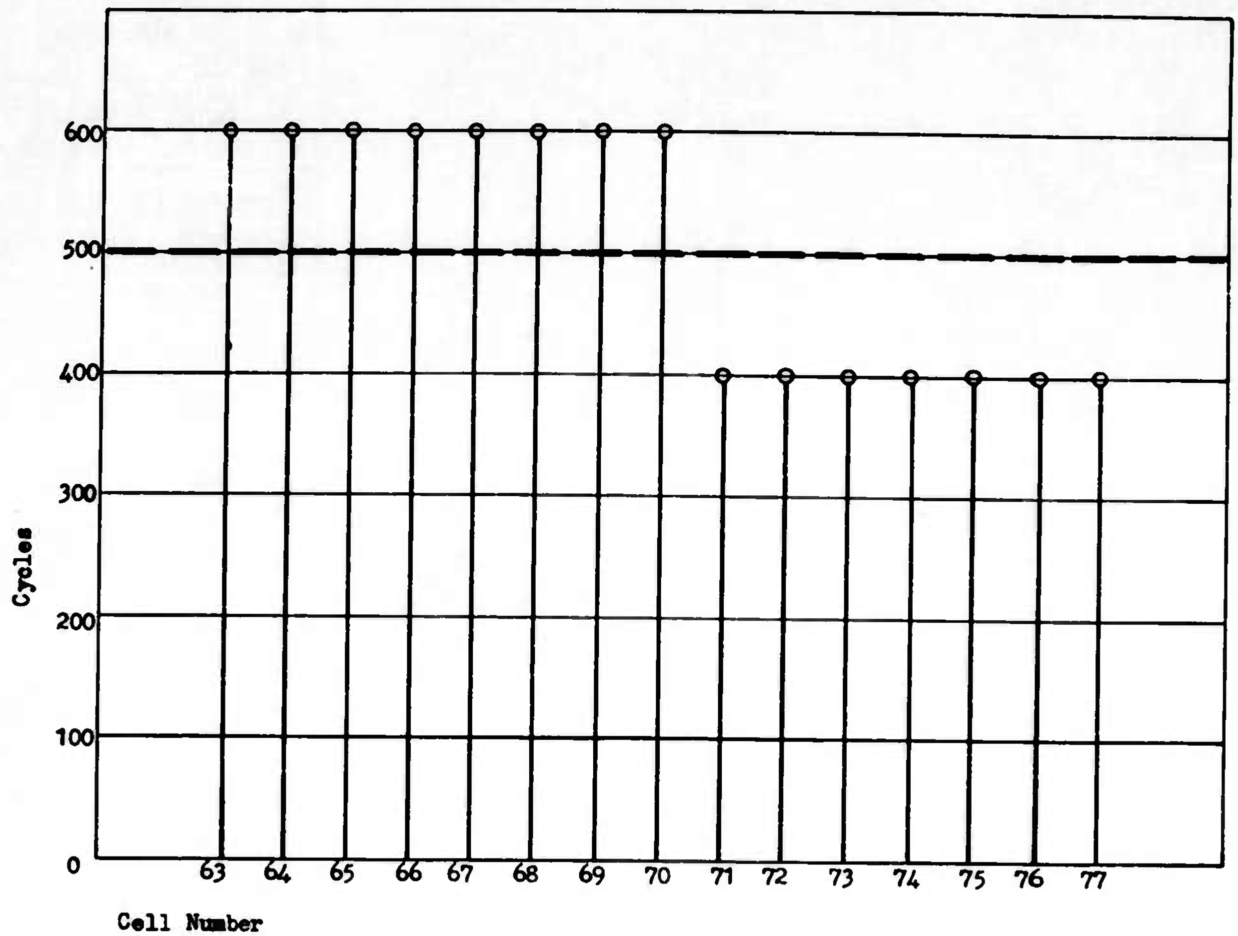


FIGURE 48

NUMBER OF CYCLES OBTAINED BY GROUP 4 CELLS

(THESE CELLS ARE STILL CYCLING)

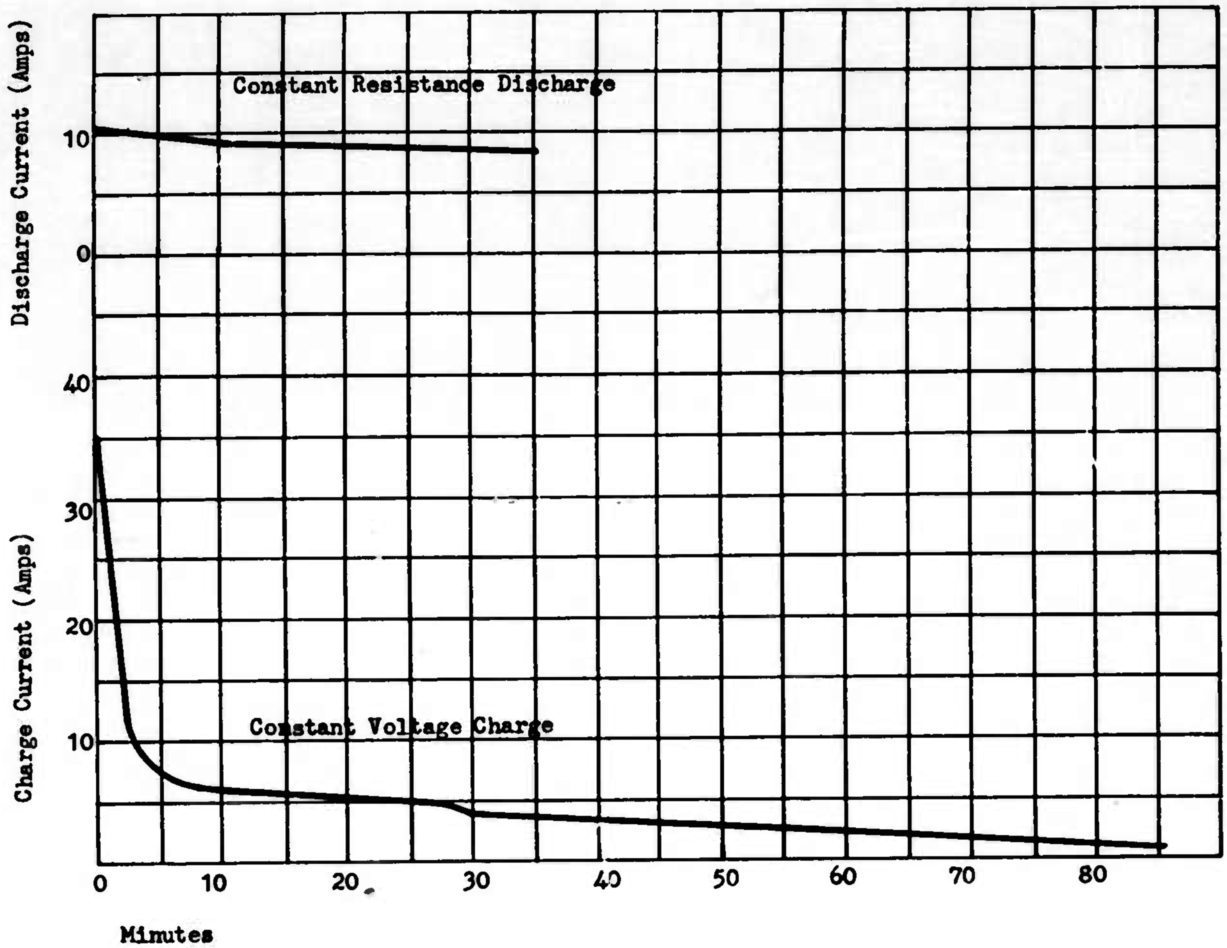


FIGURE 49

TYPICAL CHARGE AND DISCHARGE CURVE OF CURRENT FOR CELLS

IN GROUP 1, 2, 3, 4

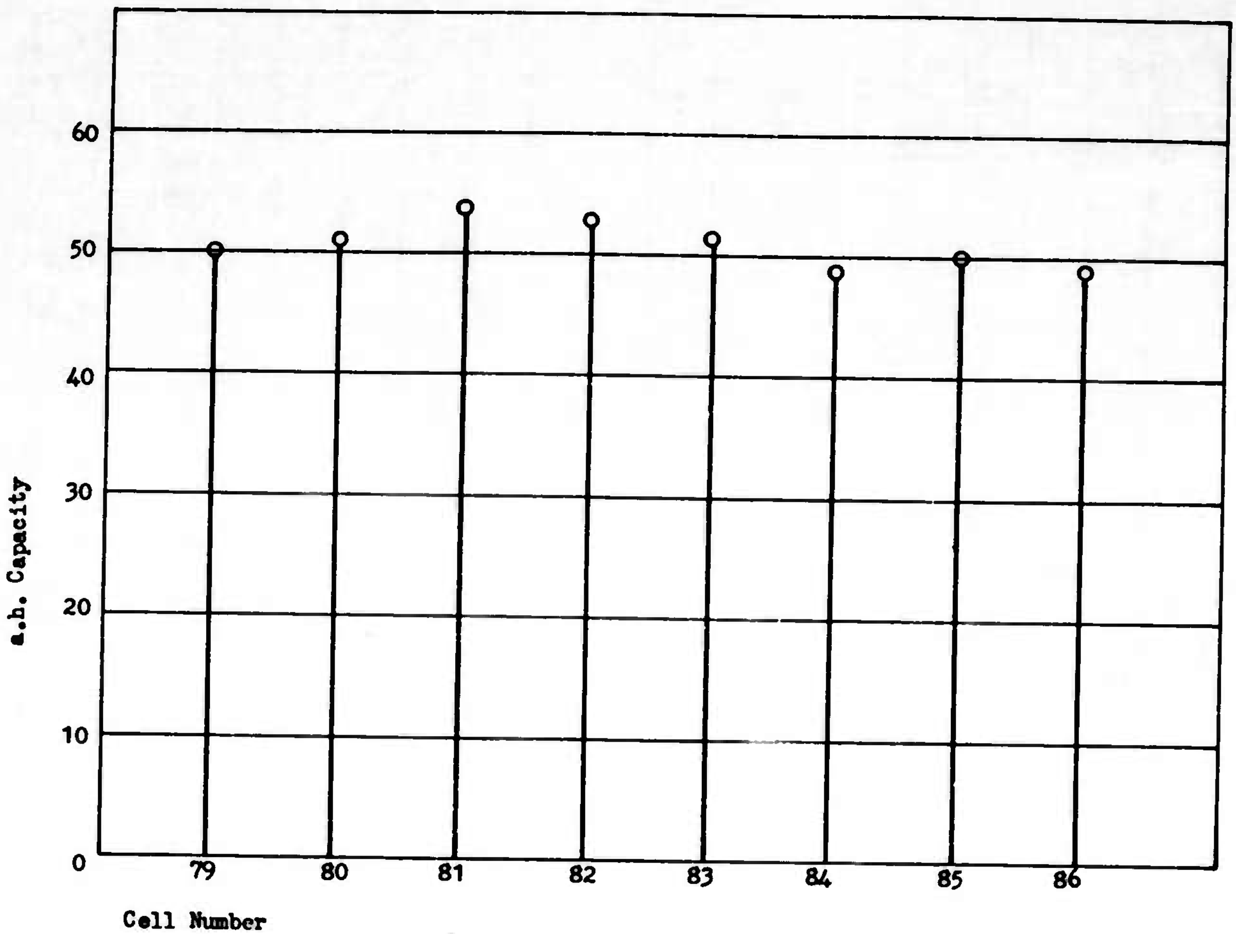


FIGURE 50

GROUP 5

AMPERE HOUR CAPACITY OF FIRST CYCLE DISCHARGE

Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio. Rpt No. ASD-TR-61-636. TEST REPORT ON SEALED SILVER OXIDE-ZINC SECONDARY CELLS. Feb 62, 85p. incl. illus; tables. Unclassified Report

Sixty-five AgO-Zn cells, constructed with hand-fabricated lucite containers and equipped with pressure gauges, were used to determine cycle life. Various combinations of separators and negative plate additives were used. Maximum cycle life obtained from one separator combination, tested at three temperature ranges and

(over)

1. Storage batteries
2. Electrochemical cells

I. AFSC project 3145, Task 314510

II. Contract AF33(600)-41600

III. Delco-Remy, Div. of Gen. Motors Corp., Anderson, Indiana

IV. J. A. Keralla

V. In ASTIA collection

VI. Aval fr OTS

three depths of discharge, was 1760 cycles at 21% depth of discharge at room temperature.

Three cells with molded nylon containers and covers and with metal terminal-to-plastic seals passed the environmental tests.

A projected battery energy-to-weight ratio utilizing 8 cells, employing best design parameters and activated in lucite jars, is about 8-watt hours per pound for 2-hour cycle.

Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio. Rpt No. ASD-TR-61-636. TEST REPORT ON SEALED SILVER OXIDE-ZINC SECONDARY CELLS. Feb 62, 85p. incl. illus; tables. Unclassified Report

Sixty-five AgO-Zn cells, constructed with hand-fabricated lucite containers and equipped with pressure gauges, were used to determine cycle life. Various combinations of separators and negative plate additives were used. Maximum cycle life obtained from one separator combination, tested at three temperature ranges and

(over)

1. Storage batteries
2. Electrochemical cells

I. AFSC project 3145, Task 314510

II. Contract AF33(600)-41600

III. Delco-Remy, Div. of Gen. Motors Corp., Anderson, Indiana

IV. J. A. Keralla

V. In ASTIA collection

VI. Aval fr OTS

three depths of discharge, was 1760 cycles at 21% depth of discharge at room temperature.

Three cells with molded nylon containers and covers and with metal terminal-to-plastic seals passed the environmental tests.

A projected battery energy-to-weight ratio utilizing 8 cells, employing best design parameters and activated in lucite jars, is about 8-watt hours per pound for 2-hour cycle.

Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio. Rpt No. ASD-TR-61-636. TEST REPORT ON SEALED SILVER OXIDE-ZINC SECONDARY CELLS. Feb 62, 85p. incl. illus; tables.

Unclassified Report

Sixty-five AgO-Zn cells, constructed with hand-fabricated lucite containers and equipped with pressure gauges, were used to determine cycle life. Various combinations of separators and negative plate additives were used. Maximum cycle life obtained from one separator combination, tested at three temperature ranges and

(over)

three depths of discharge, was 1760 cycles at 21% depth of discharge at room temperature.

Three cells with molded nylon containers and covers and with metal terminal-to-plastic seals passed the environmental tests.

A projected battery energy-to-weight ratio utilizing 8 cells, employing best design parameters and activated in lucite jars, is about 8-watt hours per pound for 2-hour cycle.

1. Storage batteries
2. Electrochemical cells

I. AFSC project 3145, Task 314510

II. Contract AF33(600)-41600

III. Delco-Remy, Div. of Gen. Motors Corp., Anderson, Indiana

IV. J. A. Keralla

V. In ASTIA collection

VI. Aval fr OTS

Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio. Rpt No. ASD-TR-61-636. TEST REPORT ON SEALED SILVER OXIDE-ZINC SECONDARY CELLS. Feb 62, 85p. incl. illus; tables.

Unclassified Report

Sixty-five AgO-Zn cells, constructed with hand-fabricated lucite containers and equipped with pressure gauges, were used to determine cycle life. Various combinations of separators and negative plate additives were used. Maximum cycle life obtained from one separator combination, tested at three temperature ranges and

(over)

three depths of discharge, was 1760 cycles at 21% depth of discharge at room temperature.

Three cells with molded nylon containers and covers and with metal terminal-to-plastic seals passed the environmental tests.

A projected battery energy-to-weight ratio utilizing 8 cells, employing best design parameters and activated in lucite jars, is about 8-watt hours per pound for 2-hour cycle.

1. Storage batteries
2. Electrochemical cells

I. AFSC project 3145, Task 314510

II. Contract AF33(600)-41600

III. Delco-Remy, Div. of Gen. Motors Corp., Anderson, Indiana

IV. J. A. Keralla

V. In ASTIA collection

VI. Aval fr OTS

Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio. Rpt No. ASD-TR-61-636. TEST REPORT ON SEALED SILVER OXIDE-ZINC SECONDARY CELLS. Feb 62, 85p. incl. illus; tables. Unclassified Report

Sixty-five AgO-Zn cells, constructed with hand-fabricated lucite containers and equipped with pressure gauges, were used to determine cycle life. Various combinations of separators and negative plate additives were used. Maximum cycle life obtained from one separator combination, tested at three temperature ranges and

(over)

1. Storage batteries
2. Electrochemical cells

I. AFSC project 3145, Task 314510

II. Contract AF33(600)-41600

III. Delco-Remy, Div. of Gen. Motors Corp., Anderson, Indiana

IV. J. A. Keralla

V. In ASTIA collection

VI. Aval fr OTS

three depths of discharge, was 1760 cycles at 21% depth of discharge at room temperature.

Three cells with molded nylon containers and covers and with metal terminal-to-plastic seals passed the environmental tests.

A projected battery energy-to-weight ratio utilizing 8 cells, employing best design parameters and activated in lucite jars, is about 8-watt hours per pound for 2-hour cycle.

Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio. Rpt No. ASD-TR-61-636. TEST REPORT ON SEALED SILVER OXIDE-ZINC SECONDARY CELLS. Feb 62, 85p. incl. illus; tables. Unclassified Report

Sixty-five AgO-Zn cells, constructed with hand-fabricated lucite containers and equipped with pressure gauges, were used to determine cycle life. Various combinations of separators and negative plate additives were used. Maximum cycle life obtained from one separator combination, tested at three temperature ranges and

(over)

1. Storage batteries
2. Electrochemical cells

I. AFSC project 3145, Task 314510

II. Contract AF33(600)-41600

III. Delco-Remy, Div. of Gen. Motors Corp., Anderson, Indiana

IV. J. A. Keralla

V. In ASTIA collection

VI. Aval fr OTS

three depths of discharge, was 1760 cycles at 21% depth of discharge at room temperature.

Three cells with molded nylon containers and covers and with metal terminal-to-plastic seals passed the environmental tests.

A projected battery energy-to-weight ratio utilizing 8 cells, employing best design parameters and activated in lucite jars, is about 8-watt hours per pound for 2-hour cycle.

Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio. Rpt No. ASD-TR-61-636. TEST REPORT ON SEALED SILVER OXIDE-ZINC SECONDARY CELLS. Feb 62, 85p. incl. illus; tables. Unclassified Report

Sixty-five AgO-Zn cells, constructed with hand-fabricated lucite containers and equipped with pressure gauges, were used to determine cycle life. Various combinations of separators and negative plate additives were used. Maximum cycle life obtained from one separator combination, tested at three temperature ranges and

(over)

1. Storage batteries
2. Electrochemical cells

I. AFSC project 3145, Task 314510

II. Contract AF33(600)-41600

III. Delco-Remy, Div. of Gen. Motors Corp., Anderson, Indiana

IV. J. A. Keralla

V. In ASTIA collection

VI. Aval fr OTS

three depths of discharge, was 1760 cycles at 21% depth of discharge at room temperature.

Three cells with molded nylon containers and covers and with metal terminal-to-plastic seals passed the environmental tests.

A projected battery energy-to-weight ratio utilizing 8 cells, employing best design parameters and activated in lucite jars, is about 8-watt hours per pound for 2-hour cycle.

Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio. Rpt No. ASD-TR-61-636. TEST REPORT ON SEALED SILVER OXIDE-ZINC SECONDARY CELLS. Feb 62, 85p. incl. i'lus; tables. Unclassified Report

Sixty-five AgO-Zn cells, constructed with hand-fabricated lucite containers and equipped with pressure gauges, were used to determine cycle life. Various combinations of separators and negative plate additives were used. Maximum cycle life obtained from one separator combination, tested at three temperature ranges and

(over)

1. Storage batteries
2. Electrochemical cells

I. AFSC project 3145, Task 314510

II. Contract AF33(600)-41600

III. Delco-Remy, Div. of Gen. Motors Corp., Anderson, Indiana

IV. J. A. Keralla

V. In ASTIA collection

VI. Aval fr OTS

three depths of discharge, was 1760 cycles at 21% depth of discharge at room temperature.

Three cells with molded nylon containers and covers and with metal terminal-to-plastic seals passed the environmental tests.

A projected battery energy-to-weight ratio utilizing 8 cells, employing best design parameters and activated in lucite jars, is about 8-watt hours per pound for 2-hour cycle.