(NASA-CR-134591) DEVELOPMENT AND FABRICATION OF SEALED SILVER-ZINC CELLS, PHASE 1 Final Report (Yardney Electric Corp., Pawcatuck, Conn.)
CSCL 10C G3/03
N74-17791
Unclas
31665

NASA CR-134591

DEVELOPMENT AND FABRICATION OF SEALED SILVER-ZINC CELLS

by I. C. Blake and C. Philip Donnel III

YARDNEY ELECTRIC DIVISION

YARDNEY ELECTRIC CORPORATION

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA Lewis Research Center

Contract NAS 3-16805

Phase I Final Report

December 1973

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1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
CR-134591		

4. Title and Subtitle DEVELOPMENT AND FABRICATION OF SEALED SILVER-ZINC CELLS	5. Report Date December 19, 1973
	6. Performing Organization Code
7. Author(s) Ivan C. Blake and C. Philip Donnel III, Yardney Electric Division, Pawcatuck, Conn.	8. Performing Organization Report No.
	10. Work Unit No.
9. Performing Organization Name and Address Yardney Electric Division Yardney Electric Corporation Pawcatuck, Connecticut 02891	11. Contract or Grant No. NAS 3-16805
	13. Type of Report and Period Covered Contractor Report
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration NASA Lewis Research Center 21000 Brookpark Road, Cleveland, Ohio 44135	14. Sponsoring Agency Code

15. Supplementary Notes

Project Manager, William A. Robertson, Energy Conversion & Materials Science Div., NASA Lewis Research Center, Cleveland, Ohio

16. Abstract

A facility was designed, constructed and equipped for the production of prismatic alkaline rechargeable battery cells. This 280 square meter facility is particularly applicable to production of high reliability Sealed Silver-Zinc rechargeable battery cells using inorganic (ceramic) separators.

This unique facility is environmentally controlled and contains separate areas for electrode fabrication, separator processing, cell assembly, cell finishing and testing. Alkaline battery cells are fabricated under carefully controlled conditions using quality assurance systems incorporating 100% traceability and 100% inspection philosophies. As an example of production capability, the facility can produce, on a one shift basis, 60,000 ampere-hours per year equivalent of Sealed Silver-Zinc rechargeable cells using inorganic separators in unit cell sizes ranging from 5 to 80 ampere-hours.

An initial production run of 125 Sealed Silver-Zinc Cells, (Model HS40-7), using inorganic separators, was made in the facility in order to provide samples for base-line performance tests. Ten (10) of these cells were given performance-characterization tests and life cycle tests. The remaining cells were delivered to NASA Lewis Research Center.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Battery Separator Silver-Zinc Battery Cell Sealed Battery Cell Inorganic Battery Separator Ceramic Battery Separator	Unclassified - Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)
Unclassified	Unclassified

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NASA-C-168 (Rev. 6-71)

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SUMMARY

A production facility, 280 square meters in area, was designed, constructed and equipped for the fabrication of high reliability prismatic, alkaline rechargeable battery cells. The facility contains separate areas for positive electrode fabrication, negative electrode fabrication, separator processing, cell assembly, cell finishing and cell testing. Specialized equipment was installed for fabrication and processing of semi-flexible inorganic separators using ceramic materials and proprietary technology supplied by NASA Lewis Research Center. An expansive reliability and quality assurance system, emphasizing 100% inspection and complete material, process and operator traceability, was developed and documented to monitor this unique facility and its fabrication techniques. This facility is capable of supporting, on a one shift basis, the fabrication of a minimum of 60,000 amperehours per year equivalent capacity of Sealed Silver-Zinc rechargeable cells using inorganic separators in unit cell sizes ranging from 5 to 80 amperehours.

The facility was first used to fabricate an initial production run of one hundred twenty-five (125) Type HS40-7 Sealed Silver-Zinc Battery Cells using inorganic separators to provide samples for base-line performance testing. All cells were given two (2) conditioning and formation cycles. The average capacity of the 125 cells on the second cycle discharge was 42.2 ampere-hours.

Ten (10) of the cells produced were given Performance Characterization tests at discharge currents ranging from 20 to 120 amperes (30 to 180 ma/sq. cm.). The same cells were then given 100% Depth of Discharge Cycle Life testing at 22°C. Discharging the cells at 20 amperes (30 ma/sq. cm.), the average cycle life to 50% loss of initial capacity (18AH) was 110 cycles. The remaining 115 cells were delivered to NASA Lewis Research Center.

The facility is now available and capable of fabricating Sealed Silver-Zinc rechargeable cells with inorganic separators utilizing high reliability production and quality assurance techniques for application to NASA programs and programs for other organizations as authorized by NASA Lewis Research Center.

INTRODUCTION

The battery industry and government organizations, particularly NASA, have expended considerable efforts during the past several years to develop sealed silver-zinc rechargeable battery cells that are efficient and reliable.

In sealed silver-zinc rechargeable cells, it is of paramount importance that generation of gases, caused by materials inside the cell or by the mode of operation, be kept at as low a level as possible to keep the internal cell pressures at safe and acceptable levels.

One method of minimizing gas generation within a cell is to design the cell using low reactivity materials, with emphasis on separator materials and all other non-electrode materials. Many organic materials may be oxidized by the charged silver-oxide positive plates, leading to formation of gases and, as a result, the commonly used materials, particularly separator materials, are not suitable for the fabrication of NASA quality sealed silver-zinc cells.

In order to solve this problem, NASA Lewis Research Center in Cleveland, Ohio, has funded several programs with private contractors to develop silver-zinc rechargeable cells using essentially inert separators and electrolyte absorbers. As an example, Astropower Laboratory at Newport Beach, California, made significant contributions to the development of improved sealed silver-zinc rechargeable cells under NASA funded programs. One such program resulted in the development and fabrication of a 40 ampere-hour sealed silver-zinc rechargeable cell which could be cycled in the sealed condition and which gave good electrical performance.

These cells were fabricated under carefully controlled and documented procedures. The consensus of opinion is that the successful performance of these cells was due to: (a) the design which was developed to minimize the possibility of failure and (b) the carefully controlled fabrication and processing conditions under which the cells were produced.

In 1970, the McDonnell-Douglas Corporation elected to discontinue operations at Astropower Laboratory in Newport Beach, California, which caused the loss of the fabricating capability for sealed silver-zinc rechargeable cells using inorganic separators. NASA Lewis Research Center decided to continue the work of developing long-life, improved, sealed silver-zinc rechargeable cells using inorganic separators for use in a variety of NASA missions and applications. Based on previous work, it was reasonable to conclude that a facility, properly designed, constructed and

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operated to provide and maintain the defined fabricating and processing conditions, would insure that all quantities of sealed silver-zinc cells would give safe, reliable and reproducible operation in a variety of applications.

It is the purpose of this report to describe how such a facility was designed, constructed and put into operation by Yardney Electric Division, Yardney Electric Corporation, 82 Mechanic Street, Pawcatuck, Connecticut, under NASA funding on Contract NAS3-16805.

TASK I - FACILITY PREPARATION

1. Objective of Task

To construct and equip a facility for the production of sealed silver-zinc cells in accordance with specifications and procedures supplied by NASA.

2. Construction of Facility

2.1 A facility was constructed and equipped for the production of sealed silver-zinc cells utilizing inorganic separators in accordance with cell specifications supplied by NASA Lewis Research Center. This facility is 19.96 x 16.46 meters and is located on the east end of the third floor of building no. 7 at the Yardney Electric Division plant in Pawcatuck, Connecticut. Building no. 7 is occupied with Engineering and Administrative offices and the third floor area was selected for the NASA facility because it is removed from the general plant production area and can be maintained in a controlled clean condition while at the same time having reasonable access for Yardney and NASA personnel.

2.2 The facility is capable of producing sealed silver-zinc rechargeable cells, using inorganic separators, at a rate of 60,000 ampere-hours of capacity per year (on a 40 hour per week basis) in cell capacities ranging from 5 to 80 ampere-hours.

2.3 There is a freight elevator access to the north side of the area and stairway access on the east end of the area. A passenger elevator is located at the west end of the third floor.

2.4 The facility layout is shown by Figure (1). The total facility area is 280 square meters and is broken down as shown below:

NO.	DESCRIPTION	DIMENSIONS (in meters)	AREA (in sq. meters)
1.	Positive fabrication area	4.57 x 5.18	23.7
2.	Negative fabrication area	4.57 x 4.88	22.3
3.	Separator and parts area	4.57 x 10.67	48.8
4.	Cell and battery assembly area	6.09 x 10.67	65.0
5.	Office area	4.57 x 4.88	22.3
6.	Reliability laboratory	3.66 x 4.88	17.9
7.	Filling, formation, cycling area	4.88 x 10.97	53.5
8.	Stockroom area	2.44 x 6.09	14.9
9.	Utility area	2.44 x 4.57	11.2
		Total	279.6

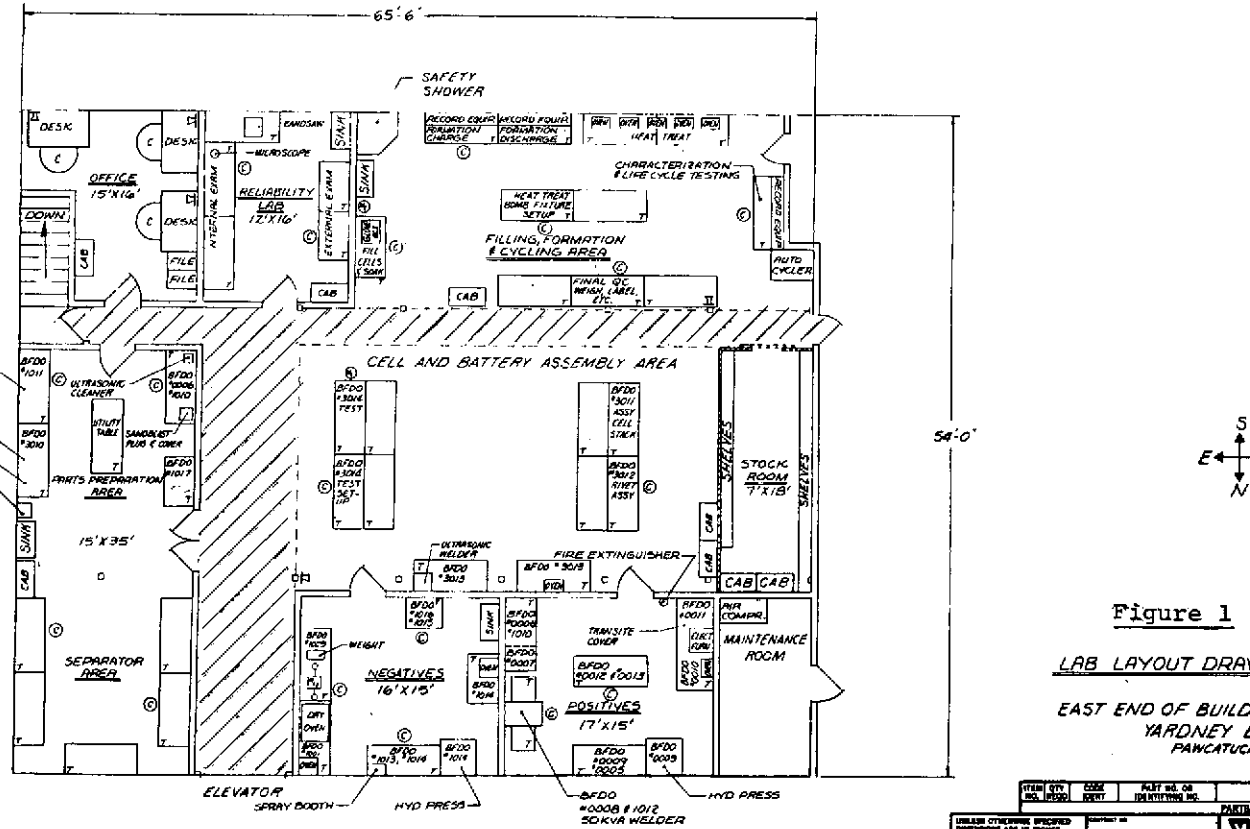

Figure 1

LAB LAYOUT DRAWING

EAST END OF BUILDING #7, 3RD FLOOR
YARDNEY ELECT DIV
PAWCATUCK, CONN

Yardney Electric Division, Pawcatuck, Conn.

PRODUCTION FACILITY FOR NASA SEALED SILVER-ZINC CELLS

D 87362 SK-3200

2.5 The positive fabrication area is 5.18 x 4.57 meters and is used for the fabrication of silver positive electrodes as well as fabrication of the silver conductor grid sub-assemblies for both positive and negative electrodes. The principal pieces of equipment in this area are a 50 KVA spot welder, a 91,000 kilogram hydraulic press for pressing the positives and an electric furnace for sintering the positives. The positive electrode fabrication area is physically separate from the rest of the fabrication operations in order to minimize contamination of the silver electrodes by other materials.

2.6 The negative electrode fabrication area is 4.57 x 4.88 meters and is physically separated from all other areas so as to minimize the possibilities of contamination of the negative electrodes by other materials. It contains a twin cone shell blender for preparation of negative mix, a large Despatch drying oven and a 91,000 kilogram hydraulic press for pressing the negative electrodes.

2.7 A third completely separate area, 4.57 x 10.67 meters, is used for the fabrication and application of separators as well as parts preparation. Two hoods are provided in the separator processing area, each hood having a table area of 0.76 x 1.83 meters and a 31 meter/minute face velocity through the hood opening. Another hood is available for mixing and application of epoxies and for preparation of terminal assemblies. OSHA approved safety cabinets are located in this area for the storage of flammable or harmful materials.

2.8 The cell and battery assembly area is 6.09 x 10.67 meters. All cell assembly operations and cell finishing operations are performed in this area. Another area, 4.88 x 10.97 meters, is used for filling, formation and cycling of cells. A sink, safety shower and eye bubbler are provided in this area.

2.9 A stockroom, 2.44 x 6.09 meters, is provided at the west end of the cell and battery assembly area and is used for storing all materials and parts that are used in the production of NASA sealed silver-zinc cells. Two locked cabinets are provided for storage of silver and silver containing materials.

2.10 The facility has a completely partitioned reliability laboratory, 3.66 x 4.88 meters, to provide an adequate area for opening of sealed silver-zinc cells following the end of useful life, with adequate table space for layout and examination of the parts of such cells. A band saw, equipped with a special holding fixture and vacuum adapter, is used to open the cells for dissection.

2.11 The facility also contains a completely partitioned office area, 4.57 x 4.88 meters.

2.12 The maintenance (utility) room is 2.44 x 4.57 meters and contains a 5HP air compressor, sandblasting equipment and two (2) switch boxes controlling the facility supply of electrical power.

2.13 The NASA-Yardney facility provides for office clean conditions in all areas, with electrode fabrication activities being completely isolated so that positive electrode fabrication cannot be contaminated by negative electrode fabrication, and both areas are physically isolated from the remainder of the facility. The temperature of the facility is controlled within the range of 22.2 $\pm$ 2.8°C. The relative humidity of the facility is controlled so that it does not exceed 70% at the temperatures indicated. A recording thermometer is kept in each fabrication area so that a permanent record of the temperature profile of each part of the facility is maintained. A recording humidity indicator is provided to demonstrate that the relative humidity is maintained within the required limits.

2.14 Temperature and humidity control are achieved by a 15 ton air conditioning unit adjacent to the west end of the facility. This is connected to an overhead duct system that feeds into the production facility. Branch ducts distribute controlled air into each designated area of the facility to insure the proper environmental balance.

2.15 The office, separator, negative, positive, reliability and maintenance areas are completely partitioned. All partitions extend from the floor to the ceiling to eliminate any possibility of process contamination. Each wall is constructed using 5 x 10 centimeter studs located on 0.41 meter centers and covered on both sides with 1.27 centimeter sheetrock and painted. The stockroom was constructed using diamond mesh wire framed in 2.54 centimeter steel channels.

2.16 The facility is wired to support a total electrical load of approximately 415 amperes. During production, the electrical diversity factor is approximately 1.25. The major power user is the 50 KVA resistance welder which operates at 208 volts AC and draws 240 amperes. The facility has adequate lighting to provide illumination commensurate with this type of facility.

2.17 Three sinks, a safety shower and an eye bubbler are installed in the facility. In addition, water supply and drains are connected to the 50 KVA welder and to the water cooler. Air supplies, run from the air compressor, are available in the Maintenance (Utility) Room, the Negative, Positive and Cell/Battery Assembly areas.

3. Facility Equipment and Tooling

Items of Major Equipment and Tooling were procured or fabricated and installed in the appropriate areas of the facility. Each item was inspected upon receipt and marked with a property sticker bearing the contract number and a coded identification number.

TASK II - CELL FABRICATION

1. Objective of Task

To fabricate, form, finish, ship and/or test one hundred twenty-five (125) forty ampere-hour (40ah) sealed silver-zinc cells using inorganic separator, cell Model HS40-7, in accordance with the drawings, specifications and procedures supplied by NASA Lewis Research Center. The one hundred twenty-five (125) cells to be fabricated in five (5) separate lots as follows:

Lot 1	10 cells
Lot 2	10 cells
Lot 3	25 cells
Lot 4	30 cells
Lot 5	50 cells

2. Cell Materials

2.1 The conductor material for the positive electrodes was Exmet product 3Ag10-3/0 in a roll width of 9.16cm ± 0.38mm. The long way of the diamonds (LWD) were parallel to the width of the Coil. In fabricating the electrode grid, it was necessary to make only one (1) cut to obtain the grid width dimension of 7.01/7.09cm.

2.2 The conductor grid material for the negative electrodes was Exmet product 5Ag38-1/0 DISTEX in a roll width of 15.24cm ± 0.76mm.

2.3 The conductor tab material for both the positive and negative conductors was fine silver strip, 0.64cm wide x 0.15mm thick. Each electrode used a tab strip length of 7.62cm.

2.4 The active positive electrode material was silver powder, Handy & Harman product "Silpowder 130", purchased in accordance with Drawing No. 1D12572 and Handy & Harman product specifications for "Silpowder 130". Two (2) lots of "Silpowder 130" were used in fabrication of the one hundred twenty-five (125) cells on this contract. These lots were identified as lots 239 and 282.

The analyses of the two lots of "Silpowder 130" were as follows:

Lot No.	239	282
Qty. in Troy oz.	700	200
Chemical Analysis:		
% Ag	99.8000	99.8200
% Ca	0.0005	0.0010
% Fe	0.0010	0.0010
% Pb	0.0010	0.0010
% H_2O	0.1975	0.1770
Apparent Density (g/in3)	15.7	14.3
Average Particle Dia. (Microns)	1.89	1.90

The apparent density values were determined using a Scott Volumeter. The average particle size in microns was measured with a Fisher Sub-Sieve Sizer.

2.5 The zinc oxide used for the negative electrode mix was the Horsehead brand manufactured by the New Jersey Zinc Company and conformed to the specifications of USP-12. The zinc oxide was packaged in plastic lined, 22.7kg. paperboard containers.

2.6 The mercuric oxide used as the inhibitor in the negative electrode mix was analytical reagent grade red mercuric oxide as manufactured by Mallinckrodt Chemical Works.

2.7 The electrolyte used was a 45 percent solution of potassium hydroxide, "Baker Analyzed" reagent grade packaged in one (1) pint, sealed polyethylene bottles. One (1) pint of this electrolyte was sufficient to fill four (4) of the type HS40-7 cells.

2.8 The Allbond epoxy and the RB3-1 epoxy used to seal the cell terminal hardware to the cell cover and also to top pot the cell was purchased from Bacon Industries, Inc. in kit form, each kit containing 0.5 liter of resin and 0.5 liter of hardener.

2.9 The inert material used for the sling, to aid in positioning the cell stack inside the cell case, was teflon film, 0.13mm thick x 8.26cm wide.

2.10 The three (3) sizes of Parker "O" rings were made of Compound E-540-8, which is ethylene-propylene and the "O" rings were shipped without preservatives, which might have interfered with proper sealing when used in the terminal assembly CB502709.

2.11 The semi-tubular rivets, used to attach the electrode tabs to the underside of the cell terminals, were produced of CONSIL 901 (coin silver) wire, 0.30cm in diameter, on a standard rivet machine.

2.12 The terminal casting, from which the finished terminal was machined, was made by centrifugally casting molten coin silver. These parts were cast using Tool No. T12-0001 and conformed to Drawing CB502712. Prior to machining, all castings were 100 percent X-rayed, a precaution taken to avoid machining castings with voids and similar defects. The castings were machined to specifications and gold-plated per Specification MIL-G-45204B (27 March 1967), Type I, Grade A, Class 1.

2.13 The metal washer used in the tab assembly was fabricated from 1.59cm diameter coin silver rod; it was then machined to conform to Drawing CB502711 and was gold-plated per MIL-G-45204B (27 March 1967), Type I, Grade A, Class 1.

2.14 The jam nuts used to secure the terminal assembly were fabricated from 1.27cm diameter coin silver rod. These parts were machined to conform to Drawing 1D12512 and were then gold-plated per Specification MIL-G-45204B (27 March 1967), Type I, Grade A, Class 1.

2.15 The cell cases were furnished by NASA Lewis Research Center. Each cell case conformed to NASA Drawing 1D12556 and was injection molded of glass fortified grade 534-801 natural polyphenylene oxide, Liquid Nitrogen Processing Corporation product NF-1006, with 30 percent glass content.

2.16 Molded cell covers, per Drawing 1D12509, were supplied by NASA Lewis Research Center. These covers were injection molded of the same material used for the cell cases. Each cover was supplied with a plug per Drawing 1D12510 which was injection molded of the same material.

3. Negative Electrode Fabrication

3.1 Each Model HS40-7 cell contained five (5) negative electrode assemblies consisting of a pressed zinc oxide powder electrode contained inside a fuel cell grade asbestos bag coated with a ceramic separator composition.

3.2 The negative conductor grid consisted of expanded silver mesh, Exmet product DISTEX 5Ag38-1/0, cut to 7.06cm x 9.12cm and welded to a fine silver strip tab, 0.64cm width x 0.13mm thick. The expanded mesh pieces and the cut silver tabs were degreased in an ultrasonic cleaner using acetone as the cleaning agent.

Following the ultrasonic cleaning, the excess acetone was shaken off and the parts were allowed to air dry. Using a locating fixture to properly position the tab in relation to the grid, the tab was welded to the DISTEX grid, using a 50 KVA resistance welder with tungstenite welding tips. Four (4) spot welds secured the tab to the conductor grid to form the negative conductor grid sub-assembly.

3.3 The powder mix used in the negative electrode was prepared in batches containing 3,920 grams of zinc oxide and 80 grams of mercuric oxide. These materials were added to both containers of a twin cone blender, alternating small amounts of each material so that the mercuric oxide was somewhat dispersed throughout the zinc oxide during the loading of the twin cone blender. The material was then mixed in the blender for sixty (60) minutes, removed from the blender and transferred to a stainless steel tray, which was then placed in a Despatch oven and allowed to dry overnight at approximately 70°C. A sample of the negative mix was then analyzed to determine the actual mercuric oxide content, using a titration method with potassium thiocyanate and ferric indicator solution. All batches used met the requirement of 1.80 - 2.20% mercuric oxide. The exact analytical method is described in "Treatise on Analytical Chemistry" by Kolthoff and Elving, Part II, Volume 3, pages 306 - 308.

3.4 Each negative electrode used two (2) absorber layers cut from potassium titanate paper furnished to the contractor by NASA Lewis Research Center. The particular material was coded product LPM174-67 and was manufactured by the Mead Corporation. Each absorber layer measured 7.06cm x 9.14cm.

3.5 In fabricating the negative electrode, 30.1 grams of negative mix was weighed out. Using the negative electrode mold, one (1) piece of potassium titanate paper was placed in the bottom of the mold. Fifty percent (50%) of the volume of negative mix was then poured into the mold on top of the potassium titanate paper. This mix was then spread evenly with a tamping tool. Next, a collector-grid assembly (see figure 2) was positioned in the mold so that it would lie flat on the mix; then the remainder of the mix was poured on top of the collector-grid assembly and again spread evenly, using a tamping tool. A second piece of potassium titanate paper was placed on the top of the mix in the mold followed by positioning of the top punch into the mold. The filled mold was then positioned between the platens of a hydraulic press and pressed at 36,000 kg. to compact the negative electrode mix around the collector-grid assembly.

3.6 Each electrode was measured to determine that the width was 7.11cm ± 0.38mm, that the length was 9.21cm ± 0.38mm, that the thickness was in the range of 0.22 - 0.23cm and the weight was in the range of 37.8 - 39.0 grams. All negative electrodes used in assembling HS40-7 cells conformed to the above requirements.

3.7 Following acceptance of each electrode on the basis of dimensions and weight, a plastic sleeve was positioned over the electrode tab and a numbered identification tab was attached to the end of the tab. Negative electrode sub-assemblies in this condition, together with appropriate traceability data, were stored in plastic boxes to await subsequent operations.

3.8 Effective with lot No. 2 of HS40-7 cells and, starting with cell serial No. 2-012, the edges of acceptable electrodes were reinforced by a light application of a two percent (2%) solution of polyphenylene oxide (PPO) in chloroform. This change was directed by the NASA Project Manager with concurrence by Yardney in order to improve the mechanical stability of the edges of the pressed negative electrodes.

4. Positive Electrode Fabrication

4.1 Each type HS40-7 cell contained six (6) positive electrodes. Each positive electrode contained 23.0 ± 0.1 grams of silver powder (product "Silpowder 130") and the completed positive electrode sub-assembly weighed from 25.2 - 25.6 grams. Each electrode measured 9.21cm x 7.11cm x 0.69 - 0.74mm thickness.

4.2 A positive electrode conductor-grid sub-assembly was fabricated by welding a fine silver strip, 7.62cm long x 0.64cm wide x 0.13mm thick, onto a rectangular silver mesh grid, Exmet product 3Ag10-3/0, cut to 7.05cm x 9.11cm dimensions and ultrasonically cleaned in acetone. A locating fixture positioned the silver tab accurately in respect to the conductor-grid prior to the application of three (3) spot welds to complete this sub-assembly.

4.3 The positive electrode assembly fabrication was accomplished by evenly distributing 23 grams of "Silpowder" around the conductor-grid sub-assembly (see figure 2) in matched metal molds and pressing to the specification thickness in a 91,000 kilograms hydraulic press.

4.4 Following the pressing operation, each positive electrode sub-assembly was dried at 125°C for one (1) hour to remove any residual moisture prior to the sintering operation.

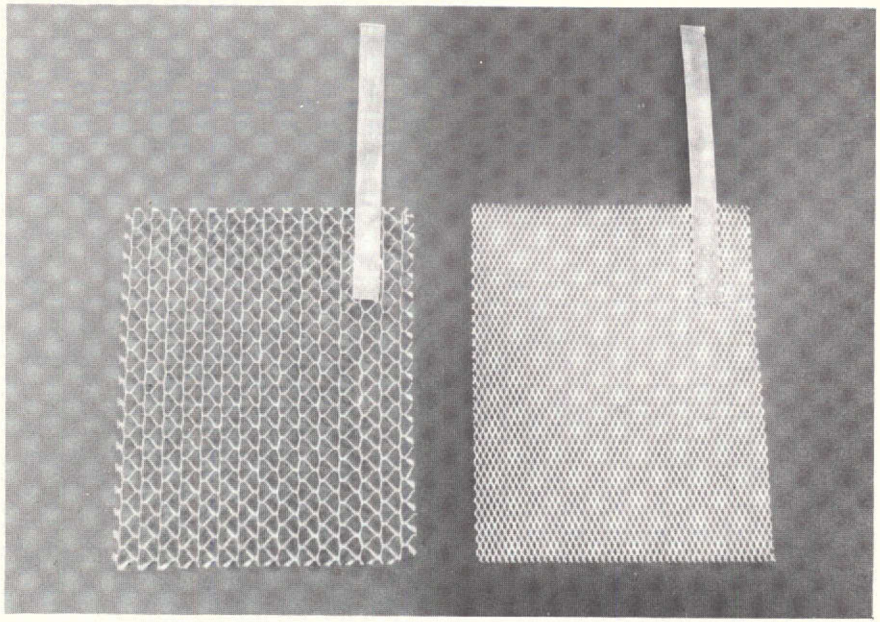

FIGURE 2

NEGATIVE AND POSITIVE ELECTRODE
GRID ASSEMBLIES

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4.5 The dried positive electrode sub-assembly was then sintered at 650°C for a period of four (4) minutes. This sintering produced a strong mechanical bond due to physical coalescence of the particles of "Silpowder 130" to each other and due to the cementing action of the sintering process, resulting in binding of the powder particles to the conductor-grid.

4.6 It should be pointed out that the molding of the positive electrode was done in a three (3) piece compression mold consisting of a base plate, a mold ring and a punch. During the pressing operation, the electrode components were pressed to a fixed dimension rather than using a pre-determined force. This was done to consistently control the thickness of the finished pressed electrode.

4.7 Following the sintering operation, positive electrode sub-assemblies were given 100 percent inspection to eliminate electrodes which might have mechanical defects, evidence of contamination or variance from dimensional and weight requirements. Those electrodes passing the 100 percent inspection had insulating sleeves applied to the tab and identifying serial numbers were attached to the tab at this point.

5. Separator Processing and Fabrication

5.1 The processing and fabrication of inorganic separators for the HS40-7 cells was carried out in accordance with proprietary procedures supplied by NASA Lewis Research Center.

The raw materials necessary to prepare and fabricate the separators were supplied by NASA Lewis Research Center.

6. Assembly of HS40-7 Cells

6.1 The complete positive and negative electrode assemblies were stacked in the proper sequence with five (5) negative electrodes and six (6) positive electrodes comprising a cell stack. Figure (3) shows a complete electrode stack inside a cell case using a teflon film as a protective sling to facilitate the insertion of the electrode stack into a cell case.

6.2 The tabs of the electrode stack were formed utilizing a "comb" assembly aid. The formed tabs were cut to length and a 0.32cm diameter hole was punched in the center of the tab stack to provide a means of riveting the tab stack to the underside of the cell terminals. (Figure 3 also shows the underside of a cover-terminal assembly).

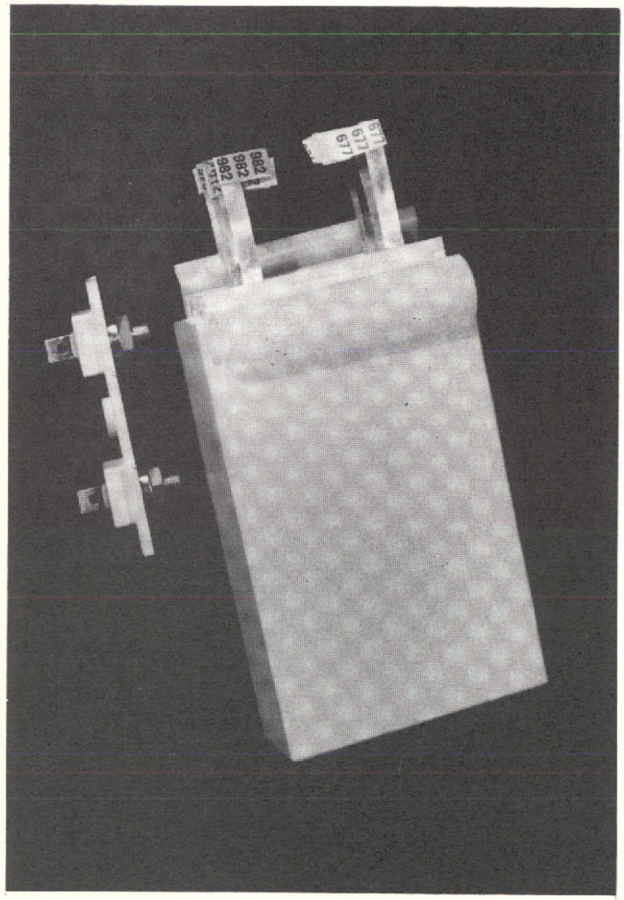

FIGURE 3

ELECTRODE STACK
IN CELL CASE

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6.3 With the electrode stack still only partially inserted into the cell case, the electrode tabs were secured to the appropriate terminal tabs using a coin silver rivet which was turned over using a special rivet setter. The area of the connections between the electrode tabs and the cell terminals was given a protective coating of Allbond epoxy. After this epoxy had set, the electrode stack was pushed completely down into the cell case and the cell cover was then secured to the corresponding ledge inside the cell case.

6.4 The cover was ultrasonically welded to the cell case, using a Branson Model 220C ultrasonic welder and a nesting fixture for properly positioning the cell directly beneath the horn of the ultrasonic welder during sealing. During this operation, the cell is placed in an oven that has been stabilized at 100°C and allowed to remain in this oven for five (5) minutes. It is then transferred immediately from the oven to the ultrasonic welding fixture and welded, using settings, hold times and weld times previously determined to be appropriate for this exact piece of equipment. The entire welding procedure takes only a few seconds.

6.5 Following the ultrasonic welding operation, each cell was placed between restraining plates inside a cylindrical metal bomb and pressurized through a special fitting to 50 psig. In order for a cell to be acceptable, there could be no evidence of leakage during a ten (10) minute period at the 50 psig level. During the fabrication of the one hundred twenty-five (125) cells on this contract, only two (2) cells failed to meet the pressure testing requirements. In one of these failures, the nesting fixture was not completely closed prior to welding and in the second case, there appeared to be a breakout in the energy director which is designed into the bottom of the cell cover. In both cases, the cells showed gross leakage immediately upon application of pressure.

6.6 After completion of the pressure test, the area between the inside seal of the cell case and the periphery of the cell cover was pre-sealed with a thin bead of RB3-1 Allbond epoxy which was then allowed to cure at room temperature for 16-24 hours.

6.7 During the course of this program, a total of one hundred twenty-five (125) Model HS40-7 cells were fabricated following completion of facilities and process review and receipt of approval from the NASA Project Manager to proceed with fabrication of Lot No. 1. These cells were produced in five (5) individual lots and the fabrication of each lot of cells was initiated only after approval from the NASA Project Manager following acceptance of each prior lot of cells.

7. Filling and Formation of Cells

7.1 The cells to be filled were first weighed to the nearest 0.1 gram in the dry state. The cells, the 45% solution of Potassium Hydroxide and all the equipment necessary to vacuum fill the cells were placed in a glove box which was flooded with dry nitrogen. One hundred and ten milliliters (110 ml) of electrolyte were carefully premeasured and introduced into the cell. The vented cell was then placed in a vacuum chamber inside the glove box and a vacuum of 710 ± 25mm of mercury was achieved in the chamber. This vacuum was maintained for thirty (30) seconds. The chamber was then allowed to return slowly to ambient pressure. The filled and vacuumed cell was weighed again and the weight gain due to filling was calculated to verify that the correct amount of electrolyte was present in the cell. The cell was restrained between two (2) steel plates 15.2cm x 11.4cm x 6.4mm thick and secured using four (4) round head bolts, 5.7cm long, and wing nuts. The filled and restrained cells remained in the nitrogen atmosphere during a soaking period of at least twenty-four (24) hours. Before removing the cell from the nitrogen atmosphere, the molded vent plug was positioned loosely in the vent hole in the cell cover.

7.2 Each cell was charged for the first formation cycle at a constant current rate of 1.5A to a voltage, while charging, of 1.98-2.00 volts or until an input of 45 ampere-hours was achieved, whichever occurred first. The cell was charged using a constant current power supply. Charging current was monitored using an ammeter with ± 1.0% accuracy. Cell voltage was monitored using a 3 1/2 digit digital voltmeter with an accuracy of ± 0.1%. The cell voltage was recorded as a function of time during charging. The cell charging input capacity was calculated and recorded.

7.3 Each charged cell was connected to the formation discharge equipment, equipment no. 3-0015. This equipment is capable of discharging and monitoring ten (10) cells simultaneously at rates between 0.5 and 10.0 amperes. Individual cell voltages may be monitored using a cell selector switch and a digital panel voltmeter with ± 0.1% accuracy. Discharge current is adjusted using a variable resistor. Currents were read on a panel ammeter with an accuracy of ± 1.0%. Individual cells reaching discharge end voltage were deleted from the circuit by means of manually actuated switches.

7.4 Each cell was discharged at a constant current rate of 6.0A to a voltage, while discharging, of 1.00 volt. The cell discharge voltage was recorded as a function of time. The cell discharge output capacity was calculated and recorded.

7.5 Each cell was then low rate drained at a constant current of 2.0A to a voltage, while discharging, of 1.00 volt. The cell drain voltage was recorded as a function of time. The cell drain output capacity was calculated and recorded.

7.6 The first formation cycle input capacity, discharge capacity and low rate drain capacity for each cell is given in Table I.

7.7 Following the completion of Formation Cycle No. 1, each vented cell was heat treated for twenty-four (24) hours at a temperature of 100°C while sealed in a cylindrical steel bomb. To minimize the presence of carbon dioxide, the bomb enclosure was purged with dry nitrogen prior to sealing. The pressure within the bomb and the temperature in the oven were recorded as a function of time during the heat treatment. At the end of the twenty-four (24) hour period, the oven was turned off and allowed to return to room temperature.

7.8 Each cell was removed from the bomb and the cell vent was thoroughly cleaned of any electrolyte residue. A molded vent plug was cemented into place in the threaded vent hole using Allbond Epoxy.

7.9 The entire cell top cavity and the cell terminal hardware were thoroughly cleaned and dried. The cell top was then completely filled with Allbond Epoxy. The epoxy encapsulated the cell terminal washer, the vertical surfaces of the terminal nut and the top surface of the cell case. The epoxy was allowed to cure at room temperature for 16 - 24 hours.

7.10 The sealed cell was given a second formation cycle using the same equipment and procedures used in Formation Cycle no. 1. Cells delivering 40 ampere-hours output at the 6.0A discharge rate with a plateau voltage of 1.42 volts or higher were considered acceptable for shipment to NASA Lewis Research Center or transfer to the test program discussed under Task III - (Cell Testing) of this Contract Report. Of the one hundred and twenty-five (125) cells given Formation Cycle no. 2, only two (2) cells failed to deliver the required 40-ampere-hours discharge output.

7.11 The charge input capacity, cell voltage at the end of charge, discharge output and low rate drain output capacities for each cell are given in Table I.

TABLE I

FORMATION CYCLES CAPACITY DATA FOR HS40-7 CELLS FABRICATED IN TASK II

CELL LOT NO. AND SERIAL NO.	FORMATION NO. 1			FORMATION NO. 2			
	CHARGE INPUT IN AMP. HRS.	DISCHARGE OUTPUT TO 1.00 VOLT IN AMP. HRS.	LOW RATE DRAIN OUTPUT IN AMP. HRS.	CHARGE INPUT IN AMP. HRS.	VOLTAGE AT END OF CHARGE	DISCHARGE OUTPUT TO 1.00 VOLT IN AMP. HRS.	LOW RATE DRAIN OUTPUT IN AMP. HRS.
1 - 001	29.25	26.20	0.93	45.00	1.971	41.57	0.42
1 - 002	29.25	25.93	1.13	45.00	1.981	41.64	0.70
1 - 003	29.25	25.99	1.16	45.00	1.975	41.65	0.44
1 - 004	29.25	25.72	1.39	45.00	1.973	41.68	0.39
1 - 005	29.25	26.10	1.15	45.00	1.977	41.88	0.47
1 - 006	29.25	25.48	1.67	45.00	1.982	42.47	0.29
1 - 007	29.25	25.73	0.87	45.00	1.982	42.07	0.48
1 - 008	29.25	25.57	0.97	45.00	1.978	41.91	0.42
1 - 009	29.25	25.33	1.35	45.00	1.985	42.08	0.52
1 - 010	29.25	25.64	1.30	45.00	1.985	41.93	0.52
1 - 011	31.50	27.51	0.95	45.00	1.977	41.81	0.22
LOT NO. 1 AVERAGE	29.45	25.93	1.17	45.00	1.978	41.88	0.44
2 - 012	31.50	27.94	0.80	45.00	1.979	40.30	0.19
2 - 013	31.50	27.41	1.09	45.00	1.981	40.31	0.28
2 - 014	31.50	27.31	1.22	45.00	1.979	40.35	0.28
2 - 015	31.50	27.46	0.63	45.00	1.982	40.21	0.34
2 - 016	31.50	27.86	1.25	45.00	1.983	39.94	0.36
2 - 017	33.00	28.13	1.06	45.00	1.998	41.75	0.37
2 - 018	33.00	28.18	1.17	45.00	1.975	38.54	0.28
2 - 019	33.00	28.62	0.77	45.00	1.995	41.68	0.47
2 - 020	33.00	28.40	0.94	45.00	1.994	41.40	0.53
2 - 021	33.00	28.28	0.94	45.00	1.992	41.61	0.56

TABLE I

FORMATION CYCLES CAPACITY DATA FOR
HS40-7 CELLS FABRICATED IN TASK II

CELL LOT NO. AND SERIAL NO.	FORMATION NO. 1			FORMATION NO. 2			
	CHARGE INPUT IN AMP. HRS.	DISCHARGE OUTPUT TO 1.00 VOLT IN AMP. HRS.	LOW RATE DRAIN OUTPUT IN AMP. HRS.	CHARGE INPUT IN AMP. HRS.	VOLTAGE AT END OF CHARGE	DISCHARGE OUTPUT TO 1.00 VOLT IN AMP. HRS.	LOW RATE DRAIN OUTPUT IN AMP. HRS.
LOT NO. 2 AVERAGE	32.25	27.96	0.99	45.00	1.986	40.61	0.37
3 - 022	33.00	27.96	1.19	45.00	1.985	42.47	0.46
3 - 023	33.00	27.78	1.48	45.00	1.984	42.68	0.40
3 - 024	33.00	27.72	1.43	45.00	1.987	42.80	0.42
3 - 025	33.00	27.36	1.69	45.00	1.987	42.78	0.43
3 - 026	33.00	27.54	1.64	45.00	1.988	42.73	0.38
3 - 027	36.00	29.24	1.61	45.00	1.993	44.13	0.46
3 - 028	36.00	29.06	1.87	45.00	1.996	44.17	0.42
3 - 029	36.00	29.65	1.64	45.00	1.994	43.90	0.53
3 - 030	36.00	29.80	1.42	45.00	1.996	44.19	0.50
3 - 031	36.00	29.09	1.85	45.00	1.998	44.12	0.67
3 - 032	31.50	26.65	1.92	45.00	1.992	42.98	0.41
3 - 033	31.50	26.81	1.63	45.00	1.995	42.97	0.39
3 - 034	31.50	27.18	1.44	45.00	1.995	42.93	0.48
3 - 035	31.50	27.30	1.35	45.00	1.995	42.88	0.43
3 - 036	31.50	27.21	1.42	45.00	1.994	43.02	0.47
3 - 037	33.00	27.01	2.04	45.00	1.993	44.38	0.43
3 - 038	33.00	27.05	2.19	45.00	1.992	44.25	0.50
3 - 039	33.00	25.86	2.98	45.00	1.993	43.31	0.53
3 - 040	33.00	26.72	2.23	45.00	1.993	44.31	0.41
3 - 041	33.00	26.95	1.76	45.00	1.992	44.47	0.51
3 - 042	36.00	29.07	1.45	45.00	1.989	41.48	0.48
3 - 043	36.00	29.71	1.00	45.00	1.985	41.92	0.44
3 - 044	36.00	29.60	1.14	45.00	1.990	43.17	0.45
3 - 045	36.00	28.91	1.93	45.00	1.995	43.06	0.51

TABLE I

FORMATION CYCLES CAPACITY DATA FOR
HS40-7 CELLS FABRICATED IN TASK II

CELL LOT NO. AND SERIAL NO.	FORMATION NO. 1			FORMATION NO. 2			
	CHARGE INPUT IN AMP. HRS.	DISCHARGE OUTPUT TO 1.00 VOLT IN AMP. HRS.	LOW RATE DRAIN OUTPUT IN AMP. HRS.	CHARGE INPUT IN AMP. HRS.	VOLTAGE AT END OF CHARGE	DISCHARGE OUTPUT TO 1.00 VOLT IN AMP. HRS.	LOW RATE DRAIN OUTPUT IN AMP. HRS.
3 - 046	36.00	29.06	1.90	45.00	1.993	42.93	0.44
LOT NO. 3 AVERAGE	33.90	28.01	1.69	45.00	1.992	43.28	0.46
4 - 047	29.25	25.11	0.60	45.00	1.989	42.63	0.40
4 - 048	29.25	25.06	0.57	45.00	1.989	42.31	0.35
4 - 049	29.25	25.05	0.81	45.00	1.987	41.77	0.42
4 - 050	29.25	24.39	1.44	45.00	1.990	42.69	0.38
4 - 051	29.25	25.05	1.16	45.00	1.991	42.50	0.41
4 - 052	31.50	27.06	1.30	45.00	1.991	43.15	0.26
4 - 053	31.50	26.69	1.49	45.00	1.988	42.98	0.36
4 - 054	31.50	26.94	1.27	45.00	1.988	43.07	0.29
4 - 055	31.50	26.78	1.38	45.00	1.991	43.15	0.41
4 - 056	31.50	26.45	1.75	45.00	1.993	43.04	0.43
4 - 057	30.00	27.34	0.22	45.00	1.996	43.04	0.47
4 - 058	30.00	27.35	0.23	43.88	2.000	42.32	0.49
4 - 059	30.00	27.49	0.25	45.00	1.996	43.27	0.44
4 - 060	30.00	27.61	0.20	43.88	1.999	42.43	0.44
4 - 061	30.00	27.65	0.12	45.00	1.999	43.35	0.48
4 - 062	27.75	25.45	0.35	45.00	1.991	42.05	0.41
4 - 063	27.75	25.52	0.32	45.00	1.988	42.02	0.35
4 - 064	27.75	25.37	0.34	45.00	1.987	42.09	0.31
4 - 065	27.75	25.32	0.43	45.00	1.986	41.70	0.35
4 - 066	27.75	25.43	0.51	45.00	1.987	41.84	0.29
4 - 067	28.50	24.18	1.15	45.00	1.990	41.40	0.25
4 - 068	28.50	24.58	1.00	45.00	1.988	41.44	0.16

TABLE I

FORMATION CYCLES CAPACITY DATA FOR HS40-7 CELLS FABRICATED IN TASK II

CELL LOT NO. AND SERIAL NO.	FORMATION NO. 1			FORMATION NO. 2			
	CHARGE INPUT IN AMP. HRS.	DISCHARGE OUTPUT TO 1.00 VOLT IN AMP. HRS.	LOW RATE DRAIN OUTPUT IN AMP. HRS.	CHARGE INPUT IN AMP. HRS.	VOLTAGE AT END OF CHARGE	DISCHARGE OUTPUT TO 1.00 VOLT IN AMP. HRS.	LOW RATE DRAIN OUTPUT IN AMP. HRS.
4 - 069	28.50	24.49	0.92	45.00	1.984	41.46	0.19
4 - 070	28.50	24.54	0.99	45.00	1.986	41.45	0.11
4 - 071	28.50	24.43	0.96	45.00	1.987	40.99	0.24
4 - 072	31.50	27.90	0.93	45.00	1.997	42.51	0.27
4 - 073	31.50	27.63	1.23	45.00	1.993	42.01	0.29
4 - 074	31.50	28.02	1.01	45.00	1.994	42.41	0.23
4 - 075	31.50	27.91	0.97	45.00	1.987	40.20	0.25
4 - 076	31.50	27.66	1.22	43.50	1.998	41.31	0.25
LOT NO. 4 AVERAGE	29.75	26.15	0.84	44.87	1.991	42.22	0.33
5 - 077	27.75	23.57	1.17	45.00	1.980	42.75	2.11
5 - 078	27.75	23.37	1.25	45.00	1.981	42.20	1.61
5 - 079	27.75	22.95	1.67	45.00	1.980	42.80	1.58
5 - 080	27.75	22.71	2.01	45.00	1.978	42.17	1.71
5 - 081	27.75	22.27	2.16	45.00	1.983	42.72	1.86
5 - 082	30.00	26.42	1.08	45.00	1.987	43.23	0.60
5 - 083	30.00	26.79	0.80	45.00	1.988	43.22	0.66
5 - 084	30.00	26.97	0.70	45.00	1.986	43.27	0.65
5 - 085	30.00	26.87	0.76	45.00	1.989	43.50	0.46
5 - 086	30.00	26.81	0.68	45.00	1.986	43.33	0.66
5 - 087	29.25	24.56	1.59	45.00	1.984	41.62	0.46
5 - 088	29.25	25.00	1.33	45.00	1.984	41.55	0.44
5 - 089	29.25	24.23	1.64	45.00	1.983	41.83	0.48
5 - 090	29.25	24.90	1.50	45.00	1.982	41.78	0.46
5 - 091	29.25	24.52	1.87	45.00	1.980	41.90	0.41

TABLE I

FORMATION CYCLES CAPACITY DATA FOR
HS40-7 CELLS FABRICATED IN TASK II

CELL LOT NO. AND SERIAL NO.	FORMATION NO. 1			FORMATION NO. 2			
	CHARGE INPUT IN AMP. HRS.	DISCHARGE OUTPUT TO 1.00 VOLT IN AMP. HRS.	LOW RATE DRAIN OUTPUT IN AMP. HRS.	CHARGE INPUT IN AMP. HRS.	VOLTAGE AT END OF CHARGE	DISCHARGE OUTPUT TO 1.00 VOLT IN AMP. HRS.	LOW RATE DRAIN OUTPUT IN AMP. HRS.
5 - 092	32.25	26.20	1.74	45.00	1.988	42.21	0.86
5 - 093	32.25	26.00	1.91	45.00	1.988	42.23	0.89
5 - 094	32.25	26.23	1.68	45.00	1.988	42.28	0.77
5 - 095	32.25	25.68	2.32	45.00	1.989	42.41	0.69
5 - 096	32.25	25.83	2.08	45.00	1.987	42.38	0.80
5 - 097	30.75	24.99	0.57	45.00	1.981	41.78	0.67
5 - 098	30.75	25.21	1.30	45.00	1.985	42.52	0.40
5 - 099	30.75	25.60	0.77	45.00	1.982	42.17	0.59
5 - 100	30.75	25.04	0.53	45.00	1.983	42.47	0.47
5 - 101	30.75	24.72	1.23	45.00	1.982	42.26	0.63
5 - 102	35.25	28.82	2.41	45.00	1.986	41.80	0.47
5 - 103	35.25	29.21	1.79	45.00	1.987	41.76	0.55
5 - 104	35.25	29.07	2.05	45.00	1.986	40.81	0.93
5 - 105	35.25	29.55	1.99	45.00	1.980	41.82	0.49
5 - 106	35.25	29.60	1.95	45.00	1.984	41.50	0.50
5 - 107	30.75	27.16	1.03	45.00	1.991	41.27	0.46
5 - 108	30.75	26.96	1.21	45.00	1.988	41.33	0.43
5 - 109	30.75	26.59	1.23	45.00	1.992	41.57	0.37
5 - 110	30.75	26.90	1.47	45.00	1.988	42.11	0.26
5 - 111	30.75	26.61	1.57	45.00	1.984	42.18	0.47
5 - 112	36.00	26.92	2.13	45.00	1.992	42.17	0.36
5 - 113	36.00	30.82	1.39	45.00	1.992	41.93	0.38
5 - 114	36.00	30.23	1.90	45.00	1.990	41.80	0.64
5 - 115	36.00	30.98	1.36	45.00	1.993	41.85	0.50
5 - 116	36.00	30.45	1.83	45.00	1.985	41.50	0.69
5 - 117	27.75	23.00	1.71	45.00	1.970	41.26	0.48
5 - 118	27.72	23.55	1.22	45.00	1.972	41.07	0.79

TABLE I

FORMATION CYCLES CAPACITY DATA FOR
HS40-7 CELLS FABRICATED IN TASK II

CELL LOT NO. AND SERIAL NO.	FORMATION NO. 1			FORMATION NO. 2.			
	CHARGE INPUT IN AMP. HRS.	DISCHARGE OUTPUT TO 1.00 VOLT IN AMP. HRS.	LOW RATE DRAIN OUTPUT IN AMP. HRS.	CHARGE INPUT IN AMP. HRS.	VOLTAGE AT END OF CHARGE	DISCHARGE OUTPUT TO 1.00 VOLT IN AMP. HRS.	LOW RATE DRAIN OUTPUT IN AMP. HRS.
5 - 119	27.75	22.74	1.96	45.00	1.964	41.88	0.41
5 - 120	27.75	23.15	1.62	45.00	1.975	41.87	0.45
5 - 121	27.75	22.65	1.83	45.00	1.967	41.22	0.62
5 - 122	36.00	28.82	2.58	45.00	1.976	42.35	0.81
5 - 123	36.00	29.67	1.49	45.00	1.976	42.47	0.86
5 - 124	36.00	29.28	1.61	45.00	1.972	42.66	0.74
5 - 125	36.00	28.88	2.20	45.00	1.977	42.59	0.67
LOT NO. 5 AVERAGE	34.62	26.39	1.55	45.00	1.983	42.13	0.70
125 CELL AVERAGE	32.59	26.74	1.33	44.97	1.986	42.24	0.51

8. Cell Finishing and Shipment

8.1 Following the second formation cycle, each cell was removed from its restraining fixture, weighed to the nearest gram, cleaned, inspected dimensionally and returned to its restraining fixture. Permanent polarity indication was marked on the top of the cell adjacent to the positive terminal. The end of the cell case on the positive side was permanently marked with the cell assembly code date, the cell serial number, the cell type, the letters "NASA" and inspection status marking. The negative end of the cell was permanently marked with the cell sealing date code and the words "YARDNEY ELECTRIC CORPORATION". The final inspection of each cell was then completed and each individual cell was packaged in a separate unit cell container designed to accomodate a single cell restrained between two (2) steel plates. Several such unit cell packages were then packed in wooden crates for shipment to NASA Lewis Research Center.

8.2 Figure (4) shows a completed Model HS40-7 Cell.

8.3 Figure (5) presents an analysis of the distribution of finished cell weights for the Model HS40-7 cell. The average cell weight, excluding steel restraining fixtures, was 889 grams. All cells weighed within the range of 879 - 898 grams.

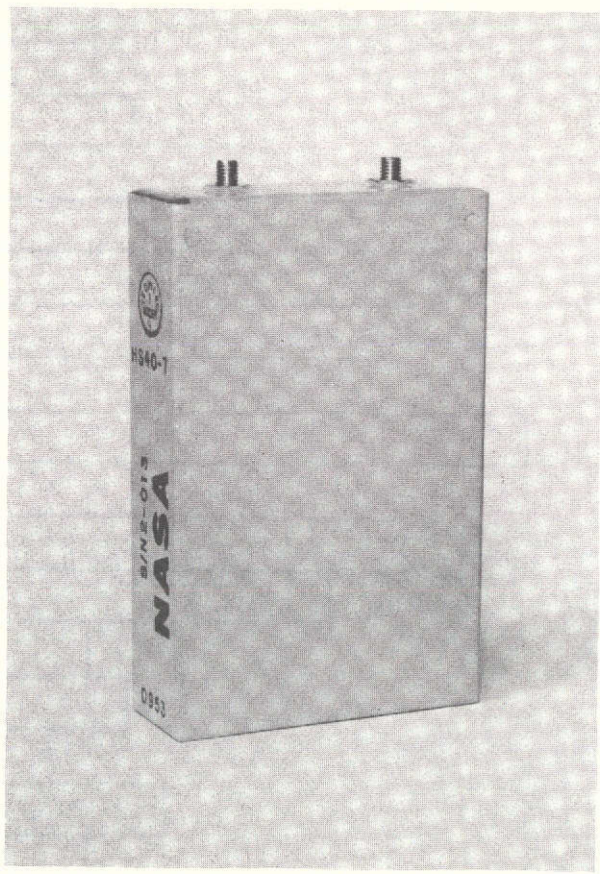

FIGURE 4

COMPLETED HS40-7 CELL

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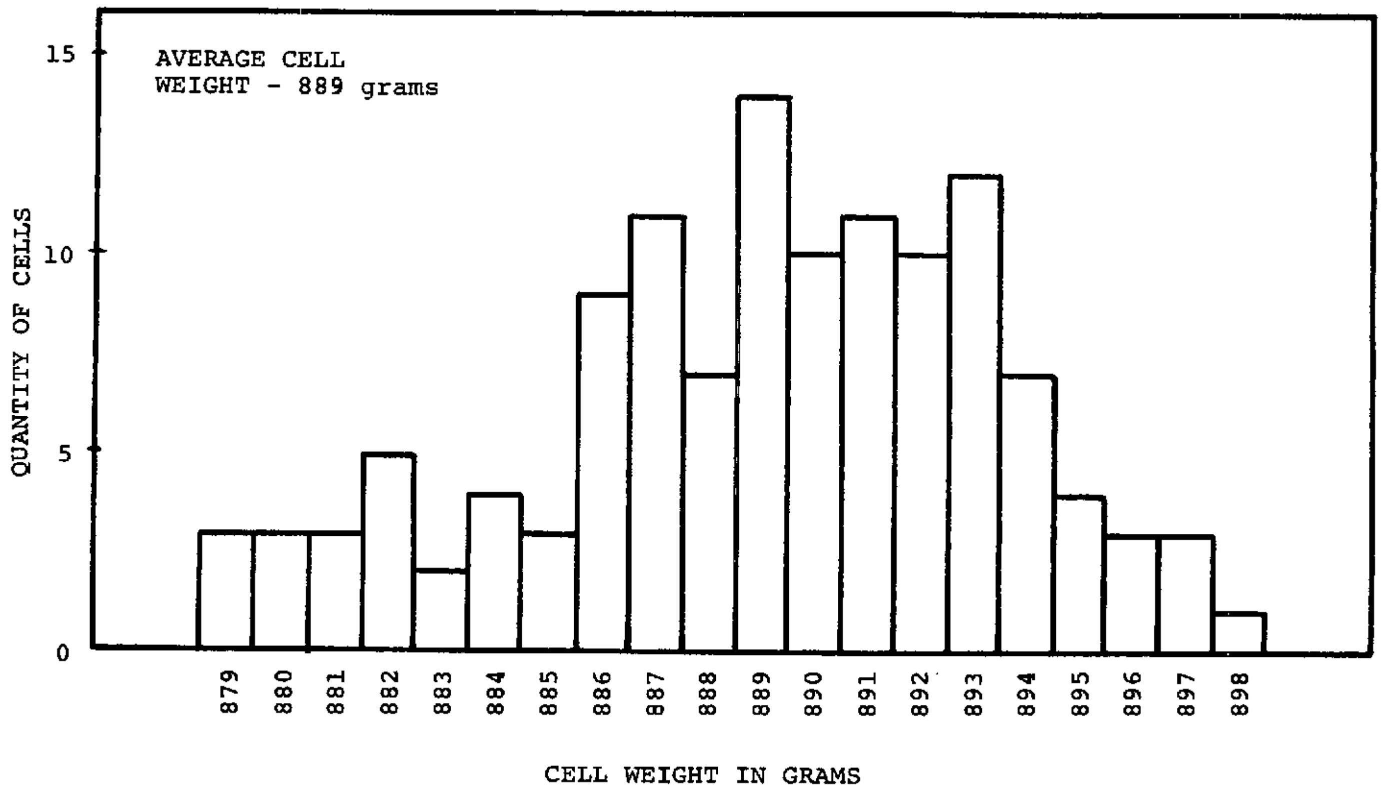
FIGURE 5

ANALYSIS OF DISTRIBUTION OF
FINISHED HS40-7 CELL WEIGHTS



TASK III - CELL TESTING

1. Objective of Task

1.1 To perform electrical tests on five (5) cells from each of the first two (2) lots of ten (10) cells fabricated, filled, formed and finished under Task II.

2. Cell Performance Characterization Tests

2.1 The cells selected by the NASA Project Manager for use in Task III are tabulated below:

Lot No. 1	Lot No. 2
S/N1-001	S/N2-012
S/N1-003	S/N2-013
S/N1-005	S/N2-014
S/N1-007	S/N2-020
S/N1-009	S/N2-021

2.2 Each selected cell was given four (4) test cycles to determine its voltage characterization at each discharge rate.

2.3 In preparation for each test discharge, each cell was charged at a constant current of 1.5 amperes to a voltage, while charging, of 1.98-2.00 volts or until a capacity input of 45.0 ampere-hours had been achieved.

2.4 Each charged cell was then discharged at the applicable test cycle discharge rate to an end voltage of 1.00 volt. The test cycle discharge rates were:

Test Cycle No.	Test Discharge Rate
1	120A
2	80A
3	40A
4	20A

2.5 Following each test discharge, each cell was further discharged at a current of 2.0 amperes to an end voltage of 1.00 volt.

2.6 The voltages on charge/discharge and low rate drains for each test cycle were continuously recorded as a function of time. The ampere-hours inputs and outputs were calculated and recorded for the applicable portions of each test cycle. The test discharge capacity and plateau voltage for each cell at each test discharge rate is given in Table II. Typical voltage curves at the test discharge rates are given in Figure 6.

TABLE II

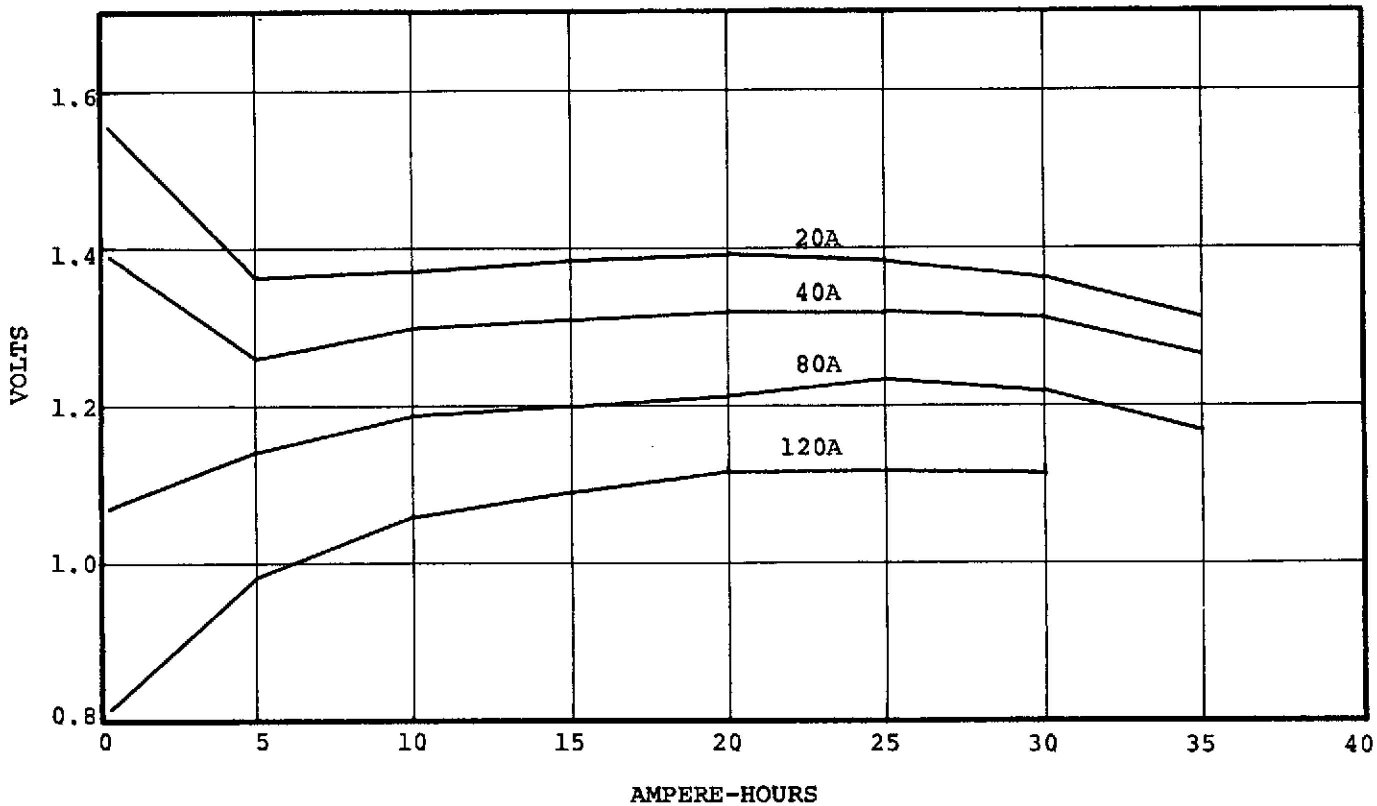
PERFORMANCE-CHARACTERIZATION TESTS
CAPACITY AND PLATEAU VOLTAGE

CELL LOT NO. AND SERIAL NO.	CURRENT							
	20A		40A		80A		120A	
	Ah	V	Ah	V	Ah	V	Ah	V
1-001	39.5	1.39	38.9	1.31	36.5	1.21	31.1	1.12
1-003	39.2	1.39	38.6	1.32	36.7	1.22	32.6	1.12
1-005	39.1	1.39	38.2	1.32	36.2	1.23	32.7	1.12
1-007	39.1	1.40	38.5	1.32	36.6	1.23	32.4	1.12
1-009	39.0	1.39	38.2	1.31	36.2	1.22	31.3	1.12
2-012	37.6	1.39	38.7	1.32	36.7	1.21	28.4	1.10
2-013	36.8	1.39	38.5	1.32	36.6	1.22	27.5	1.10
2-014	37.7	1.38	38.9	1.32	37.0	1.22	29.8	1.11
2-020	37.3	1.39	38.1	1.32	37.8	1.23	33.8	1.13
2-021	37.0	1.39	38.3	1.32	37.3	1.22	32.4	1.12

NOTE: Cells were drained at 2.0A to 1.00V after each specific test discharge (Drain output not shown)

FIGURE 6

TYPICAL VOLTAGE CURVES FOR CELL MODEL HS40-7
AT FOUR DISCHARGE RATES



3. 100% Depth of Discharge Cycle Testing

3.1 The ten (10) Model HS40-7 cells which were used for the Performance Characterization Tests were then cycled continuously on a 100% depth of discharge regime until failure. For the purpose of this test program, a cell was considered to have failed from the capacity standpoint when the ampere-hours output on discharge became less than 50% of the initial capacity level of 40.0 ampere-hours. During a period of life cycle testing, three (3) separate life cycle test regimes and one (1) cell conditioning regime were used. These regimes were put into effect at the direction of the NASA Project Manager. The electrical parameters and the cycle effectivity of each regime are given in Table III.

3.2 The ten (10) Model HS40-7 cells were life cycle tested using an automatic cycler designed and fabricated under this contract. This automatic cycler was constructed in accordance with Yardney Drawing 13174. This equipment has the capacity of continuously and automatically cycling twelve (12) individual Sealed Silver-Zinc Cells with charging rates varying between 0.10 and 10.00 amperes and with discharge rates up to 30.0 amperes. The equipment consists of a programmed constant current power supply, a timer and a charge/discharge mode control chassis, a cycle counter chassis, twelve (12) individual cell control modules and a filtered air-cooling fan, with all equipment housed in one (1) protective enclosure. Twelve (12) connectors are provided on the side of the enclosure and externally connected to the test cells. A separate 0-2.50 volts range, 24 plot point strip chart recorder was used to record cell voltages during life cycling.

3.3 During the equipment evaluation tests on the automatic cyclers (using prototype HS40-7 Sealed Silver-Zinc Cells) it was found that the second plateau peak voltage achieved by a cell being charged at a C/10 rate exceeded the cell voltage cutoff setting of 1.98-2.00 volts for a period of 5-6 minutes. This false voltage peak caused the equipment to terminate the charging portion of a cycle prematurely, therefore an additional circuit was designed and installed on each of the twelve (12) cell control modules which enabled the equipment to bypass this voltage peak and terminate the charge portion of a cycle when a cell was completely charged as indicated by a permanent second plateau peak voltage which persisted for longer than six (6) minutes. This modification to the automatic cycler was authorized and completed in accordance with Amendment No. 2 to the contract.

3.4 The ten (10) Model HS40-7 test cells were life cycled using the above listed equipment, being alternately charged and discharged under the applicable test regimes until failure. The input and output capacity for each cell on each cycle completed was determined from the data automatically plotted by the strip chart recorder.

TABLE III

100% DOD CYCLE TESTING REGIMES

TEST REGIME DESIGNATION	REGIME PARAMETERS		REGIME CYCLE EFFECTIVITY	
	CHARGE	DISCHARGE	Lot #1	Lot #2
A	4.0 amps for 10 hours or to 1.98-2.00 volts	20 amps for 2 hours or to 1.00 volts	1-33	1-27
B	3.6 amps for 12 hours or to 1.98-2.00 volts	20 amps for 2 hours or to 1.00 volt	34-96	28-90
Conditioning Cycles	3.6 amps for 12 hours or to 1.98-2.00 volts	20 amps for 2 hours or to 1.00 volt. 6.0 amps to 1.00 volt 2.0 amps to 1.00 volt	97	91
	1.5 amps to 1.99 volts or 45AH input	6.0 amps to 1.00 volt 2.0 amps to 1.00 volt	98	92
C	2.0 amps for 22 hours or to 1.99 volts	20 amps for 2 hours or to 1.20 volts	99 and on	93 and on

3.5 Figures (7 - 16) present summaries of the data on the ten (10) test cells. These figures show a plot of output capacity only, since, even at the point of failure, which was defined as a capacity lower than 50% of initial capacity, the ratio of cycle output to input capacity was usually greater than 0.90.

3.6 It can be seen from figures (7 - 16) that the ten (10) test cells had either exhibited a sustained 50% capacity loss or had failed to accept a charge prior to the completion of Cycle #120. Based on the Failure Analysis of cell S/N 1-009 and cell S/N 2-014, it was decided to continue the cycling of the eight (8) remaining test cells until they would no longer accept charge, indicating a permanent breakdown in the separator system.

4. Failure Analysis

4.1 After the completion of 100% DOD Cycle Testing, the failed cells were given extensive external and internal examination to determine the cause of failure.

4.2 The open circuit voltage of the restrained cell was read and recorded and examination of the cell top, terminal assemblies and the visible portions of the cell case was completed prior to removing the steel restraining plates. Phenolphthalein indicator was used to verify the presence (or absence) of electrolyte leakage in the cell top and terminal assembly areas.

4.3 With the restraining plates removed, the cell was cleaned, weighed, and examined again for electrolyte leakage, bulging and cell case defects or damage. The open circuit voltage was also read and recorded after removal of restraining plates.

4.4 Using a band saw and fixtures designed for this purpose, a cut was made through the narrow side of the cell case just below the case to cover weld area adjacent to the positive terminal. The cell was then positioned in a large glass funnel so that the free electrolyte in the cell cavity would drain out through the cut in the cell case and be collected. The quantity of free electrolyte was measured and sealed in a clean polyethylene bottle.

4.5 Using the band saw and fixturing, a series of cuts were made through the cell case walls which resulted in the removal of the cell case material between the case-to-cover weld area and the area approximately 2.5mm above the top of the cell stack. The condition of the positive and negative tab-to-terminal connection areas was noted.

FIGURE 7

PERFORMANCE SUMMARY
100% DOD CYCLE TESTING

CELL S/N 1-001

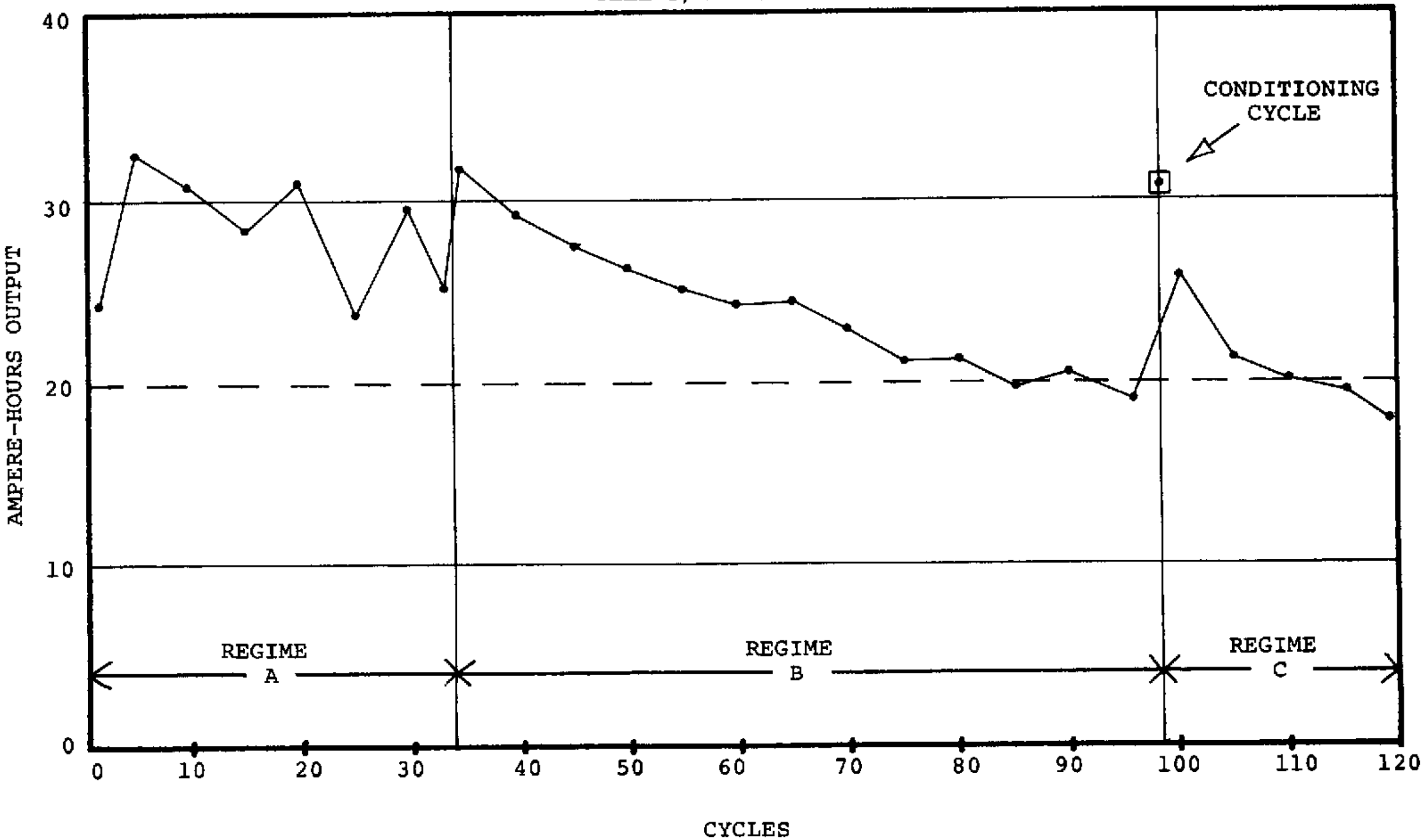


FIGURE 8

PERFORMANCE SUMMARY
100% DOD CYCLE TESTING

CELL S/N 1-003

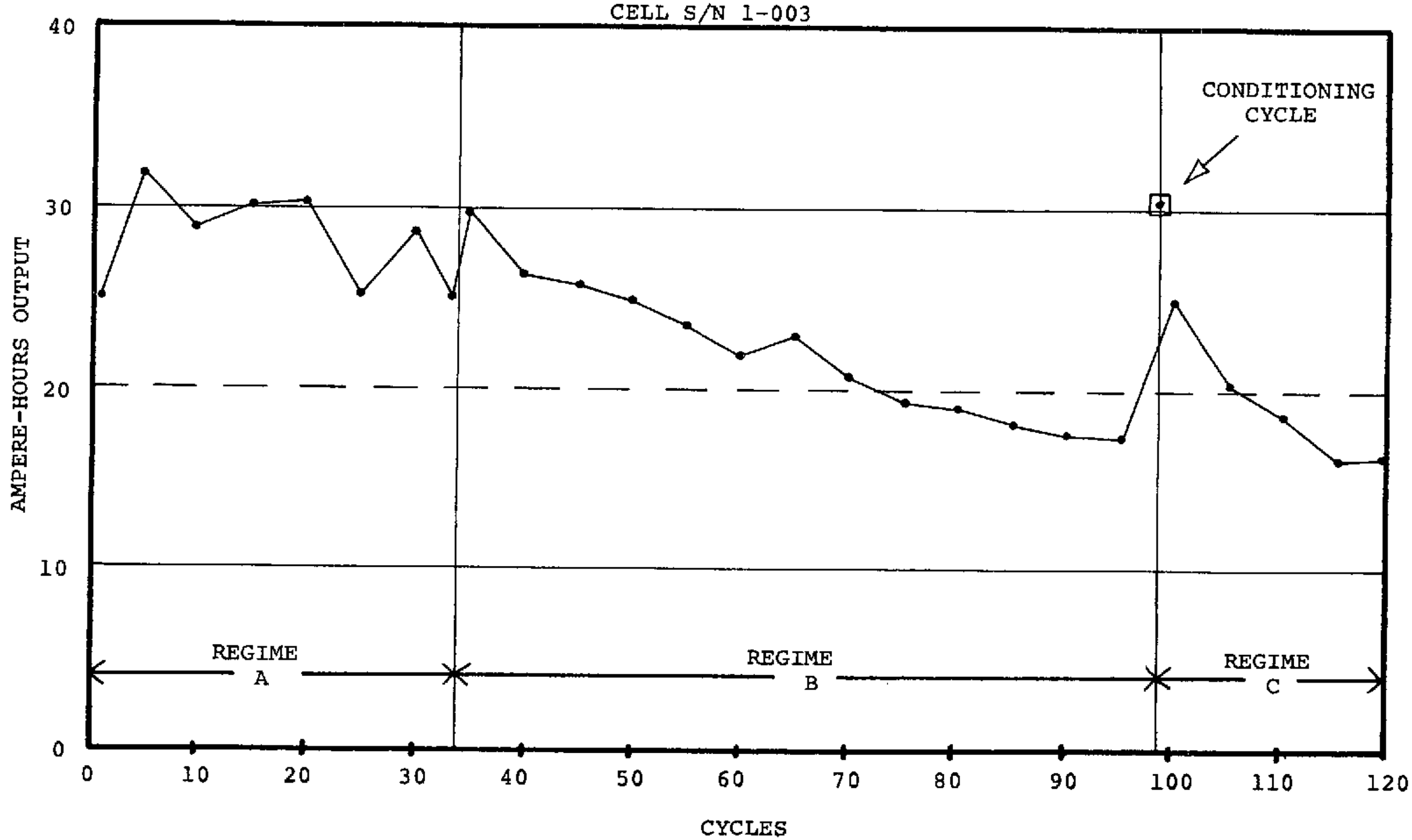


FIGURE 9

PERFORMANCE SUMMARY
100% DOD CYCLE TESTING

CELL S/N 1-005

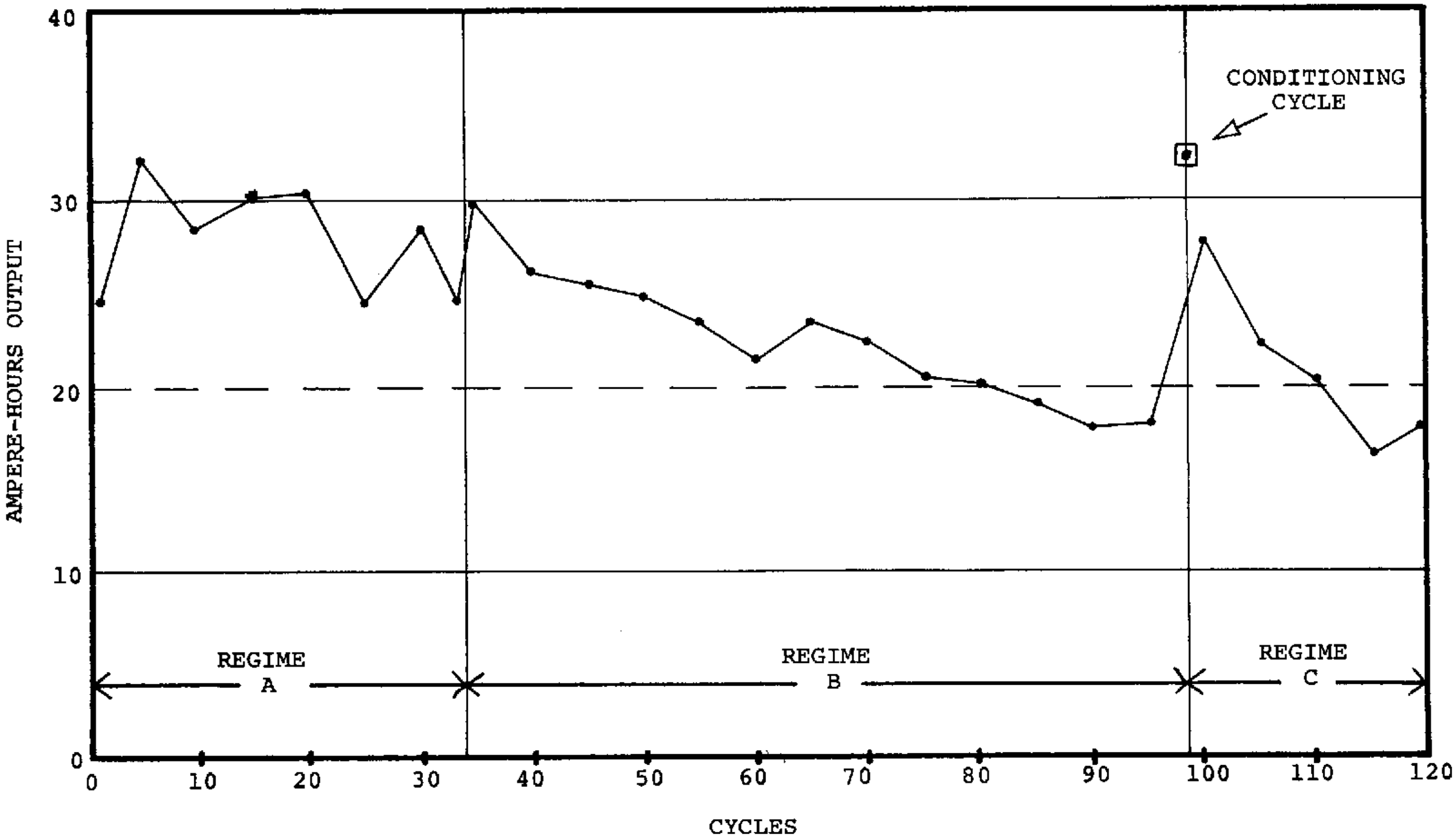


FIGURE 10

PERFORMANCE SUMMARY
100% DOD CYCLE TESTING

CELL S/N 1-007

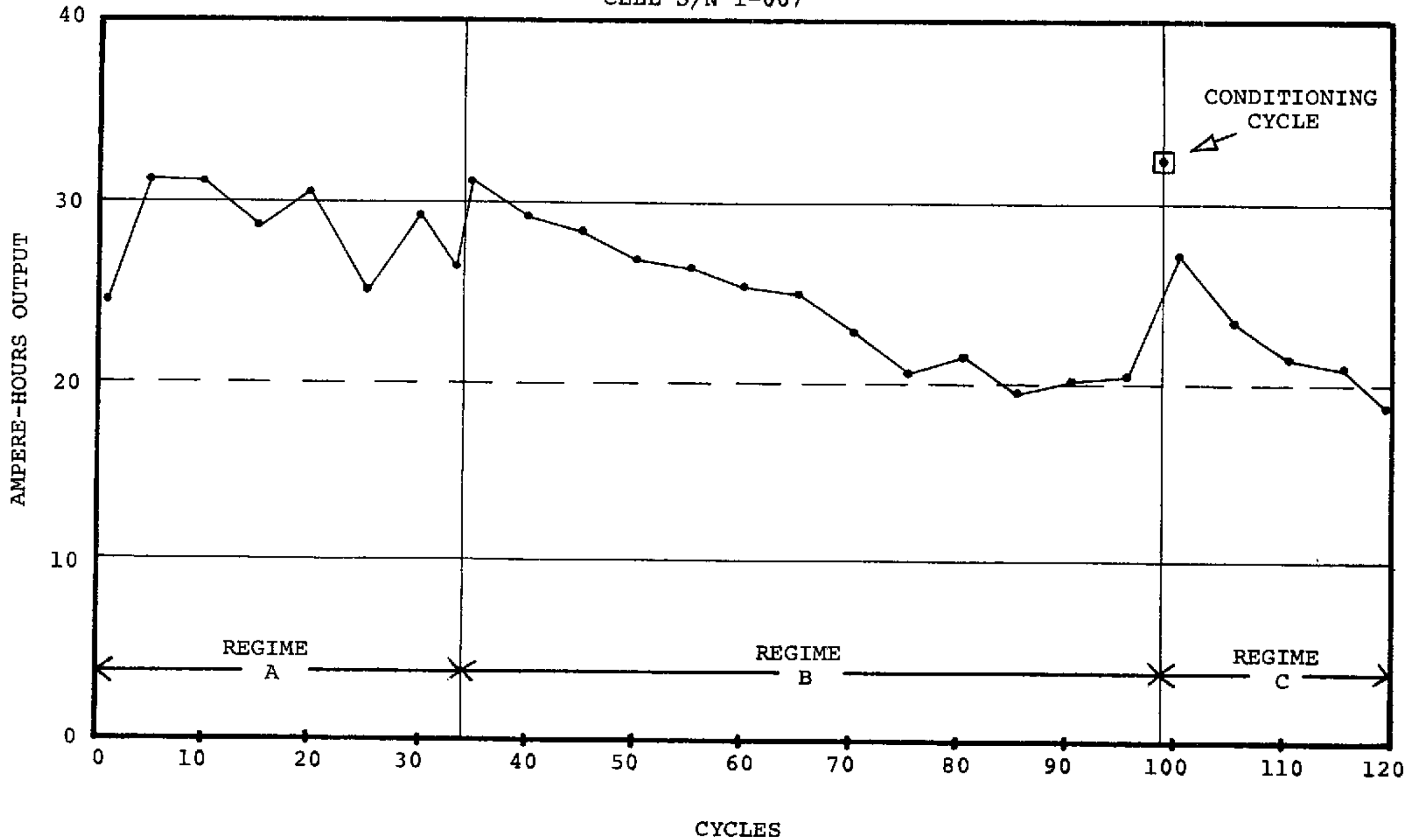


FIGURE 11

PERFORMANCE SUMMARY
100% DOD CYCLE TESTING

CELL S/N 1-009

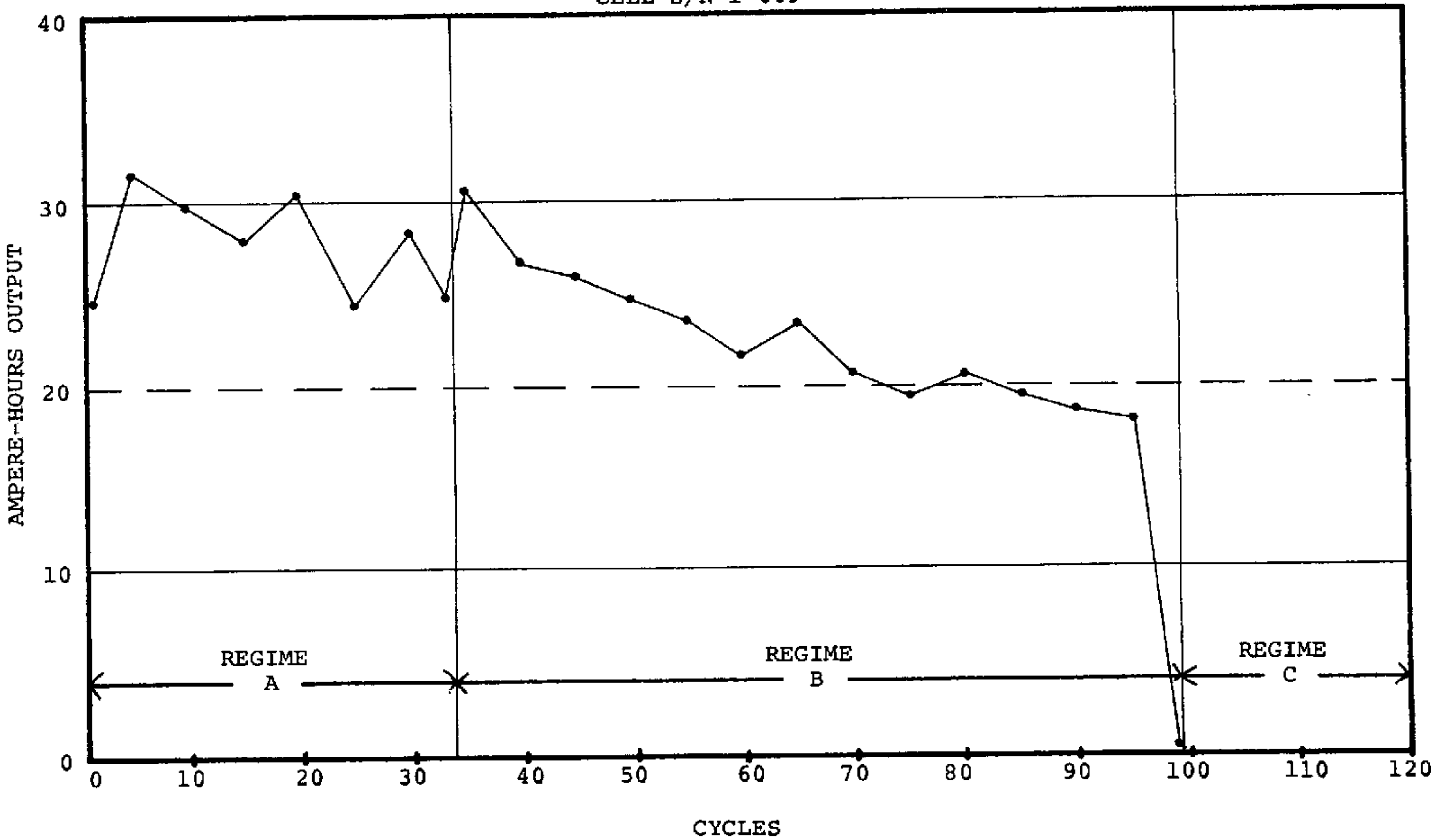


FIGURE 12

PERFORMANCE SUMMARY
100% DOD CYCLE TESTING

CELL S/N 2-012

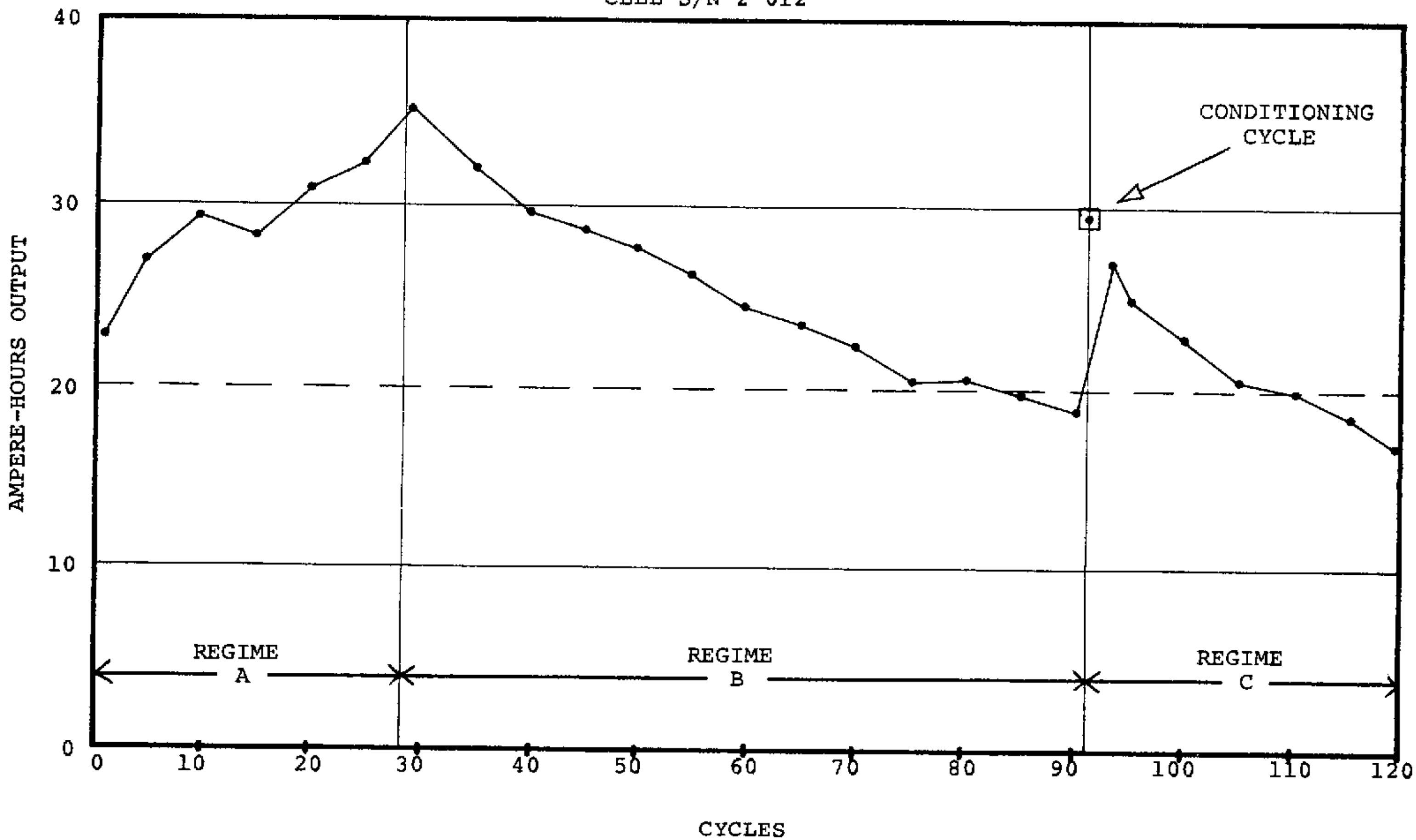


FIGURE 13

PERFORMANCE SUMMARY
100% DOD CYCLE TESTING

CELL S/N 2-013

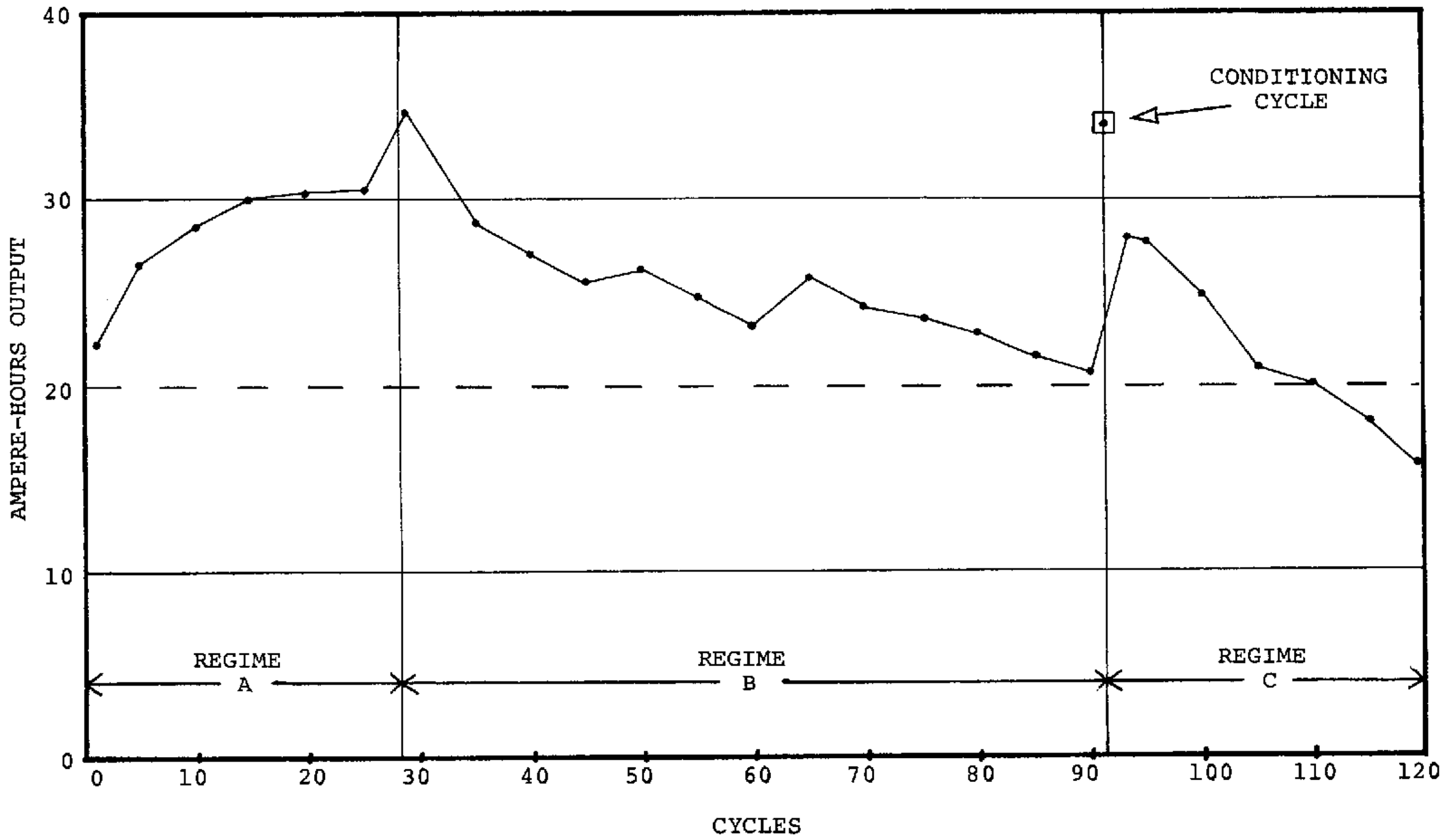


FIGURE 14

PERFORMANCE SUMMARY
100% DOD CYCLE TESTING

CELL S/N 2-014

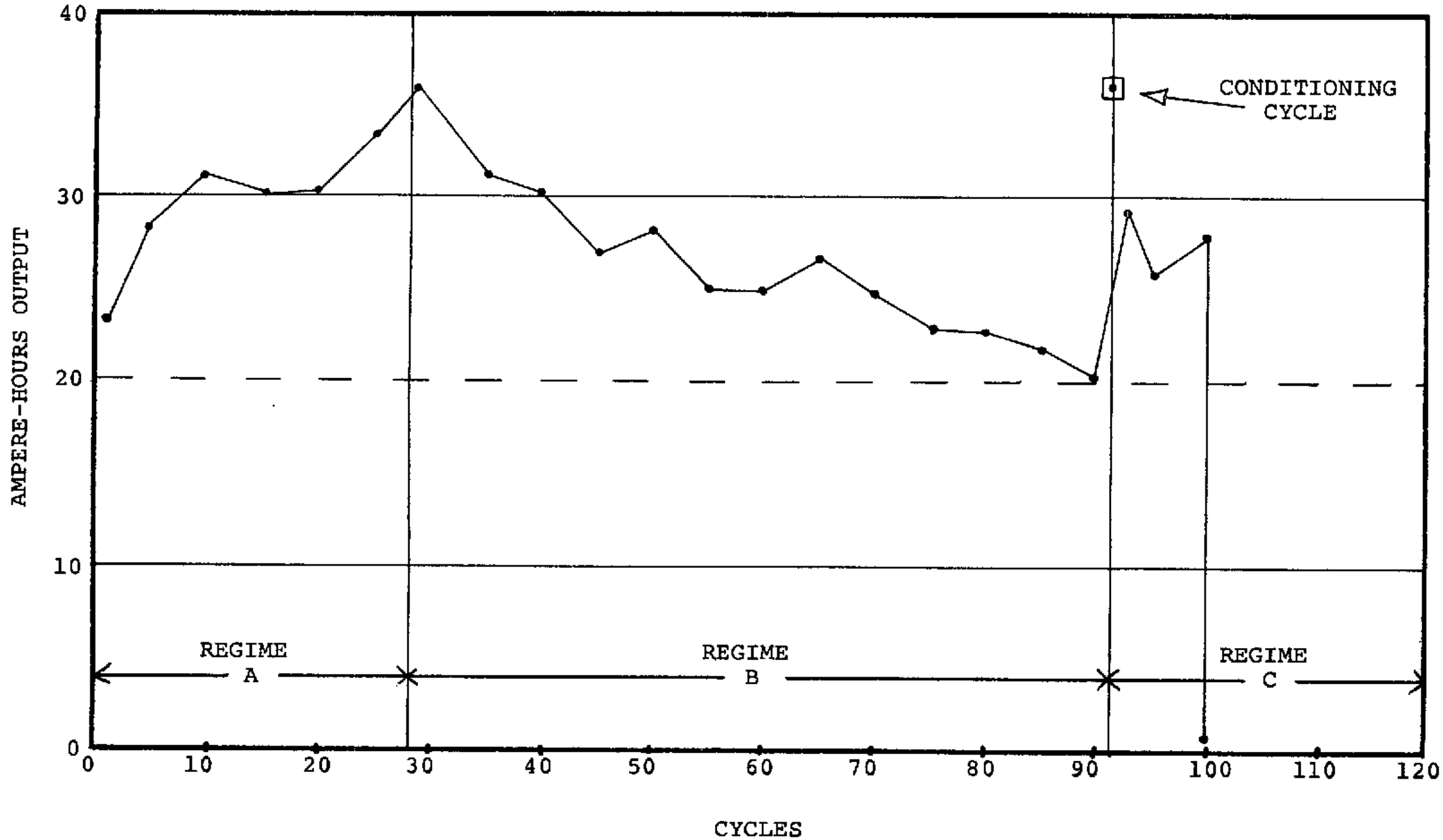


FIGURE 15

PERFORMANCE SUMMARY
100% DOD CYCLE TESTING

CELL S/N 2-020

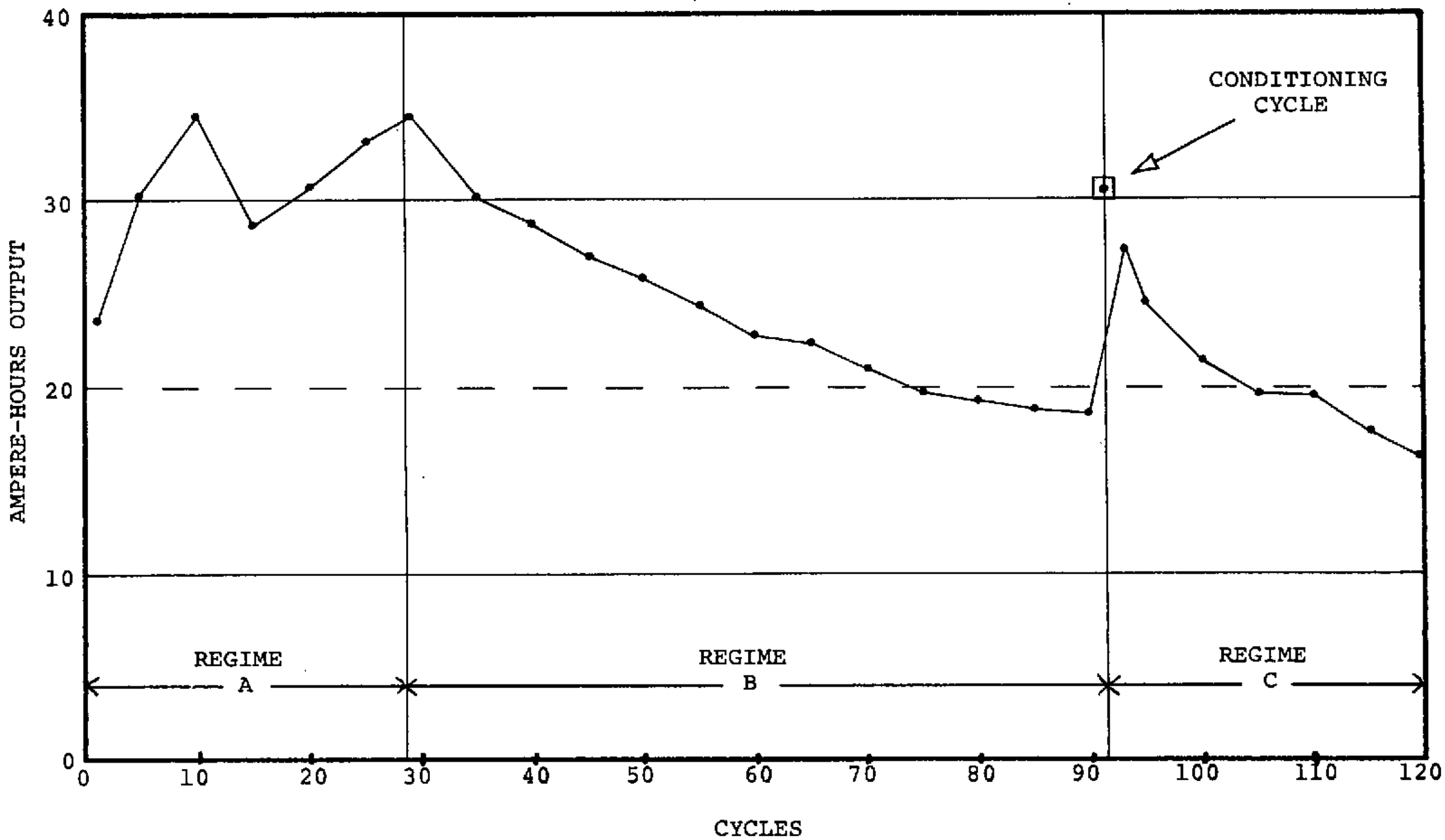
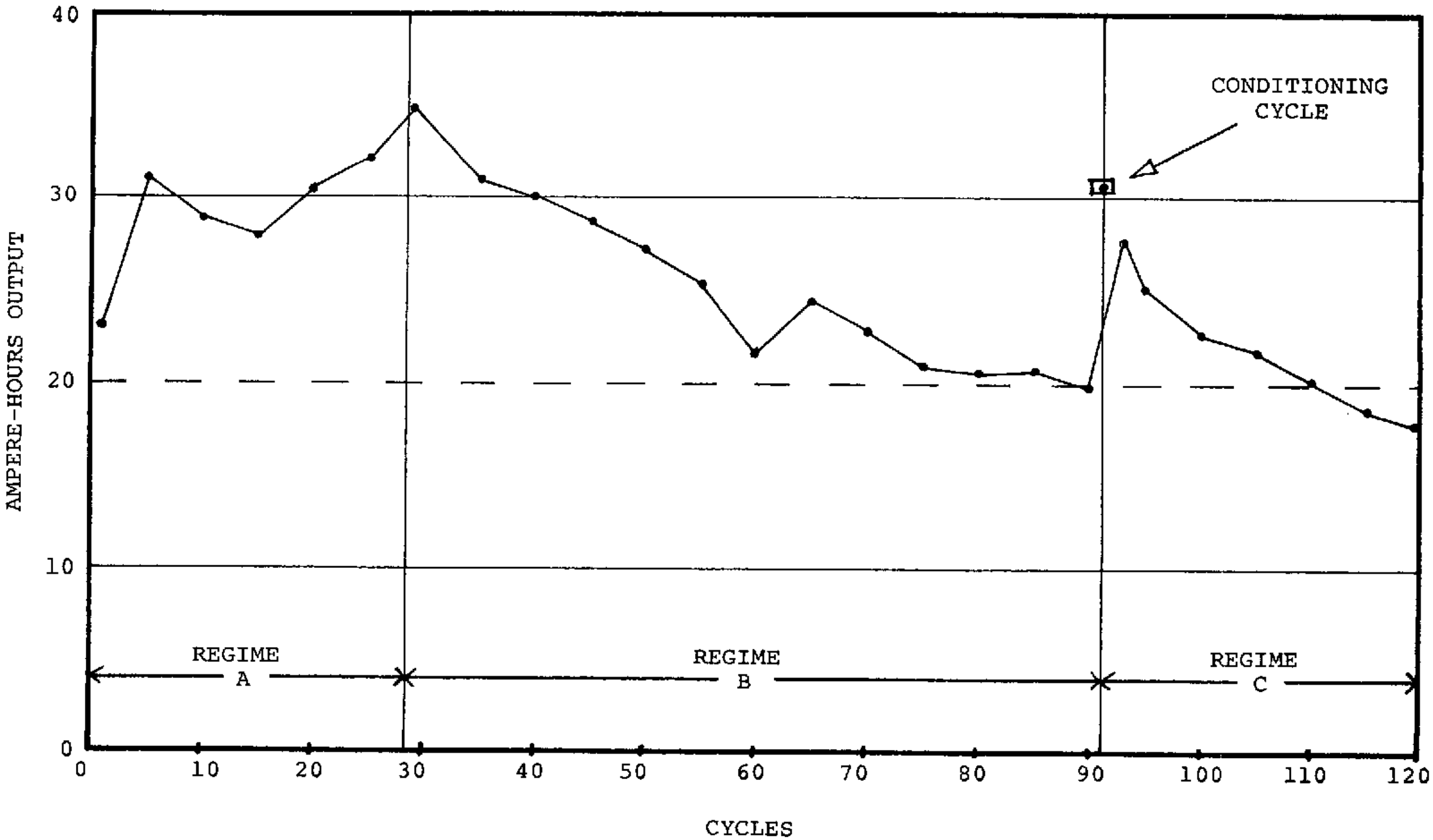


FIGURE 16

PERFORMANCE SUMMARY
100% DOD CYCLE TESTING

CELL S/N 2-021



4.6 The tabs were disconnected from their respective terminals and carefully formed to an upright position. The quantity and condition of the tabs was observed and noted. Using a digital voltmeter, the open circuit voltage, between each positive electrode tab and every negative electrode tab, was read and recorded.

4.7 The cell case was then removed from the cell stack. The general condition of the cell stack and cell case were noted with particular emphasis on the quantity and location of active material.

4.8 The cell stack was carefully disassembled and the electrodes individually identified. Observations were recorded on the condition of the separator on each electrode. In this phase of the failure analysis, the plate-to-plate open circuit voltage readings were used as a guide to indicate the areas where increased care in dissection and more detailed observation would reveal detrimental conditions in the separator.

4.9 Areas of pronounced deterioration in the separator and penetration by active material were more closely scrutinized. These areas were photographed or sketched to supplement the observations recorded.

4.10 The separator bags were then opened and the physical condition of the electrodes noted. Particular attention was paid to the shape change of the negative electrode and the loss of active material.

4.11 Three (3) of the ten (10) test cells have been subjected to Failure Analysis. These were cells S/N 1-005, 1-009, and 2-014. All three (3) cells failed due to being unable to accept charge. The failures were caused by Zinc penetration through the Negative Separator Bag.

4.12 In cells S/N 1-005 and 2-014, this penetration was in the form of a nodule which had pushed its way into the Positive Separator bag material. The growth of the nodule within the Positive Separator bag material ultimately completed the connection between the electrodes, causing the failure.

4.13 In cell S/N 1-009, the penetration manifested itself as a 0.8 square centimeter metallic zinc deposit, 0.05 millimeters thick, on the outside of the Negative Separator bag between electrodes. Silver migration through the adjacent Positive Separator bag completed the connection between the electrodes.

4.14 Loss of effective area in the Negative Electrodes of cell S/N 1-009 was estimated to be five percent (5%). Cell S/N 1-005, which ran thirty-three (33) more cycles than S/N 1-009, showed an estimated effective area diminution of between five and seven percent (5%-7%).

4.15 The only Lot No. 2 cell dissected, S/N 2-014, had noticeably less Negative Electrode shape change and its effective area reduction was estimated to be three percent (3%). We attribute this to the introduction of the edge dipping (reinforcement) process on Lot No. 2 Negative Electrodes, described in Task II, Paragraph 3.8, of this report.

TASK IV - RELIABILITY AND QUALITY ASSURANCE

1. Objective of Task

To develop, implement and document an effective and integrated system of controls on all materials, processes, equipment, environmental conditions, inspections, analyses, and tests related to the manufacture of Sealed Silver-Zinc cells in the NASA-Yardney Facility.

2. General System Organization

2.1 The Quality Assurance systems presently in use in the Yardney Electric Division meet the requirements of Military Specification MIL-Q-9858A - Quality Program Requirements - and NASA Reliability and Quality Assurance Publication NHB 5300.4(1C). The system for calibration of measuring and testing equipment satisfies the requirements of Military Specification MIL-C-45662A - Calibration System Requirements. The effective implementation of these systems has been demonstrated in the successful participation by Yardney Electric Division in many programs requiring high reliability cells and batteries.

2.2 In order to deal more specifically with the objectives and requirements of the Program for Development and Fabrication of Sealed Silver-Zinc Cells, an organizationally separate Reliability and Quality Assurance System was established. The organization of this system is established in the Reliability and Quality Assurance Program Plan, RQAPP #400. This plan identifies the functions and activities which affect reliability and quality and assigns authority and responsibility for the implementation of the policies and procedures under which the system operates. This plan was submitted to and approved by the NASA Project Manager.

2.3 A series of five (5) Supplements to the Reliability and Quality Assurance Program Plan was prepared to detail the methods, equipment and data requirements of the inspections, tests and analyses involved in implementing the Program Plan during the Cell Fabrication and Cell Testing Tasks. The titles and scope of these

Supplements are as follows:

a. Supplement I, the Quality Inspection Plan (QIP#400), defines the sequence of fabrication operations and the related quality and reliability controls. The criteria for the inspection of cell materials and in-process inspection of fabricated assemblies are detailed in this supplement. Also included are the procedures and forms used in maintaining traceability controls.

b. Supplement II, the Acceptance Test Procedure (ATP#400), contains the procedures for Completed Item inspection and Cell Test Log compilation.

c. Supplement III, the Performance-Characterization Test Procedure (PCT#400), describes the test circuitry and test methods used in accomplishing the Performance-Characterization Test portion of Task III.

d. Supplement IV, the Life Cycle Test Procedure (LCT#400), outlines initiating, monitoring and documenting the 100% DOD Cycle Testing phase of the cell testing accomplished under Task III.

e. Supplement V, the Failure Reporting, Analysis and Corrective Action Procedure (FRACA#400), contains the methods for test cell failure analysis and reporting.

2.4 The Yardney Instructions Manual (DOC-QA-200) was included in the Program Plan documentation as Supplement VI. This document contains general quality assurance system implementing procedures which were used as noted in the Program Plan, RQAPP#400.

3. Reliability Provisions

3.1 Facility and Process Review

A review of the preparation of the facility and cell fabrication processes was scheduled for a period prior to the initiation of deliverable cell manufacture. An agenda was prepared and supplied to the review participants from Yardney and to the NASA Contracting Officer fifteen (15) days prior to the start of the review. The agenda outlined the systematic evaluation of the facility construction, major equipment, tooling, cell materials, fabrication processes, quality inspections and traceability controls.

3.2 Failure Reporting, Analysis and Recommended Corrections

A system was established for reporting and analyzing cell failures experienced in the Cell Testing phases of the contract. The failure analysis methods and reporting requirements are defined in Document FRACA #400, Supplement V to the Reliability and Quality Assurance Program.

4. Quality Assurance Provisions

The Quality Assurance System, as defined in the Reliability and Quality Assurance Program Plan, was implemented in accordance with the applicable Program Plan supplements.

4.1 Cell materials were inspected using the procedures and criteria contained in Section 5 of the Quality Inspection Plan, QIP #400.

4.2 The component sub-assembly and assembly operations were monitored by performing the inspections and analyses specified in Section 6 of QIP #400. The cell formation cycles and cell heat treating were also monitored in accordance with Section 6.

4.3 The facility environmental conditions and equipment controls were maintained as detailed in Section 7 of QIP #400. The safety policy included in this procedure section was fully implemented.

4.4 The traceability of materials, component assemblies, processes, inspections, equipment usage and operators was maintained and documented using the procedures and forms contained in Section 8 of QIP #400.

4.5 The completed cells were inspected and the Cell Test Logs were prepared in accordance with the Acceptance Test Procedure, ATP #400.

4.6 The ten (10) cells selected by the NASA Project Manager were given Performance Characterization Tests in accordance with the requirements of the contract using the procedures outlined in PCT #400.

4.7 The ten (10) cells, having completed Performance Characterization Tests, were subjected to 100% DOD Cycle Testing as specified in the contract and as directed by the NASA Project Manager. The Life Cycle Test procedure, LCT #400, was followed in accomplishing this testing.

5. Contract Reliability and Quality Assurance Summary

The results of the implementation of the Reliability and Quality Assurance Provisions are summarized in this section of the report. For the sake of brevity, the summary of Quality Assurance System results details only those facets of the program where defective materials were detected.

5.1 Reliability Summary

5.1.1 The Facility and Process Review was conducted as scheduled. Using the review agenda as a guide, the facility construction, major equipment, tooling, cell materials, fabrication processes and techniques, quality inspections and traceability controls were evaluated in each of six (6) basic areas:

1. Pre-parts fabrication and cover assembly
2. Positive Electrode Fabrication
3. Negative Electrode Fabrication
4. Separator Fabrication and Application
5. Cell Assembly
6. Cell Filling, Formation, Finishing and Testing

The results of the Facility and Process Review were documented in a report which was submitted to and approved by the NASA Project Manager.

Three (3) pre-production cells, type HS40-7, were fabricated during the Facility and Process Review. These cells were subsequently filled, given Formation Cycle #1, heat treated, sealed and top potted, given Formation Cycle #2, subjected to Performance Characterization Tests and used to evaluate the automatic cell cycling equipment. Data generated during the testing of these cells was forwarded to the NASA Project Manager.

5.1.2 The Failure Reporting, Analysis and Recommended Corrections system defined in Document FRACA #400 has been used on three (3) of the ten (10) cells subjected to 100% DOD Cycle Testing. The results of these failure analyses are summarized under Task III - Cell Testing, paragraphs 4.11 through 4.14, of this Contractor Report.

5.2 Quality Assurance Summary

5.2.1 The inspection of cell materials detected only one lot of material which was nonconforming. The first shipment of 700 Troy ounces of Silver Powder, ordered and inspected to Dwg. 1D12572, was rejected for having an apparent density of 17.1 grams per cubic inch as measured with the Scotts Volumeter. The material, "Sil-powder 130", batch no. 224, was returned to the vendor and replaced with material which met the Apparent Density specification of 12.0 - 16.0 g/in3.

5.2.2 The in-process inspections of materials and parts produced during Cell Fabrication and processing operations detected less than 0.5% defective parts in the conductor grid assembly, sealed separator bag, cell cover assembly and cell assembly areas. This low rate of rejection can be attributed to proper tooling design and operator training. The majority of the few defects found in these areas were caused by mis-handling.

5.2.3 The eight (8) batches of Negative Mix that were blended were acceptable. The percent Mercuric Oxide content for each batch was analyzed and ranged between 1.95% and 2.06% with an overall average of 2.01% for the eight (8) batches.

5.2.4 The results of the inspection of Negative Electrode Sub-Assemblies for the one hundred twenty-five (125) cells were as follows:

Total Quantity Inspected -- 841
Total Quantity Accepted -- 686
Total Quantity Rejected -- 155

Percent (%) Rejected -- 18.4%

The breakdown of defects is as follows:

Attribute	Quantity	Percent
Visual	68	8.1
Length	1	0.1
Width	3	0.4
Thickness	33	3.9
Weight	50	5.9

5.2.5 The results of the inspection of Positive Electrode Sub-Assemblies for one hundred twenty-five (125) cells were as follows:

Total Quantity Inspected -- 915
Total Quantity Accepted -- 796
Total Quantity Rejected -- 119

Percent (%) Rejected -- 13%

The breakdown of defects is as follows:

Attribute	Quantity	Percent
Visual	85	9.3
Length	0	0.0
Width	5	0.5
Thickness	11	1.2
Weight	18	2.0

Note: Of the 85 electrodes rejected for visual attributes, 48 were rejected from Lot 2 for contamination caused by a high sulfur content table covering.

5.2.6 The results of the inspection of Negative Electrode Assemblies - Bagged for the one hundred twenty-five (125) cells were as follows:

Total Quantity Inspected -- 693
Total Quantity Accepted -- 641
Total Quantity Rejected -- 52

Percent (%) Rejected -- 7.5%

The breakdown of defects is as follows:

Attribute	Quantity	Percent
Cast Film Thickness	19	2.7
Bagged Assembly Weight	4	0.6
Surface Defects	29	4.2

5.2.7 The results of the inspection of Positive Electrode Assemblies - Bagged for the one hundred twenty-five (125) cells were as follows:

Total Quantity Inspected -- 862
Total Quantity Accepted -- 778
Total Quantity Rejected -- 84

Percent (%) Rejected -- 9.7%

The breakdown of defects is as follows:

Attribute	Quantity	Percent
Cast Film Thickness	37	4.3
Bagged Assembly Thickness	3	0.3
Bagged Assembly Weight	30	3.5
Surface Defects	14	1.6

5.2.8 Of the one hundred twenty-five (125) cells that were sealed by ultrasonic welding, two (2) failed to pass the pressure test. In the first instance the cell nesting fixture which positions the cell in relation to the welding horn, was not completely closed. The second failure was attributed to a breakout or glass fiber concentration in the cell cover energy director. Using more care in securely positioning the cell in the nesting fixture eliminated the recurrence of failures similar to the first instance. Close visual examination of covers used for subsequent assemblies resulted in no further failures in ultrasonic sealing.

5.2.9 Of the one hundred twenty-five (125) cells given Formation Cycle No. 2, two (2) cells failed to meet the discharge capacity requirement of 40.0 ampere-hours output to an end voltage of 1.00 volt. Cell S/N 2-016 delivered 39.94 ampere-hours and cell S/N 2-018 delivered 38.54 ampere-hours. No apparent reason could be determined for these failures or for the fact that the average discharge capacity for the ten (10) cells of Lot No. 2 was the lowest of the five (5) lots given formation cycles.

5.2.10 The inspection of the one hundred twenty-five (125) completed cells detected only one (1) defect. Cell S/N 5-081 exhibited indications of possible electrolyte leakage between the terminal and the jam nut at the cell's Negative Terminal.

5.2.11 The results of the Performance Characterization Tests per PCT #400 and the 100% DOD Cycle Testing per LCT #400 are discussed in the Task III - Cell Testing section of this Contractor Report.

6. Additional Data

Figures (17 and 18) present charge and discharge voltage curves for Cell S/N 2-020 on 100% Depth of Discharge Test Cycles 10, 50, 90 and 93. Cycle 93 was the first cycle after the Conditioning Cycle (Cycle #92).

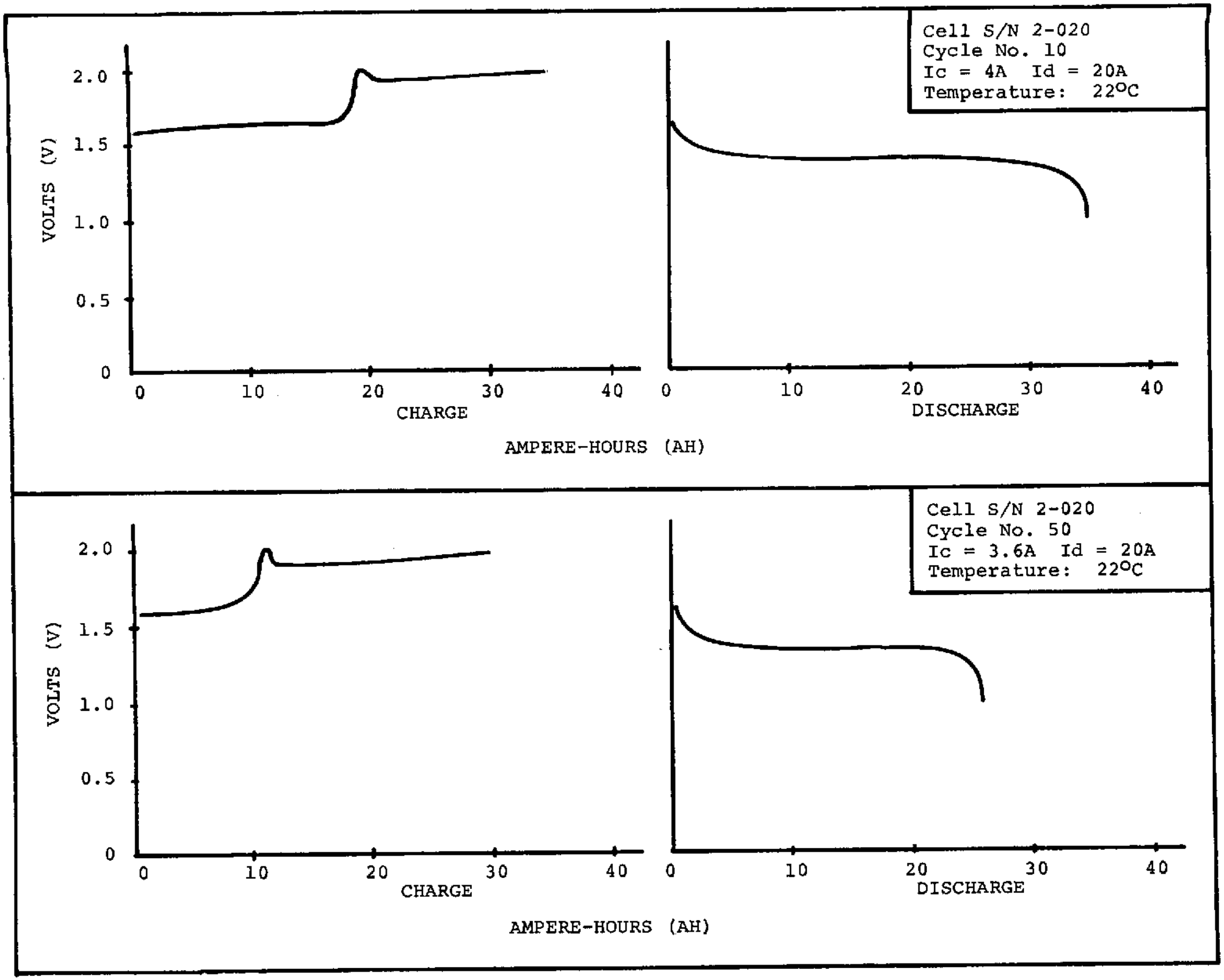


FIGURE 17 - CHARGE AND DISCHARGE VOLTAGE CURVES

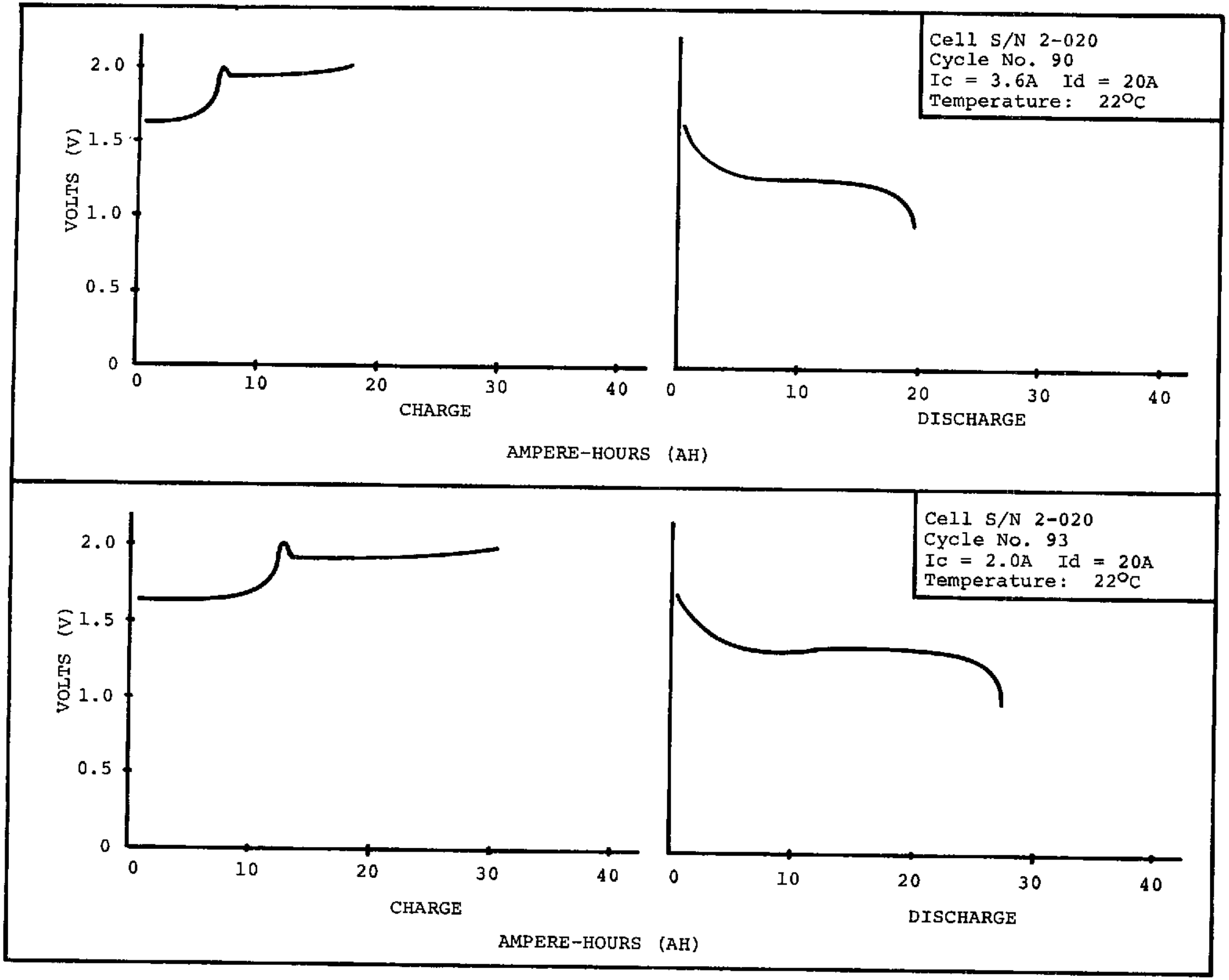


FIGURE 18 - CHARGE AND DISCHARGE VOLTAGE CURVES