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FINAL REPORT

NATIONAL AERONAUTICS SPACE ADMINISTRATION
GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

Contract NAS5-1607

ESB Report No. M-6-63

THE ELECTRIC STORAGE BATTERY COMPANY
MISSILE BATTERY DIVISION
RALEIGH, NORTH CAROLINA

21 March 1963

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[illegible]
[illegible], Goddard Space Flight Center
Contract NAS5-[illegible]
[illegible] Report No. [illegible]

FOREWORD

This is the final report on the design, development and testing of a standard line of low rate, high energy density, sealed, secondary silver oxide-zinc cells for the National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Maryland, to meet the final report requirement of Contract NAS5-1607.

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NASA, Goddard Space Flight Center
Contract NAS5-1607
[illegible] Report No. [illegible]

ABSTRACT

Experimental work resolving the effects of plate thickness, sealing techniques, and various separator systems led to the design of a standard line of non-magnetic, sealed, low rate silver-oxide-zinc cells for space applications. Three cell sizes with nominal ratings of 20, 50, and 100 ampere-hours were constructed and tested. Contract objectives of 65 to 75 watt-hours per pound and 5 to 6 watt-hours per cubic inch have been met by the 20 ampere-hour cells and exceeded by the two larger sizes at discharge rates between 20 and 1000 hours in the temperature range 10°C to 50°C. Discharges at the 2000-hour rate are in progress with no serious degradation in performance expected.

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I. INTRODUCTION

A. Contract Objectives. - The general objective of Contract NAS5-1607, awarded to The Electric Storage Battery Company, Missile Battery Division, on November 21, 1960, was the design, development and testing of a standard line of low rate, high energy density, sealed, secondary silver oxide-zinc cells for space applications.

Specifically, three cell sizes (rated at 30, 60, and 100 ampere-hours) of similar construction were to be developed with the following characteristics as design objectives:

1. Actual capacities of 30, 60, and 120 ampere-hours, respectively, when discharged at the 20-hour to 1-year rate to 1.1 volts per cell.
2. Operating voltages (at 20-hour to 1-year rate) of 1.65 to 1.45 volts per cell.
3. Energy densities (at 20-hour to 1-year rate) of 65 to 75 watt-hours per pound and 5 to 6 watt-hours per cubic inch, based on first cycle output.
4. Operating life of 1 year.
5. Maximum shelf storage capacity loss of 1, 4, 10, and 20 per cent per month at 0, 22, 38, and 54 degrees C, respectively.
6. Position insensitivity.
7. Magnetic field intensity at a point three feet from the cell of 10^{-5} gauss or less.

B. Previous Reports. - The following reports have been submitted on Contract NAS5-1607:

1. First Quarterly Report, ESB Report No. E-21-62, March 27, 1962.
2. Second Quarterly Report, ESB Report No. E-33-62, May 22, 1962.
3. Third Quarterly Report, ESB Report No. E-49-62, August 17, 1962.
4. Fourth Quarterly Report, ESB Report No. E-96-62, December 21, 1962.

C. Coordination. - The following meetings were held between NASA and ESB personnel to discuss progress on this contract:

Date	Location	Personnel Present: NASA	Personnel Present: ESB
2/8/62	Goddard Space Flight Center Greenbelt, Md.	P. Donnelly	A. Chreitzberg D. Colbeck
4/6/62	ESB-Missile Battery Div. Raleigh, N. C	F. Yagerhofer	A. Chreitzberg J. Szabo D. Colbeck
6/14/62	Goddard Space Flight Center Greenbelt, Md.	P. Donnelly T. Bennigan F. Yagerhofer	A. Chreitzberg D. Colbeck
12/13/62	Goddard Space Flight Center Greenbelt, Md.	P. Donnelly T. Bennigan	A. Chreitzberg

II. EXPERIMENTAL WORK LEADING TO FINAL CELL DESIGN

A. Positive Plate Type and Thickness Investigation. - In order to maximize energy density in watt-hours per pound and watt-hours per cubic inch, active

material should be distributed into the smallest number of thicker plates consistent with a lack of serious polarization from the increased current density this involves.

Experimental cells, with polarities as listed in Table I, were designed to investigate the performance of cells containing relatively thick plates for the best combination of energy density and efficiency (ampere-hours per gram of silver). Positive plate thickness was varied at three levels (0.064, 0.092, and 0.146 inch) with plates made by two fabrication techniques (pressed powder and the ESB proprietary dispersed plastic process) used at each level for a total of six different plate packs, each of which was designed to fit into the same cell case.

Eighteen of these sealed cells (three of each type) were fabricated, charged at rates of 0.80 to 0.92 amperes (5 ma per gm of silver) to 1.95 to 1.97 volts per cell, and then discharged at the 10-hour rate based on nominal capacity (see Table I). Charge and discharge rates were based on capacity rather than current density because plate packs rather than individual plate types were being compared. A second and third cycle were completed on the cells with discharges at the 100 and 50-hour rates, respectively. During all three cycles, cells 1, 2, 3, 13, 14, and 12 were discharged at room temperature (25°C), cells 4, 5, 6, 13, 14, and 15 at 10°C, and cells 7, 8, 9, 16, 17, and 18 at 50°C. From the second cycle on, a two step charge program was instituted. Following a charge of the type used for the first cycle, an additional charge period at a reduced rate

approximating 2.5 milliamperes per gram of silver was continued until each cell again reached 1.95 to 1.97 volts.

All cell types, when discharged at the 10-hour rate at 10°C, displayed low voltages. At a meeting between NASA and ESB personnel at the Goddard Space Flight Center on June 14, 1962, it was decided that, rather than making separator adjustments which would raise the voltage at the sacrifice of wet stand capability, the voltage of cells discharged at the 20-hour rate at 10°C be determined - the 20-hour rate being the highest anticipated drain on the final design cells. Accordingly, six cells (S/N's 2, 3, 6, 8, 12, and 18) were subjected to a fourth cycle at the 20-hour rate of discharge. Satisfactory voltages were obtained.

Table II lists the data obtained from the four cycles of this experiment. Figures 1 and 2 display discharge curves showing the effect of temperature on cells containing 0.064 inch thick positive plates when discharged at the 10 and 100-hour rates, respectively. Figures 3 and 4 show the effect of rate on similar cells discharged at 10 and 50°C, respectively. Figure 5 is typical of the 10 sets of comparative discharge curves of each of the six cell types tested under a given set of rate and temperature conditions.

Cell No. 11 shorted internally during the third cycle discharge and was post-mortemed. The short was found to have occurred over the top of the separator, not through it. Final design cells on this contract have an epoxy resin pot which encapsulates the open tops of the separator envelopes, preventing shorts of this type. During the same cycle, the external circuit

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through which cells 7 and 16 were being discharged was shorted accidently in the test room. Both cells accepted a fourth cycle charge normally.

Efficiency and energy density data from the first three cycles of this experiment are summarized in Table III. From these data and the voltage levels displayed over the range of rates and temperatures investigated, it was concluded that the cells containing 0.064 inch thick positive plates made by the dispersed plastic process had given the best over-all performance. In order that the cell case mold for the two smaller final design models could be ordered on schedule, a decision as to which plate thickness and type to use had to be made when only two cycles of information were available. A summary (Second Quarterly Report, ESB Report No. E-33-62, Table VII) similar to that in Table III was compiled and the same conclusion as above was reached at that time. Thus, plates made by the dispersed plastic process and in the thickness range of 0.064 inch were selected for use in cells designed for qualification testing.

B. Separator Studies. - In an attempt to provide the qualification cells with the best over-all separator system consistent with their low rate, high energy density nature, a number of separator materials were tested and the most promising of these combined into various separator systems for evaluation in cells.

1. Physical and Chemical Tests. - Seventeen separator system components, as listed in Table IV, were tested for their relative chemical and physical properties.

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The following tests were performed:

a. Dry thickness and wet thickness after equilibration in 40 per cent KOH for 72 hours. From this data, cell pack tightness estimates were calculated.

b. Dry weight and wet weight after equilibration in 40 per cent KOH for 72 hours. From this data, relative electrolyte retention in cc of 40 per cent KOH per square inch per mil of separator and the per cent void were determined.

c. A.C. impedances at 60 cps were measured in 40 per cent KOH at 25°C.

d. Mean pore diameters were measured from the rates of flow of 40 per cent KOH through the separators under a static head by the method of Bruins et al (Third Quarterly Report, March 1 - May 31, 1956, Contract No. Da-36-039-SC-73180, Signal Corps Project No. 31-1628).

A summary of the results is given in Table V. A low molecular weight amine was liberated from all of the Polypor samples tested when the sample was equilibrated in 40 per cent KOH. Samples were immersed in 40 per cent KOH for 48 hours at room temperature and the odor persisted. The samples and solutions were then evacuated for two hours. Two days later strong amine odors could be detected. It was concluded at that time that Polypor would not be used in Goddard cells unless

the cause of this undesirable reaction was eliminated by the supplier.

2. Cell Tests on Various Separator Systems. - Unsealed S-7.5 cells were constructed to test 13 separator systems for their relative effects on cell impedance, input, and outputs at the 10-hour rate discharge before and after a storage in the wet-charged state for 14 days at 71°C. Each separator system was tested in duplicate.

Table VI summarizes the results of the cell tests. The cell free-space ratios are the values calculated for the individual separator systems. Each cell was designed to provide expansion space for the separator system predicted by the wet thickness given in Table V. Cell impedances were measured before and after charge to observe any immediate effects of charged plates on the separators. The impedance of cells 11 and 12, having ESB-Reeves synthetic cellophane, increased remarkably. Open-circuit voltages of all cells were measured in the oven to observe relative losses during the 14-day charged stand. Cells 13, 14, 15, and 16 shorted in the oven and were not discharged. Capacity losses in per cent were calculated on the basis of the first cycle outputs at the 10-hour rate by the equation $\frac{(D-S)}{D} \times 100$ (see Table VI). Cells 25 and 26 gave such improved performance on the second cycle that per cent capacity losses were also calculated on the basis of second cycle inputs by the equation $\frac{(C-S)}{C}$ 100 (see Table VI). To maximize energy densities, the product of mean per cent capacity loss and wet spacing between plates (separator system total thickness) should be minimized. The 13 separator

systems have been ranked in this way in the column of Table VI entitled "Capacity Loss-Spacing Factor." The systems are also ranked alphabetically, on their respective shelf stand capabilities only, in the last column. The "A" category systems are the best systems of those tested. Of the "A" category systems, EEB selected the system:

a. 1 layer EEB-Reeves White Synpor 0.004" wet

b. 5 layers 193 PUD-0 Cellophane 0.015" wet

to be used in Model 216 and 217 cells for storage and performance tests. When a lot of Polypor WA shipped to EEB/MEU later than that tested above was found to evolve no amines when equilibrated in KOH, the separator system:

a. 1 layer Dynel EM403

b. 1 layer Polypor WA

c. 5 layers 193 PUD-0 Cellophane

was included in the design of Model 218 cells. In adding an extra layer of cellophane to the system which displayed the best "Capacity Loss-Spacing Factor" in Table VI, it was believed that the increase in wet spacing would be more than compensated for by a decrease in capacity loss rate.

C. Elimination of High Voltage Plateau. - The magnitude of the high voltage plateau observed during discharge is dependent upon the relative proportion of AgO and Ag_2O in the surface layers of the positive plates, increasing as the molar ratio AgO/Ag_2O increases. This ratio is dependent

upon the following factors:

1. The nature of the previous charge.
2. The storage history on charged stand.
3. The electrolyte volume, composition, and the separator system.
4. The discharge rate and temperature.

The interaction of the factors above makes correlation of the magnitude of the AgO plateau with any one factor difficult except at discharge rates in excess of 1000 hours. At such low rates, chemical reactions which reduce AgO to Ag_2O in the surface layers adjacent the separator system become important at high discharge temperatures, and smaller AgO voltage plateaus are therefore normally associated with higher discharge temperatures, as shown in Figures 19 and 20.

A voltage moderating technique to eliminate the initial peaks seen in the vast majority of discharges run on this contract (e.g. Figure 5) was investigated. This technique, originally conceived by Dr. Paul Bruetschi of the Carl F. Norberg Research Center and modified by Mr. A. M. Chreitzberg of the Missile Battery Division, involves the addition to the plate pack of two extra, thin positive plates with a separate terminal. The remainder of the cell is completely charged with the extra plate terminal isolated. Shorting the main positive terminal to the uncharged plate terminal should then reduce high voltage AgO sites in the main

positive plates by the following electrochemical reaction:

$$AgO + Ag \longrightarrow Ag_2O$$

Completely Charged (+) Plates (Highest Voltage)	Uncharged (+) Plates (Lowest Voltage)	All (+) Plates (Intermediate Voltage)

While no capacity is lost by the above process (all plates are discharged into the external load), the weight and space expenditure will slightly reduce the operating energy density.

Six cells were designed, built, and tested to evaluate this technique. Three levels of silver addition as extra thin plates, representing 3, 8, and 13 per cent of the silver in the main plates, were included in the experiment with a replication of two cells of each type. Sufficient data was accumulated to demonstrate that the method will indeed depress the voltage at the beginning of a discharge as shown in Figure 6.

Considerable work in such areas as determining the optimum location in the cell pack of the auxiliary positives, testing cell seals with a third electrode involved, and developing a satisfactory switching arrangement would be required to render cells of this type practical for use in space. While it is believed that any difficulty encountered in these areas could be overcome, the expense involved placed this work beyond the scope of the present contract. Thus, this innovation was not included in the design of the qualification cells.

D. Negative Plate Binder Studies. - Based on prior experimental work, polyvinyl alcohol (P.V.A.) was evaluated as a negative plate binder. In an attempt to obtain some insight into the optimum concentration of binder to use, 1, 3, or 5 per cent finely ground P.V.A. was incorporated as a dry powder in negative active material mixes. Each mix was used to fabricate SS-7.5 negative plates for two cells.

The SS-7.5 sealed cell, a standard line high-rate unit with a nominal capacity of 7.5 ampere-hours, was selected for this experiment because the cell can be cycled in a relatively short period of time (charged at the 20-hour rate, discharged at the 1-hour rate, based on nominal capacity).

To date, 30 deep discharge cycles have been completed by these six cells. Discharge performance is illustrated in Figure 7 where it is compared with data, obtained previously, on a battery consisting of 5-SS7.5 cells containing Teflon binder in the negative plates. During cycles 1, 2, 3, 4, 5, 17, and 30, each cell was charged at 0.33 ampere to an individual cutoff voltage of 2.10 volts, then discharged at a constant current of 7.5 amperes to an individual cutoff voltage of 1.80 volts. Cycles 6 through 16 and 18 through 29 were conducted on an automatic cycling device. Cells were charged in series at 0.33 ampere until the first cell reached 2.05 volts (decreased from 2.10 as a safety measure) at which time the charge on all six cells was terminated.

The six cells were discharged in series through a constant resistance of 1.27 ohms which permitted approximately 7.5 amperes of current flow at the beginning of discharge but an average current of 6.3 amperes over the entire run. Termination of discharge of all six cells occurred when the first cell potential decreased to 1.20 volts. Thus, the values plotted in Figure 7 for the automatic cycles represents performance limited by the worst cell in the group.

It was concluded from the results of the above experiment that the addition of finely ground P.V.A. powder is an excellent substitute for the standard Teflon powder binder used in negative plates. The per cent of P.V.A. added would appear to depend upon the ultimate use of the cell involved. Out to 17 cycles no benefit was derived from adding more than 1 per cent binder. Thus, for high energy density (which is degraded by excess inactive material) and limited cycle life applications, 1 per cent P.V.A. would seem to be an optimum choice. At the 30th full cycle, larger P.V.A. additions appeared to be beneficial to capacity.

The P.V.A. binder results had not been obtained by the time the Model 216, 217, and 218 designs were frozen so that P.V.A. was not used as a negative plate binder in the qualification cells.

E. Low Recombination Studies. - Six 40 A.H. sealed cells were constructed with 0.064 inch dispersed plastic positive plates, standard separator system of one layer 0.005 inch Spunger and five layers 0.0009

inch cellophane, standard negative plates, and 1440 electrolyte varying in volume per cell from no free electrolyte to a fully flooded condition. Two cells were potted improperly during the installation of pressure gages. The remaining four cells, S/N 31, 42, 48, and 52, have completed three full cycles. Table VII summarizes pertinent data observed during the testing period. If the charge capacities and discharge capacities are summed over these three cycles by electrolyte level as shown below, the conclusion may be drawn that either "dry" or "1/2 full" electrolyte levels are to be desired over the "flooded" condition. In the final cell designs the dry condition was selected to optimize weight as well as capacity delivered with minimum cell operating pressures.

Parameter	Electrolyte Level		
	Dry	1/2 Full	Flooded
Inputs, A.H.	172.0	175.3	165.4
Outputs, A.H.	151.4	153.9	143.5
Efficiency*, %	88.0	88.0	87.0

(*) $\frac{\text{Output}}{\text{Input}} \times 100$

F. Cell Case Materials. - Of several materials investigated, white Cycolac T-2502 (ABS type polystyrene) conformed most closely to requirements that had been established:

1. Non-magnetic material
2. Capable of being sealed reliably
3. Inert to attack by battery electrolyte
4. Strong enough to support any internal pressure generated

during normal operation over the range of anticipated use temperatures.

A single, adjustable, polystyrene type mold was purchased to supply Cycolac cell cases for Models 216 and 217. Cases for Model 218 cells were obtained by cutting sections from an existing 3-cell monoblock.

Burst pressure tests were conducted on cell cases of the type used for the qualification cells and on a Model 218 type cell case and monoblock made of polystyrene RMD4511 (for comparison) with the following results:

Case Type	Material	Burst Pressure* (p.s.i.g.)
Model 216 (2 tests)	Cycolac	90, 90
Model 217 (2 tests)	Cycolac	150, 115
Model 218	Cycolac	130
Model 218	Polystyrene	45
Model 218 Type Monoblock	Cycolac	150
Model 218 Type Monoblock	Polystyrene	75

(*) All tests were conducted on unsupported cell cases at room temperature.

These burst pressures are far in excess of any pressures that should be generated within the cells for which these cases are used provided the "Service and Operating Instructions" supplied with the cells (sec III, D) are followed to the letter. On charge, oxygen is evolved when cell

voltage exceeds 2.00 volts and internal pressure increases. If a cell is permitted to reverse on discharge, pressure will also be built up. The listed charge and discharge voltage cutoffs (1.96 ± 0.01 and 1.1 volts per cell, respectively) should, therefore, always be applied.

As an added precaution, the cells should be clamped across the short dimension while being charged, discharged, or during storage at temperatures in excess of 0°C. If the cell internal pressures were permitted to build up, bulging of the unsupported sides would likely be observed prior to rupture. An additional advantage of Cycolac over some other case materials is that it splits rather than shatters when its burst pressure is reached.

G. Cell Sealing Material. - An epoxy resin, Shell Epon 815 (catalyzed with triethylenetetramine) has been used by ESB as a cell seal with excellent results. For cells on this contract, where maximum energy per unit weight was being sought, it was decided to investigate the possibility of obtaining an equally reliable seal with a lighter material.

Experiments with epoxy foams were abandoned when tests indicated insufficient adhesion of this material to silver lug wires.

Much more satisfactory results were obtained from tests of Epon 815 and TETA filled with lightweight Emerson and Cuming silicon dioxide "Eccospheres." At the largest filler ratio consistent with a usable viscosity, the cured mix had a density only 59 per cent that of the resin alone and no degradation in sealing ability was observed in initial tests.

To evaluate this material, two 20 ampere-hour cells were fabricated using "Eccospheres" in the sealing resin. These cells were subjected to four deep discharge cycles, at which time one of the cells was taken apart so that the underside of the seal and the adhesion to the cell case wall could be examinated. No degradation of the seal was apparent, and the cell case wall fractured at the seal line instead of pealing away from the seal. The remaining cell completed three additional deep discharge cycles, one at 10°C, for a total of seven cycles over a period of approximately six months after which the seal was still completely intact.

On the basis of this experiment, "Eccosphere" filled epoxy resin was used for the upper seal of the Model 216, 217, and 218 cells. However, due to the small aperture through which the mix had to be poured, viscosity considerations dictated the use of a somewhat lower proportion of filler to resin. This mix ratio provides a cured seal material with a density 66 per cent that obtained from the resin and catalyst above.

E. Charge Retention of Sealed Low Rate Test Cells. - Low rate 30 A.H. sealed cells are on storage in the fully charged state at temperatures of -18, +10, 32, and 50°C. Table VIII summarizes the discharge capacities observed at the 100-hour rate after each storage period completed to date and gives the average capacity loss per month at each storage time, assuming no loss at the lowest storage temperature of -18°C. All storage tests will not be completed until March, 1963. At that time a set of capacity retention curves will be plotted to allow capacity losses to be estimated for any storage time and temperature within the experimental range of data. First estimates indicate capacity losses in per cent per month decrease with increasing storage time and with decreasing storage temperature.

III. DESIGN AND FABRICATION OF MODEL 216, 217 and 218 CELLS

A. Design. - Based on the foregoing experiments as well as ESB's experience in sealed silver oxide-zinc batteries, the Model 216, 217, and 218 cells, corresponding to the 20, 50, and 100 ampere-hour ratings, respectively, were designed with the parameters listed in Table IX. A half scale sketch showing the relative size of the three models is included as Figure 8.

B. Production. - Production of the qualification lot cells by the Engineering Pilot Line was relatively trouble-free. Two cells of each type (Model 216-S/N 13 and 32, Model 217-S/N 1 and 28, and Model 218-S/N 3 and 17) were completed before work on the other cells was started.

Two trouble areas were encountered in the fabrication of the six units. A problem occurred in arriving at a precise establishment of the electrolyte level prior to the primary sealing operation. Due to the construction of the cells and the opaque case material, a measured quantity of electrolyte could not be used, nor could filling to a precise level be accomplished by direct visual examination. Consequently, the capacity delivered by these first cells on test (see Table XII), relative to that of other cells of the same model, was the poorest obtained to date. In subsequent units, the electrolyte level was adjusted by an improved technique. Satisfactory results were obtained when this operation was performed by engineering personnel, but later Model 216 cell data has shown that more engineering is needed to evolve a standard production procedure for this cell size.

The second problem was encountered in eliminating bubbles from the final epoxy seal beneath the cell cover plate. Initially, this was corrected by drilling through the cell cover into the bubble void, filling with the epoxy "Bocomphere" mix, and then resealing with a patch and polystyrene cement. In later cells the bubbles were removed by a superior potting technique before the epoxy cured out.

C. Shipment. - A total of 35 cells were shipped to Goddard Space Flight Center on schedule, November 30, 1962. Table X lists the serial numbers of the 20 Model 216, 10 Model 217, and 5 Model 218 cells shipped, along with pertinent electrical and physical characteristics, and the manner in which they were selected from the qualification lots. One intercell

connector for each cell was shipped on a later date (Element 5, [illegible]).

D. Operation Instructions. - Service and Operating Instructions (Element No. [illegible]) were prepared for use by Goddard in testing the qualification cells. Copies of this document were included with the cells shipped. [illegible]/[illegible] Document [illegible], which supersedes the [illegible] Table I, [illegible], Table II and determined the average output voltage from [illegible] to 1.96 ± 0.01 so that the instructions would apply to cells in general, is reproduced as Appendix A to this report.

IV. [illegible] ON QUALIFICATION LOT CELLS

A. Charge Acceptance. - All cells were charged in accordance with the original "Service and Operating Instructions" as follows:

1. Charge at 0.5A (Model 216), 1.15A (Model 217), or 2.5A (Model 218) supply constant current to a voltage of 1.97 ± 0.01 volts.
2. Then charge at 0.1A (Model 216), 0.5A (Model 217), or 1.0A (Model 218) supply constant current until the voltage again reaches 1.97 ± 0.01 volts.

Input capacities are shown in Tables XII and XIII.

The charge of Model 217 cell S/N's 25, 29, and 30 was interrupted for several hours by a power failure. Their input's were higher than those of cells with uninterrupted charge programs. This would tend to add weight to the theory (mentioned in the Third Quarterly Report, Page 6) that periods of charge interruption increase capacity accepted by cells.

with thick plates. This theory suggests that a reaction between the highest and lowest oxidation states in the positive plate will proceed to form the intermediate state (see II C). In this way areas of unchanged silver, which were previously isolated, are able to accept charge.

Model 217 cell S/N 's 7, 8, 13, and 26 were on charged stand for almost two months at room temperature while awaiting equipment modification prior to being discharged under vacuum. A "topping" charge at 0.58 ampere added 11 to 12 ampere-hours of capacity to each cell.

Early indications are that a large part of the input capacity increase brought about by charge interruption is available on discharge.

B. Discharge Rate. - A test schedule (Table XI) was set up corresponding to that outlined in the original proposal but modified to have the 20-hour rather than the 10-hour rate as the highest cell drain (see II, A). In implementing this schedule, tests on 35 cells have been completed as summarized in Table XII and Section IV-C. The remaining 21 cells are currently on test as outlined in Table XIII.

Discharge curves for the different rates at 10, 25, and 50°C and the rates noted are presented as follows:

Figure	Model No.	Rate (Hours)
9	216	20
10	216	100
11	216	1000
12	216	2000
13	217	20
14	217	100
15	217	1000
16	217	2000
17	218	20
18	218	100
19	218	1000
20	218	2000

Mid-point voltages from these curves were used to plot power characteristic curves for the Model 216, 217, and 218 as shown in Figures 21, 22, and 23, respectively. The increase of watt-hours per pound with cell size is demonstrated in Figure 24 where the values of all cells tested to date (omitting the six cells with improper electrolyte adjustment) are plotted as watt-hours per pound versus capacity.

Following completion of their first cycles, Model 216-S/N 1, Model 217-S/N 19, and Model 218-S/N 19 cells were recharged and subjected to a series of 5-second loaded voltage readings at 25°C with rates varying up to the equivalent of the 1-hour rate. The voltage versus current density plots derived from these readings are presented in Figure 25. The upper curve of each pair shows the voltages observed on fully charged cells as currents were increased stepwise from zero amperes. The lower curve of each pair shows voltages observed when the current was decreased in the same load intervals to zero. Operating voltage of these cells at

25°C should fall between or near these curves for fully charged cells. Charged stand will drop initial voltages, especially after storage at temperatures in excess of 32°C.

C. Storage Tests. - Capacity loss of Model 216 and 218 cells on storage at 50°C is being investigated. The experiment calls for storage periods of 0.5 (2 Model 218 cells), 1.0 (2 Model 218 cells), and 2.0 (2 Model 218 and 2 Model 216 cells) months to be followed by discharge at the 100-hour rate at room temperature.

Discharges have been completed on the 218 cells following 0.5 and 1.0 months of storage; performance is illustrated in Figure 26 where a comparison is made to the discharge curve of cell S/N 19 which was also discharged at the 100-hour rate at 25°C but with zero storage.

Based on actual mean capacity losses, the figures indicate a loss of 14.3 per cent capacity after 1/2 month and 20.7 per cent after 1 month charged storage at 50°C. However, due to the exceptionally high input accepted by cell S/N 19 which was being used as a control, the following calculations probably arrive at a more realistic expression of what capacity loss may be expected from Model 218 cells stored at this temperature.

	Cell S/N				
Storage Period at 50°C (Mos.)	0	[illegible]	1/2	[illegible]	[illegible]
Input Capacity (Amp-Hrs)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Output Capacity (Amp-Hrs)	178.9	[illegible]	[illegible]	[illegible]	[illegible]
Output/Input X 100 (%)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

	Storage Period at 50°C (Months)		
	0	1/2	1
(A) Mean Output/Input X 100 (%)	[illegible]	[illegible]	[illegible]
(A) X Median Input of qualification lot cells (179.4 Amp-Hrs) (Amp-Hrs)	[illegible]	[illegible]	[illegible]
Capacity loss over storage period (Amp-Hrs)	-	[illegible]	[illegible]
% Capacity loss over storage period	-	[illegible]	[illegible]
% Capacity loss per month		11.4	13.9
Proposed capacity loss (% per month)			[illegible]

V. FUTURE WORK CONTRACT NAS5-1607

A. Reports on Results of Tests in Progress. - Two addenda to this report will be submitted to the Goddard Space Flight Center. The first of these will contain data on all the discharges listed in Table XIII (except that of Model 217-S/N 8) and on the experimental cell 6 and 9 month storage tests in process (see II, E). It will be forwarded about April 15, 1963. Performance of Model 217-S/N 8, which is presently being discharged at the 2000-hour rate at 50°C, under vacuum, will be reported about June 1, 1963, via the second addendum.

VI. PERSONNEL

The following salaried personnel of The Electric Storage Battery Company, Missile Battery Division, participated in performance of Contract NAS5-1607:

Employee	Function
A. M. Chreitzberg	Project Manager
D. B. Colbeck	Project Engineer
J. F. Szabo	Project Engineer (Separator Studies)
J. Reifel	Tooling Engineer
A. H. Haddock	Test Engineer
R. Coleman	Drafting Supervisor
Y. M. Stallings	Sr. Engineering Technical Writer
G. Kalas	Pilot Line Supervisor
L. V. Rajagh	Chemical Technician
E. G. Heinsohn	Electrical Technician
A. G. Alexander	Electrical Technician
W. T. Whitley	Electrical Technician
W. R. Wright	Test Technician

VII. SUMMARY AND CONCLUSIONS

A. Experimental Work Leading to Design of Qualification Cells - Models 216 (Nominal 20 A.H.), 217 (Nominal 50 A.H.) and 218 (Nominal 120 A.H.). -

1. Experimental cells of six types, differing in positive plate thickness (0.146, 0.092, and 0.064 inch) and positive plate fabrication technique (pressed powder and ESB proprietary dispersed plastic process), were tested at all combinations of three discharge rates (10, 50, and 100-hour rates) and three discharge temperatures (10, 25, and 50°C). Cells containing 0.064 inch thick dispersed plastic positives provided the highest combination of energy density (watt-hours per pound and per cubic inch) and efficiency (ampere-hours per gram of silver). Dispersed plastic positive plates with thicknesses in the order of 0.064 inch were incorporated into qualification cell designs.

2. Separator material tests and separator system evaluation in cells stored charged at 71°C revealed that, of all combinations studied, the following provided the best capacity loss protection coupled with minimum space requirement:

a. 1 layer of ESB-Reeves White Sympor
   5 layers of 193 PUD-O Cellophane

b. 1 layer of Dynel EM-403
   1 layer of Polypor WA
   5 layers of 193 PUD-O Cellophane

System (a) was used in Model 216 and 217 qualification cells, while Model 218 units contained system (b), modified by the addition of one extra layer of cellophane.

3. The ability of a novel voltage moderating technique to depress initial discharge voltage was demonstrated. The need for additional development, beyond the scope of the present contract, precluded its use in qualification cells.

4. Data from 30 deep discharge cycles on high rate test cells show that dry polyvinyl alcohol powder, incorporated into the negative plate mix, acts as a satisfactory binder. These results were not obtained in time for P.V.A. to be considered for the Model 216, 217, and 218 negative plate designs.

5. Test cells devoid of free electrolyte and half filled with electrolyte delivered higher capacity with lower cell operating pressures than those flooded with electrolyte. The "dry" condition was selected

for the qualification lot cells to minimize weight.

6. Burst pressure tests on the light weight plastic cell cases indicated pressures as high as 90 psig can be sustained with no damage. Operating pressures measured during development tests did not exceed 20 psig except when overcharged at constant current to 2.1 volts or over-discharged beyond cell reversal.

7. Addition of silicon dioxide "Escompheres" to epoxy sealing resin results in a cell case seal of equal reliability to that of the resin alone, with a 30-40 per cent saving in weight. This "filled" resin was used for the final seal on qualification lot cells.

8. Charged stand capacity loss rates of 15.0, 3.2, and 2.9 per cent per month at 50, 32, and 10°C, respectively, have been observed to date in experimental cell tests. Additional results, derived from cells currently in long term storage at 10°C, are expected to change the average capacity loss percentage at that temperature to a value below the 2.9 per cent per month shown above.

B. Conformance of Model 216, 217 and 218 Cells to Contract Objectives. -

1. Specific:

Contract Objective	Mean and (Range) of Test Results to Date(*) Model 216	Model 217	Model 218
a. Capacities of 30, 60, and 120 Amp-Hrs.	38 (36/42)	79 (74/89)	167 (152/179
b. Energy densities of 65 to 75 watt-hrs/lb.	72 (66/79)	82 (75/91)	88 (76/93)

Contract Objective	Mean and (Range) of Test Results to Date (*) Model 216	Model 217	Model 218
c. Energy densities of 5 to 6 watt-hrs/in^3	5.5 (5.1/6.1)	7.4 (6.7/8.1)	8.2 (7.2/8.6)
d. Shelf capacity loss 20% max/month at 54°C (**)	-	-	12.3 at 50°C
e. Operating voltage 1.45/1.65 volts (***)	(1.45/1.85)	(1.45/1.85)	(1.45/1.85)
f. Operating life of 1 year	No test - ESB opinion - cells will operate successfully at one year rate at temperatures below 32°C.		
g. Position Insensitivity	Model 217 cells discharging at the 2000-hour rate for 1250 hours upside down and upright are performing identically.		
h. Magnetic Field intensity 10^{-5} gauss max. at 3 ft.	No test - non-magnetic materials used, magnetic field intensity should be negligible.		

Notes:

(*) Data for two cells of each type with improper electrolyte level adjustment not included so that values shown will be more representative of anticipated future observations.

(**) Experimental cell tests indicate smaller losses than remaining contract objective of 1, 4, and 10 per cent capacity loss per month at 0, 22, and 38°C, respectively.

(***) Initial voltage peaks are eliminated by storage at elevated temperatures but with a small sacrifice in capacity e.g. Model 218 cells-15 days storage at 50°C - operating voltage 1.45/1.58 - capacity loss 6 per cent.

2. General. - Results obtained to date indicate that the Model 216, 217, and 218 cells meet or exceed all contract objectives with the sole exception of having initial discharge voltages above desirable levels.

TABLE I

DESIGN PARAMETERS OF CELLS IN PLATE THICKNESS EXPERIMENT

Parameters	Cell Serial Numbers					
	3,6A9	2,5A8	1,4A7	12,15A18	11,14A17	10,13A16
Positive Plate Thickness (in.)	0.064	0.092	0.146	0.064	0.092	0.146
Positive Plate Type	DP	DP	DP**	PP***	PP	PP
No. of Positive Plates	8	6	4	8	6	4
Wt. of Silver per cell (gm.)	175.2	190.8	204.0	146.4	159.0	169.6
Total Positive Plate Area (in^2)	72.48	54.36	36.24	72.48	54.36	36.24
Nominal* Capacity (Amp-Hrs.)	43.9	47.7	51.0	43.9	47.7	50.9
Center Negative Plate Thickness (in.)	0.085	0.123	0.195	0.085	0.123	0.195
No. of Center Negatives	7	5	3	7	5	3
End Negative Plate Thickness (in.)	0.049	0.071	0.112	0.049	0.071	0.112
No. of End Negatives	2	2	2	2	2	2
Wt. of Zinc Oxide per Cell (gm.)	118.1	135.8	151.5	108.7	124.7	139.0

Electrolyte: 40 per cent KOH saturated with ZnO

Separator System: 1 layer of White Synpor, .005 inch
5 layers of cellophane, 193 PUD-0, .0009 inch

Cell Case External Dimensions (in.): 3.655 x 2.058 x 1.730

(*) Based on 0.25 and 0.30 amp-hrs. per gram of silver for "DP" and pressed powder plates, respectively.

(**) EEB proprietary dispersed plastic process.

(***) Pressed powder process.

TABLE II

PERFORMANCE DATA ON PLATE THICKNESS EXPERIMENT

Cell No.	First Cycle Input: Pos. Plate Thick. (In.)	Type	Charge Current (1) (Amps.)	Input (AH) (2)	Efficiency (AH/Gm Ag)	First Cycle Discharge: Nominal Rate (Hrs) (3)	Discharge Current (Amps.)	Discharge Temp. (°C)	Output To 1.1 V (AH)	Efficiency (AH/Gm Ag)	% Of Input	Energy Density (Wh/lb)
1	0.146	DP(6)	0.92	65.5	0.321	10	5.10	25	54.6	0.268	84	60.2
2	0.092	DP	0.85	59.6	0.312	10	4.77	25	52.5	0.275	88	63.9
3	0.064	DP	0.80	54.9	0.313	10	4.39	25	47.9	0.272	87	60.3
4	0.146	DP	0.92	64.3	0.315	10	5.10	10	42.1	0.206	66	44.8
5	0.092	DP	0.85	68.1	0.357	10	4.77	10	47.3	0.248	70	54.9
6	0.064	DP	0.80	55.6	0.317	10	4.39	10	53.7	0.306	97	65.2
7	0.146	DP	0.92	61.4	0.301	10	5.10	50	55.5	0.272	91	63.4
8	0.092	DP	0.85	68.1	0.357	10	4.77	50	66.4	0.348	98	81.6
9	0.064	DP	0.80	55.6	0.317	10	4.39	50	56.4	0.322	101	74.9
10	0.146	FP(7)	0.92	65.5	0.386	10	5.10	25	52.5	0.309	80	64.4
11	0.092	FP	0.85	59.6	0.375	10	4.77	25	53.0	0.333	89	67.2
12	0.064	FP	0.80	54.9	0.375	10	4.39	25	47.4	0.323	86	63.4
13	0.146	FP	0.92	64.3	0.379	10	5.10	10	42.1	0.248	66	49.0
14	0.092	FP	0.85	67.1	0.422	10	4.77	10	48.1	0.302	72	59.4
15	0.064	FP	0.80	52.0	0.355	10	4.39	10	43.6	0.293	84	58.0
16	0.146	FP	0.92	64.3	0.379	10	5.10	50	60.4	0.356	94	72.8
17	0.092	FP	0.85	67.1	0.422	10	4.77	50	54.6	0.344	81	74.0
18	0.064	FP	0.80	52.0	0.355	10	4.39	50	51.8	0.347	100	73.3

TABLE II

PERFORMANCE DATA ON PLATE THICKNESS EXPERIMENT
(Continued)

Cell No.	Second Cycle Input: Full Chg. Current (Amps) (1)	THC at Full Rate (Hrs) (2)	Time at Half Rate (Hrs) (2)	Input (AH)	Effic. (AH/gm of Ag)	% of First Cycle Output	Max. Pressure Obs. (psig)	Second Cycle Discharge: Nominal Rate (Hrs) (3)	Disch. Current (Amps.)	Disch. Temp. (°C)	Output to 1.3 V (AH)	Effic. (AH/gm of Ag)	% of First Cycle Output	Energy Density (Watt-Hrs/lb) (4)	Pressure Ex. Discharge (psig)
1	0.92	44.7	25.2	52.8	0.259	97	5	100	0.51	25	58.4	0.287	107	72.1	6
2	0.85	58.7	16.5	56.7	0.297	108	5	100	0.48	25	59.4	0.312	113	75.8	5
3	0.80	69.4	27.3	66.4	0.376	138	5	100	0.44	25	63.7	0.364	133	86.4	3
4	0.92	31.3	12.2	34.4	0.170	82	4	100	0.51	10	49.7	0.251	118	61.4	1
5	0.85	39.3	10.4	37.8	0.195	80	3	100	0.48	10	49.7	0.256	106	64.5	1
6	0.80	53.3	28.2	53.9	0.308	100	3	100	0.44	10	52.4	0.341	117	82.5	2
7	0.92	28.8	60.2	56.5	0.278	102	7	100	0.51	50	65.4	0.330	117	81.2	1
8	0.85	77.7	0.8	66.3	0.348	100	5	100	0.48	50	66.6	0.347	100	86.0	3
9	0.80	53.3	36.8	57.3	0.328	102	2	100	0.44	50	59.0	0.328	102	80.5	4
10	0.92	44.7	14.6	47.9	0.282	91	3	100	0.51	25	54.5	0.321	104	72.0	3
11	0.85	58.7	2.5	51.0	0.321	95	5	100	0.48	25	54.5	0.343	102	74.2	4
12	0.80	69.4	4.8	57.4	0.392	121	5	100	0.44	25	54.0	0.368	114	77.2	3
13	0.92	31.3	10.8	33.8	0.201	81	4	100	0.51	10	46.1	0.265	110	61.0	2
14	0.85	39.3	9.7	37.5	0.237	78	3	100	0.48	10	43.6	0.264	93	60.0	2
15	0.80	40.8	6.6	35.3	0.243	81	5	100	0.44	10	46.8	0.304	107	67.8	1
16	0.92	44.2	11.1	45.8	0.270	76	4	100	0.51	50	56.3	0.323	94	75.0	2
17	0.85	60.6	0.9	49.1	0.327	98	1	100	0.48	50	50.5	0.302	93	71.0	1
18	0.80	53.3	5.6	44.9	0.309	87	3	100	0.44	50	46.9	0.302	93	68.5	1

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TABLE II

PERFORMANCE DATA ON PLATE THICKNESS EXPERIMENT
(Continued)

Cell No.	Third Cycle Input: Full Chg. Current (Amps)(1)	Time at Full Rate (Hrs)(2)	Time at Half Rate (Hrs)(2)	Input (AH)	Effic. (AH/gm of Ag)	% of Second Cycle Output	Max. Pressure Obs. (psig)	Third Cycle Discharge: Nominal Rate (Hrs)(3)	Disch. Current (Amps)	Disch. Temp. (°C)	Output to 1.3 V (AH)	Effic. (AH/gm of Ag)	% of Second Cycle Output	Energy Density (Watt-Hrs/lb)	Pressure at Time of Disch. (psig)
1	0.92	51.3	5.0	49.5	0.243	85	2	50	1.02	5	47.5	.237	--	57.7	2
2	0.85	75.5	8.5	67.7	0.355	114	2	50	0.95	25	70.1	.364	120	69.7	3
3	0.80	65.2	14.3	57.9	0.330	91	2	50	0.88	25	60.3	.321	95	60.8	3
4	0.92	43.2	17.9	47.9	0.246	96	3	50	1.02	10	49.5	.252	100	60.0	5
5	0.85	42.1	19.8	44.2	0.228	89	2	50	0.95	10	46.4	.239	91	52.7	4
6	0.80	39.1	10.9	51.3	0.261	92	2	50	0.88	10	48.2	.39	100	82.6	4
7	0.92	43.2	51.2	63.3	0.319	97	3	Test	Circuit	Short	See	Text)	--	--	--
8	0.85	42.1	19.8	44.2	0.228	66	1	50	0.95	10	45.8	.237	69	59.7	34
9	0.80	39.1	10.9	51.3	0.280	87	2	50	0.88	10	49.2	27.4	83	69.1	22
10	0.92	52.5	5.0	50.6	0.259	94	1	50	1.02	25	44.0	.246	79	53.6	1
11	0.85	75.5	8.5	67.7	0.425	124	2	Batt.	Short	See	Text	--	--	--	--
12	0.80	65.1	14.3	57.8	0.395	107	1	50	0.88	25	60.0	.304	11[illegible]	65.9	2
13	0.92	43.2	12.6	45.5	0.261	99	3	50	1.02	1[illegible]	50.3	.208	10[illegible]	67.0	3
14	0.85	48.1	19.8	44.2	0.260	101	2	50	0.95	10	43.7	.266	100	60.3	[illegible]
15	0.80	39.1	10.9	51.3	0.333	110	1	50	0.88	10	50.7	.323	108	73.4	4
16	0.92	43.2	26.5	51.9	0.297	90	1	Test	Circuit	Short	(See	Text)	--	--	--
17	0.85	42.1	19.8	[illegible]	0.[illegible]	[illegible]	2	50	0.95	50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
18	0.80	39.1	10.9	51.3	0.327	109	3	50	0.88	50	43.9	.273	93	63.4	2

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TABLE II

PERFORMANCE DATA ON PLATE THICKNESS EXPERIMENT
(Continued)

Cell No.	Fourth Cycle Input: Full Chg. Current (Amps)(1)	Time at Full Rate (Hrs)(2)	Time at Half Rate (Hrs)(2)	Input (AH)	Effic. (AH/gm of Ag)	% of Third Cycle Output	Max. Pressure Obs. (psig)	Fourth Cycle Discharge: Nominal Rate (Hrs)(3)	Disch. Current (Amps)	Disch. Temp (°C)	Output to 1.3 V (AH)	Effic. (AH/gm of Ag)	% of Third Cycle Output	Energy Density (Watt-Hrs/lb)	Pressure at Time of Disch. (psig)
1	0.92	30.4	23.9	39.0	0.195	82	2	--	--	--	--	--	--	--	--
2	0.85	54.3	16.2	61.6	0.320	88	3	20	2.39	10	56.6	0.295	81	70.1	1
3	0.80	73.4	8.5	65.7	0.341	106	3	20	2.20	10	61.2	0.328	101	79.8	[illegible]
4	0.92	23.3	8.5	27.4	0.139	55	2	--	--	--	--	--	--	--	--
5	0.85	33.3	20.2	37.8	0.196	94	1	--	--	--	--	--	--	--	--
6	0.80	73.4	8.5	65.7	0.340	102	3	20	2.20	10	67.1	0.364	108	86.0	1
7	0.92	47.8	6.4	44.9	0.236	-	1	--	--	--	--	--	--	--	--
8	0.85	44.4	20.2	44.8	0.231	98	1	20	2.39	10	38.2	0.197	83	46.9	0
9	0.80	49.1	27.3	45.4	0.246	92	1	--	--	--	--	--	--	--	--
10	0.92	35.4	6.4	30.9	0.178	72	2	--	--	--	--	--	--	--	--
11	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
12	0.80	38.0	20.7	31.7	0.339	86	3	20	2.20	10	47.3	0.309	79	66.5	30
13	0.92	29.3	6.4	28.9	0.178	79	2	--	--	--	--	--	--	--	--
14	0.85	38.4	19.3	38.4	0.233	88	1	--	--	--	--	--	--	--	--
15	0.80	38.0	20.7	31.1	0.288	91	2	--	--	--	--	--	--	--	--
16	0.92	48.8	25.5	37.5	0.230	--	1	--	--	-	--	--	--	--	--
17	0.85	38.4	20.7	38.0	0.235	86	1	--	--	--	--	--	--	--	--
18	0.80	49.1	14.5	40.3	0.257	92	1	20	2.20	10	40.7	0.259	93	57.4	43(5)

Notes:
1. Current corresponds to approximately 5 milliamperes per gram of silver.
2. To a cutoff voltage of 1.35 to 1.37 volts per cell.
3. Nominal capacity based on 0.25 amp-hrs per gram of silver for 20 plate cells and 0.30 amp-hrs per gram of silver for present greater plate cells.
4. Dry unsupported cells.
5. This cell was allowed to increase as discharge-pressure dropped to 4 psig after 35 hours.
6. Supported plastic.
7. Sealed Plastic.

TABLE XIX

SUMMARY OF DATA FROM THREE CYCLES OF
PLATE THICKNESS EXPERIMENT

Pos. Plate Type	Pos. Plate Thick. (in)	Efficiency: Mean AH/gm. of Ag. at all Temp. — First Cycle (10-Hr. Rate)	Second Cycle (100-Hr. Rate)	Third Cycle (50-Hr. Rate) (2)	All Three Cycles	Mean Watt-Hrs. Per Lb. - All Rates - All Temp.	Mean Watt-Hrs. Per in³ - All Rates - All Temp.	Rank (3), All Three Cycles: AH/gm of Ag	Watt-Hrs. Per Lb.	Watt-Hrs. Per in³	Mean of Ranks
DP (4)	0.146	0.249 (1)	0.289	0.245	0.261	62.6	5.90	6	6	3	5.0
DP	0.092	0.290	0.306	0.270	0.289	69.8	6.37	5	3	2	3.3
DP	0.064	0.300	0.342	0.311	0.318	75.9	6.63	2	1	1	1.3
PP (5)	0.146	0.304	0.303	0.267	0.291	64.1	5.64	4	5	5	4.7
PP	0.092	0.326	0.303	0.259	0.296	65.8	5.60	3	4	6	4.3
PP	0.064	0.323	0.325	0.328	0.325	70.1	5.70	1	2	4	2.3
DP	All	0.280	0.312	0.280	0.291	69.7	6.31				
PP	All	0.317	0.310	0.291	0.306	66.6	5.65				
Both	0.146	0.277	0.296	0.256	0.276	63.3	5.77				
Both	0.092	0.308	0.305	0.265	0.293	67.9	6.00				
Both	0.064	0.312	0.334	0.320	0.322	73.0	6.17				

(1) Theoretical maximum is 0.5 A.H./gm of Ag.
(2) Cells 7, 11, and 16 not included in third cycle calculations (see text).
(3) Lowest ranking digit corresponds to best performance.
(4) Dispersed plastic.
(5) Pressed powder.

TABLE IV

SEPARATOR MATERIALS STUDIED

Identification Number	Material Description	Source
1	Polypor WA, Nylon, Control Standard	Niemann Bros., New York
2	Polypor WA, on Nonwoven Nylon	Niemann Bros., New York
3	Polypor WA, on Nonwoven Polypropylene	Niemann Bros., New York
4	Polypor WA, on Coarse Resorcinol Treated Nylon	Niemann Bros., New York
5	Nylon 9134	Frank IX Sons, New York
6	Synpor, White, Expanded Pore, PVC	ESB-Reeves, Glenside, Pa.
7	Synpor, Grey, Normal Pore, PVC	ESB-Philadelphia-Industrial Division
8	Porothene, Microporous Polyethylene	C.F. Norberg Research Center, Yardley, Pa.
9	RAI Permion 300, Chemically Modified Polyethylene	Radiation Applications, Inc., New York
10	RAI Permion 600, Irradiated Cellophane	Radiation Applications, Inc., New York
11	Cellophane 193 PUD-0	E.I. Dupont, Wilmington, Delaware
12	Fibrous Sausage Casing	Visking Co., Chicago, Ill.
13	Visking Clear Cellulose	Visking Co., Chicago, Ill.
14	Avisco Clear Cellulose "C"	American Viscose Co., Marcus Hook, Pa.
15	Avisco Silver Treated Cellulose "A"	American Viscose Co., Marcus Hook, Pa.
16	Avisco Silver Treated Cellulose "B"	American Viscose Co., Marcus Hook, Pa.
17	Synthetic Cellophane 3:1:1 - 103EP*	ESB-Reeves Co., Glenside, Pa.

(*) Material is brittle - still under development.

TABLE V

CHEMICAL AND PHYSICAL PROPERTIES OF SEPARATOR SYSTEM MATERIALS

Material No. (1)	Thickness (Mils) Dry	Wet in 40% KOH	Weight (Mg/in²) Dry	Wet Weight Increase In 40% KOH (4)	Retention of 40% KOH Electrolyte (cc/in²/mil)	% Void	Mean Pore Diameter (μ)	60 Cycle/sec. A.C Impedance in 40% KOH (milliohm/in²/mil)
1 (3)	4.0	4.0/4.0(2)	35	42/50	.0087/.0095	53	580	1.16/0.93
2 (3)	10.0	10.0	58	198/202	.145/.0162	88	1520/2220	1.31/0.99
3 (3)	4.2	5.0/4.7	33	60/69	.0086/.0104	52	886/746	1.70/1.58
4 (3)	5.8	5.3/5.1	34	85/84	.0116/.0125	72	578	0.58/0.58
5	1.6	1.6	23	28/27	.0111/.0107	74	Open Mesh	1.38/1.31
6	4.0	4.0/4.0	33	54/57	.0096/.0102	59	880/784	1.12/1.07
7	8.0	7.7/9.7	39	107/127	.0100/.0117	61/74	780/1150	2.85/1.01
8	2.5	4.0	11	48	.0086	53	588/358	2.18/1.25
9	1.0	1.3/1.2	22	22/12	.0126/.0071	77	157.7/6.12	9.26/13.3
10	1.0	2.2/2.2	25	30/30	.0095/.0095	58	3.36/3.1	16.2/6.6
11	0.9	3.0/2.5	23	54/56	.0129/.0160	78	11.8/0.92	1.75/1.87
12	3.0	7.0/6.7	50	102/106	.0104/.0112	64/68	10.8/4.3	1.64/1.64
13	2.0	6.0/6.0	52	104/103	.0124/.0122	76	1.97	1.59/2.07
14 (6)	3.3	7.8/8.2	81	146/127	.013/.0117	81/77	1.62/1.39	1.86/2.13
15	3.2	7.7/7.2	82	143/114	.0134/.0113	80	11.0	2.13/2.18
16	3.5	7.9/7.1	88	151/117	.0137	82/77	12.2	1.30/2.17
17	4.7	6.7/6.3	113	105/34	.0111/.0039	68	28-21/22	3.6-[illegible].7/1.2-1.[illegible]

(1) See Table IV.
(2) All values before slash (/) represent room temperature data, those after slash data after 2 weeks soak at 71°C.
(3) Gave off pungent odor of amine when immersed in KOH.
(4) Blotted to remove excess.
(5) Measured by observing diffusion rate through material.
(6) All values of material 14 were in error (typographical) as reported in Second Quarterly Report Table VII - are correct as shown above.

TABLE VI

CHEMICAL AND PHYSICAL PROPERTIES OF SEPARATOR SYSTEM MATERIALS

Material	Thickness (Mils) Dry	Wet in 40% KOH	Weight (Mg/in²) Dry	Wet Weight Increase In 40% KOH (4)	Retention of 40% KOH Electrolyte (cc/in²/mil)	% Void	Mean Pore Diameter (μ)	60 Cycle/sec. A.C Impedance in 40% KOH (milliohm/in²/mil)
Dynel on Ny 193 Polypor VA-[illegible] 193 PUDO	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Polypor VA-[illegible] 193 PUDO	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Polypor VA Reconstituted Treated 192 PUDO	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Polypor VA on Polyethylene 193 PUDO	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Polypor VA on Non Woven Rylon 193 PUDO	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Polypor VA-[illegible] Pellon 1111-103 AF	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Polypor VA-[illegible] Pellon 600	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Polypor VA Pellon 500	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Permaline 193 PUDO	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Polypor, White 193 PUDO	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Polypor, White 193 PUDO	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Rylon 5134 193 PUDO	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Polypor, Gray 193 PUDO	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE VI

UNSEALED 8-7.5 CELL TESTS ON SEPARATOR SYSTEMS
(Continued)

Test Cell No.	Charge Input First Cycle (A.H.)	Open-Circuit Voltage (Volts) After Charge	Open-Circuit Voltage (Volts) Before Discharge	Output "B" 10-Hr. Rate at 25°C to 1.20 V/C (A.H.)
1	11.7	1.85	1.855	10.8
2	11.9	1.85	1.855	11.0
3	11.5	1.85	1.855	10.4
4	11.3	1.85	1.855	10.1
5	11.7	1.85	1.855	10.5
6	11.5	1.85	1.855	10.5
7	11.0	1.85	1.855	8.5
8	11.0	1.85	1.860	9.8
9	10.8	1.85	1.860	9.3
10	10.6	1.85	1.855	9.4
11	11.3	1.845	1.795	7.3
12	11.7	1.845	1.825	7.7
13	12.2	1.85	1.855	8.6
14	11.2	1.85	1.855	8.3
15	11.8	1.85	1.855	9.4
16	11.9	1.85	1.855	9.4
17	11.7	1.85	1.855	9.4
18	12.4	1.85	1.855	10.9
19	12.6	1.855	1.855	10.0
20	12.4	1.85	1.855	10.8
21	8.2	1.85	1.855	8.2
22	8.1	1.85	1.855	8.7
23	13.4	1.85	1.855	11.1
24	12.9	1.855	1.855	10.6
25	12.2	1.855	1.855	7.8
26	12.3	1.855	1.855	7.8

TABLE VI

UNSEALED 8-7.5 CELL TESTS ON SEPARATOR SYSTEMS
(Continued)

Test Cell No.	Charge Input "C" Second Cycle (A.H.)	Open-Circuit Stand at 71°C Open-Circuit Voltage - Volts Intervals in Days: Initial	3rd	7th	10th	15th	Output "B" 10-Hr Rate At 25°C To 1.20 V (A.H.)
1	12.8	1.86	1.86	1.85	1.85	1.85	10.1
2	12.8	1.86	1.86	1.85	1.85	1.83	9.6
3	12.5	1.86	1.86	1.85	1.84	1.85	8.8
4	12.5	1.86	1.86	1.85	1.85	1.83	8.5
5	12.5	1.86	1.86	1.85	1.85	1.82	8.1
6	12.5	1.86	1.86	1.85	1.85	1.83	8.2
7	12.5	1.86	1.86	1.85	1.84	1.80	7.7
8	12.5	1.86	1.86	1.85	1.86	1.84	9.1
9	12.5	1.86	1.86	1.85	1.86	1.85	9.0
10	12.8	1.86	1.86	1.86	1.86	1.84	9.4
11	12.5	1.86	1.82	1.59	1.59	1.58	1.1
12	12.5	1.86	1.78	1.59	1.58	1.58	1.3
13	12.7	1.86	1.86	1.85	1.38	0	0
14	12.8	1.86	1.85	1.84	1.84	0	0
15	13.4	1.86	1.86	1.85	1.66	0	0
16	13.4	1.86	1.86	1.85	1.59	0	0
17	12.8	1.86	1.86	1.85	1.84	1.83	8.3
18	13.2	1.86	1.86	1.85	1.85	1.82	8.4
19	13.2	1.86	1.86	1.85	1.85	1.83	8.4
20	12.8	1.86	1.86	1.85	1.86	1.84	8.7
21	10.6	1.86	1.86	1.86	1.86	1.84	8.1
22	10.7	1.86	1.86	1.86	1.86	1.83	8.7
23	13.6	1.86	1.86	1.86	1.86	1.84	8.8
24	13.4	1.86	1.86	1.85	1.86	1.84	8.7
25	12.6	1.86	1.86	1.85	1.85	1.84	8.1
26	12.5	1.86	1.86	1.85	1.85	1.84	8.2

TABLE VI

UNSEALED 8-7.5 CELL TESTS ON SEPARATOR SYSTEMS
(Continued)

Test Cell No.	Capacity Loss $\frac{(B-D)}{(B)}$ 100 (%)	Capacity Loss $\frac{(C-D)}{(C)}$ 100 (%)	Rank	Capacity Loss Spacing Factor $\frac{(C-D)}{(C)}$ 100 X "A" (% Inch)
1	6.5	21		
2	13	25	A	.391
3	15	30		
4	16	32	B	.496
5	23	35		
6	24	34	B	.622
7	10	38		
8	7.5	37	B	.553
9	3.5	26		
10	0.5	27	A	.460
11	85	91		
12	83	90	F	1.63
13	Short	Short		
14	Short	Short	F	NA
15	Short	Short		
16	Short	Short	F	NA
17	76	82		
18	78	82	[illegible]	1.23
19	76	82		
20	19	32	D	0.91
21	2.0	24		
22	0.3	19	A	0.408
23	11	28	B	0.442
24	18	35		
25	NA	23		
26	NA	26	A	0.459

TABLE VII

EFFECT OF ELECTROLYTE LEVEL ON PERFORMANCE
OF SEALED LOW RATE TEST CELLS

	Electrolyte Level In Cell			
	Dry	% Full	Flooded	
Cell Serial Number	31	52	42	48
First Cycle: Input (AH) to 1.97 volts	61.4	63.5	[illegible]	61.1
Output (AH) 20 Hr. Rate(2.2 Amp)10°C	43.6	40.1	42.9	45.8
Efficiency: AH/gm Ag	0.25	0.23	0.24	0.26
% of Input	71	63	73	75
Second Cycle:* Input (AH) to 10 psig	57.2	53.0	57.5	54.4
Charge cutoff voltage, volts	2.20	2.17	2.15	2.14
Efficiency: % of first cycle input	93	84	97	89
% of first cycle output	131	132	134	119
Pressure observed on stand after charge to 10 psig:				
After: 50 hrs.	5.5	4.5	7.2	3.5
140 hrs.	3.5	3.5	7.0	2.0
158 hrs.	3.5	3.0	6.5	0.0
Recharge capacity to 10 psig, A.H.	4.0	5.3	5.7	4.8
Total Input capacity, A.H.	61.2	58.3	63.2	59.2
Discharge at 10°C - 20 Hr. Rate:				
Lower, plateau voltage, volts	1.48	1.49	1.45	1.45
Output capacity, A.H.	61.4	61.0	59.9	32.1
Pressure at end of discharge, psig	4.0	4.0	7.2	3.0
Efficiency: % of 2nd cycle input	100	105	95	54
% of 1st cycle output	141	152	140	70
A.H./gm Ag	0.35	0.35	0.34	0.18
Third Cycle: Input (A.H.) to 1.97 volts	49.4	53.6	43.1	32.4
Efficiency: % of 2nd cycle output	80	88	68	101
Discharge at 25°C at 20 Hr. Rate:				
Lower plateau voltage, volts	1.51	1.51	1.51	1.51
Average voltage (Calc.), volts	1.519	1.531	1.512	[illegible]
Capacity, A.H.	46.4	52.8	40.7	67.1
Max. press during disch., psig.	3.5	3.0	6.0	3.5
Efficiency: Output as % of:				
3rd cycle Input	94	98	95	[illegible]
2nd cycle Output	76	87	68	[illegible]
A.H./gm Ag	0.27	0.30	0.23	[illegible]
All Cycles: Net Input**, A.H.	20.6	21.5	21.9	7.7

(*) Pressure gages leaked on 1st cycle-repaired between 1st and 2nd cycle.
(**) Total input minus total output over 3 cycles.

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TABLE VIII

CAPACITY RETENTION OF LOW RATE SEALED TEST CELLS
DURING CHARGED STORAGE AT TEMPERATURES OF -18, +10, 32 and 50°C
POSITIVE PLATE THICKNESS = 0.064 INCH

Storage Temp. (°C)		Residual Capacity (AH) and Storage Time (Days) 23	38	58	97	X̄	Mean Calculated Capacity Loss Per Month of Charged Sto[rage] (Mean Capacity Retained at -18°C to Represent % O[f]) 23	38	58	97	X̄
50		25.9 23.3	29.4 24.0	20.5 -							
	S	49.2	53.4	20.5							
	X̄	24.6	26.7	20.5		24.6	21.6	7.5	15.8		1[illegible]
32		28.3 27.9	29.6 27.1	30.8 27.0	28.5 26.0						
	S	56.2	56.7	57.8	54.5						
	X̄	28.1	28.3	28.9	27.3	28.1	6.2	3.2	1.0	2.3	[illegible]
10		30.8 26.0			30.6 26.6						
	S	56.8			57.2						
	X̄	28.4			28.6	28.5	4.9			0.94	2.
18		30.0 27.8			34.3 25.8						
	S	57.8			60.1						
	X̄	28.9			30.1	29.5	-			-	-

(*) Sample Calculation:-23 days storage at 50°C. % Capacity Loss = $\frac{30 \text{ days}}{23 \text{ days}} \times \frac{29.5 \text{ Amp-Hrs.} - 24.6 \text{ Amp-Hrs}}{29.5 \text{ Amp-Hrs.}} \times 100 = 21.6\%$

TABLE IX

[illegible] OF CELL DESIGN [illegible]

	Model Number 216	217	[illegible]
External Cell Dimensions (Max.)			
Length (in)	0.[illegible]	1.205	1.568
Width (in)	2.335	2.385	3.448
Height (in) To top of cell case	5.830	5.030	5.898
Height (in) To top of terminal	6.2[illegible]	6.49	6.458
Volume [illegible] cell case	[illegible]	[illegible]	31.55
[illegible]	[illegible]	[illegible]	2.92
Internal Dimensions of Cell Case (in)			
Length (in)	0.53[illegible]	[illegible]	1.300
Width (in)	2.1[illegible]	2.15[illegible]	3.275
Height (in) To bottom of reinforcing plate	[illegible]	[illegible]	5.[illegible]
Positive Plate Data			
Thickness (in)	[illegible]	0.051	0.0[illegible]
Width (in)	[illegible]	2.00	3.12
Height (in)	[illegible]	4.60	4.63
No. of plates per cell	3	6	6
Weight of silver per cell (g)	115	229	515
Nominal capacity (Amp-Hrs)-based on 0.27 Amp-Hrs per gram of silver	31	62	132
Negative Plate Data			
Center plate thickness (in)	0.064	0.064	0.0[illegible]
End plate thickness (in)	0.038	0.038	0.0[illegible]
Width (in)	2.00	2.00	3.12
Height (in)	4.81	4.81	4.63
No. of center plates per cell	2	5	5
No. of end plates per cell	2	2	2
Separator Data			
Positive separator material No. 1	White Sympor	White Sympor	[illegible]
Thickness of Pos. Sep. Mat'l No. 1 (in)	0.0045	0.0045	0.[illegible]
No. of layers of pos. sep. mat'l No. 1	1	1	[illegible]
Positive separator material No. 2	-	-	[illegible]
Thickness of pos. sep. mat'l No. 2 (in)	-	-	[illegible]
No. of layers of pos. sep. mat'l No. 2	-	-	
Positive diaphragm material	193 PUD-O Cellophane	193 PUD-O Cellophane	[illegible]
Thickness of pos. diaphragm mat'l (in)	0.0009	0.0009	[illegible]
No. of layers of positive diaphragm mat'l	5	5	[illegible]
Free space allowance (based on min. cell length)	[illegible]	3.[illegible]	[illegible]

TABLE X

ELECTRICAL AND PHYSICAL CHARACTERISTICS OF QUALIFICATION CELLS SHIPPED TO GODDARD SPACE FLIGHT CENTER

Model	S/N	Input Capacity (Amp-hrs)	A.C.* Impedance (Ohms)	Weight (gm.)	S/N	Input Capacity (Amp-hrs)	A.C.* Impedance (Ohms)	Weight (gm.)
216	3	44.0	0.44	377	19	44.5	0.46	341
	4	44.0	0.45	300	21	44.0	0.46	300
	5	43.8	0.45	379	22	44.0	0.45	375
	6	44.7	0.44	380	23	44.4	0.44	374
	7	44.0	0.44	300	26	44.3	0.46	377
	10	44.4	0.44	381	27	43.7	0.46	375
	14	44.0	0.45	377	28	43.2	0.46	374
	16	44.4	0.46	376	29	45.2	0.46	376
	17	44.0	0.44	377	30	43.3	0.46	375
	18	43.2	0.45	377	34	44.4	0.46	375
217	8	85.8	0.29	667	17	83.7	0.26	667
	9	85.8	0.29	669	20	84.6	0.28	666
	10	84.6	0.28	662	23	84.4	0.28	662
	15	85.8	0.29	665	24	84.5	0.29	660
	16	83.2	0.28	664	27	83.2	0.28	660
218	2	179.4	0.21	1330	10	182.1	0.23	1342
	6	179.4	0.24	1326	29	182.1	0.25	1316
	7	182.1	0.25	1342				

(*) This characteristic is determined prior to charge as a quality control measure to provide indication of satisfactory activation.

Selection of cells for shipment was based on input capacity as follows:

Model 216 - Median charge capacity of lot ± 30% of the range
Model 217 - Median charge capacity of lot ± 21% of the range
Model 218 - Median charge capacity of lot + 15%
- 0% of the range

TABLE XI

SCHEDULE OF EXB TESTS ON QUALIFICATION LOT CELLS

	Serial Number		
	Model 216	Model 217	Model 218
40 - Hour Rate			
At 10°C	1	1, 33	3
At 25°C	12	19, 30	17
At 50°C	13	31, 26*	22
100 - Hour Rate			
At 10°C	2	2, 34	14
At 25°C	33	28, 29	19
At 50°C	1	7*, 14	23
1000 - Hour Rate			
At 10°C	21	12, 25	15
At 25°C	9	5, 32	13
At 50°C	12	13*, 21	25
2000 - Hour Rate			
At 10°C	25	4, 18**	20
At 25°C	8	6**, 11	18
At 50°C	15	8*, 22	1
100 - Hour Rate at 25°C After Storage at 50°C			
For 1/2 Month			18, 28
For 1 Month			4, 16
For 2 Months	20, 24		8, 11

(*) Discharge under vacuum - c.a. 8 mm of Hg.
(**) Discharge upside down.

TABLE XIII

DISCHARGE PERFORMANCE OF QUALIFICATION LOT SEALED CELLS THAT HAVE COMPLETED TEST

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Model	S/N	Input Capacity (Amp-Hrs)	Nominal Discharge Rate (Hrs)	Discharge Temp. (°C)	Initial Capacity (Amp-Hrs)	% of Rated	Effic. Amp-Hrs. per Cu. Ft. of Shift	Energy Per Lb.	Density Watt-Hrs. per Lb.
216	1	40.2	20	1.55	—	10	36.7	69	5.1
	10	40.4	20	1.55	—	10	28.4	70	4.0
	13	40.2	20	1.55	—	10	28.3	70	4.2
	15	40.4	100	0.31	—	10	38.1	94	5.4
	11	40.3	100	0.31	—	10	39.9	94	5.7
	11	40.8	100	0.31	—	10	36.2	85	5.2
	31	40.8	1000	—	52	10	40.4	94	6.0
	9	45.3	1000	—	52	10	41.6	92	6.1
	12	45.7	1000	—	52	10	46.1	85	6.7
217	14	43.3	20	3.10	—	10	43.6	93	6.6
	13	44.1	20	3.10	—	10	74.4	91	6.7
	19	44.0	20	3.10	—	10	77.5	95	7.0
	30	43.8	20	3.10	—	10	89.0	95	8.0
	31	44.4	20	3.10	—	10	77.5	94	7.1
	2	44.4	100	0.62	—	10	77.4	96	7.1
	34	44.4	100	0.62	—	10	77.6	96	7.2
	20	76.7	100	0.62	—	10	87.8	90	8.2
	20	84.1	100	0.62	—	10	84.9	95	7.9
	14	86.6	100	0.62	—	10	78.4	90	7.3
	12	85.5	1000	—	25	10	84.7	98	8.0
	5	81.2	1000	—	25	10	77.6	96	7.3
	22	81.2	1000	—	25	10	72.9	91	7.3
218	10	151.9	20	6.55	—	10	125.0	77	5.5
	13	154.4	20	6.55	—	10	126.9	83	5.9
	22	177.5	20	6.55	—	10	163.5	92	6.3
	14	159.4	100	1.39	—	10	152.2	95	6.2
	19	154.8	100	1.39	—	10	178.9	95	6.4
	23	168.9	100	1.39	—	10	170.5	93	6.5
	15	168.1	1000	—	11.4	10	169.9	93	6.6
	13	174.8	1000	—	11.4	10	167.2	96	6.3
	25	161.4	1000	—	11.4	10	167.3	92	6.3

(*) Cells with poor electrolyte level adjustment see III, B.

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TABLE XIII

QUALIFICATION LOT CELLS CURRENTLY ON TEST

Model	S/N	Input Capacity (Amp-Hrs)	Nominal Discharge Rate (Hrs)	Discharge Temp. (°C)	Special Treatment	Estimated Completion Date
216	8	45.9	2000	Room (25)	None	3/17/63
	15	42.2	2000	50	None	3/17/63
	20	42.8	100	Room (25)	2 months charged storage at 50°C before discharge	2/9/63
	24	42.8	100	Room (25)	2 months charged storage at 50°C before discharge	2/9/63
	25	42.2	2000	10	None	3/17/63
217	4	83.2	2000	10	None	3/17/63
	6	85.5	2000	Room (25)	Discharge upside down	3/17/63
	7	93.9*	100	50	Discharge under vacuum	2/9/63
	8	99.6*	2000	50	Discharge under vacuum	5/20/63
	11	86.0	2000	Room (25)	None	3/17/63
	13	93.3*	1000	50	Discharge under vacuum	3/27/63
	18	83.2	2000	10	Discharge upside down	3/17/63
	22	85.8	2000	50	None	3/17/63
	25	92.1	1000	10	None	2/20/63
	26	93.9*	20	50	Discharge under vacuum	2/5/63
	32	81.3	1000	Room (25)	None	2/20/63
218	1	187.8	2000	50	None	3/17/63
	8	177.9	100	Room (25)	2 months charged storage at 50°C before discharge	2/9/63
	11	176.1	100	Room (25)	2 months charged storage at 50°C before discharge	2/9/63
	18	182.9	2000	Room (25)	None	3/17/63
	20	189.7	2000	10	None	3/17/63

(*) Includes 11 to 12 ampere-hour "topping" charge prior to commencement of discharge.

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FIGURE 3

EFFECT OF RATE ON VOLTAGE AT 1[illegible]°C
DISCHARGE CURVES OF PLATE THICKNESS EXPERIMENT
CELL NO. 6 CONTAINING 0.06A" THICK
POSITIVE PLATES MADE BY THE DP PROCESS

FLOW	RATE - BASED ON NOMINAL CAPACITY
— — —	100 - Hour
— — —	50 - Hour
	20 - Hour
———	10 - Hour

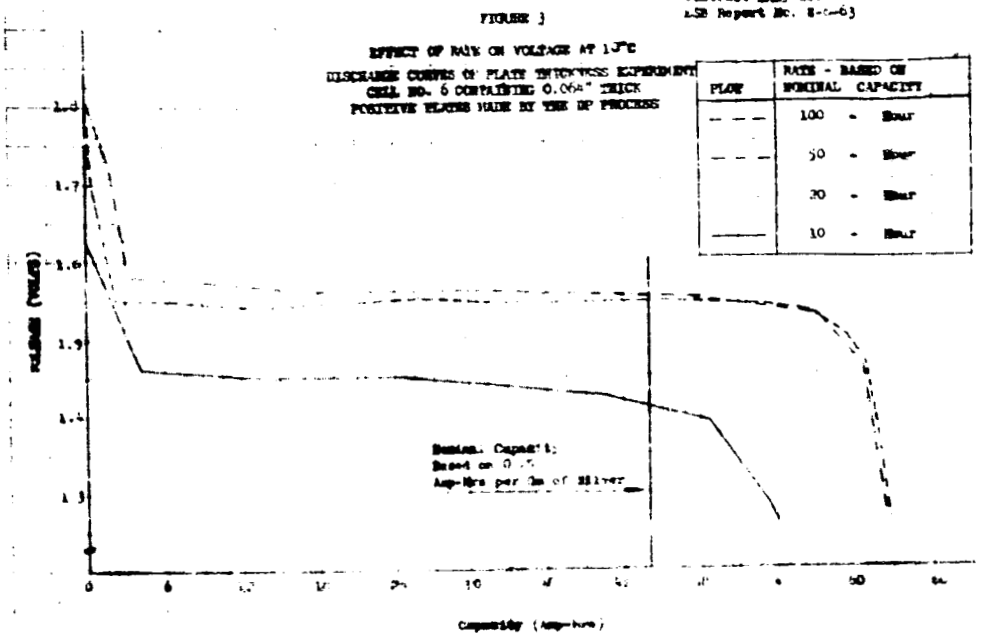

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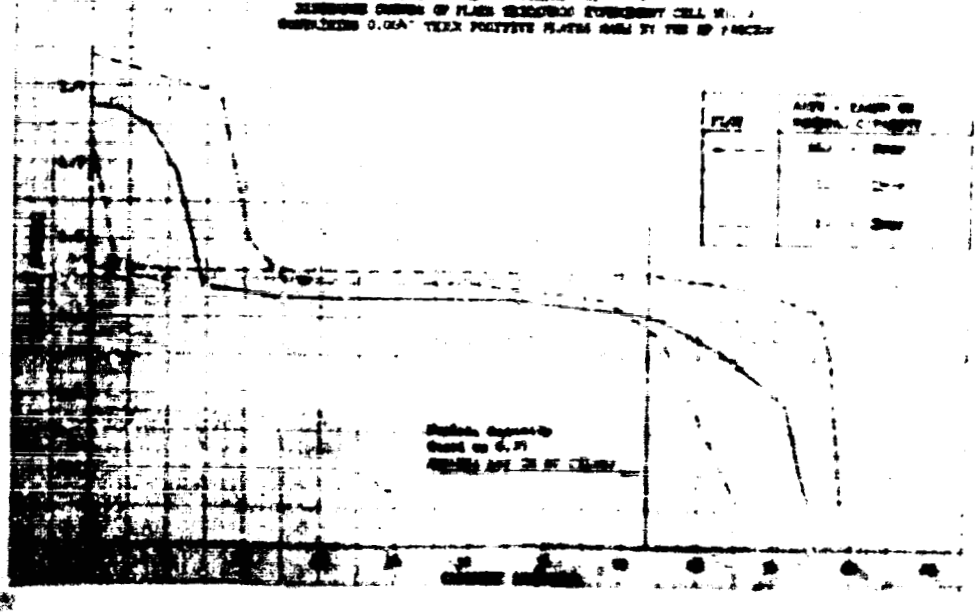
FIGURE [illegible]

EFFECT OF RATE ON VOLTAGE AT [illegible]°C
DISCHARGE CURVES OF PLATE THICKNESS EXPERIMENT CELL NO. [illegible]
CONTAINING 0.06A" THICK POSITIVE PLATES MADE BY THE DP PROCESS

FLOW	RATE - BASED ON NOMINAL CAPACITY
[illegible]	[illegible] - Hour
[illegible]	[illegible] - Hour
[illegible]	[illegible] - Hour



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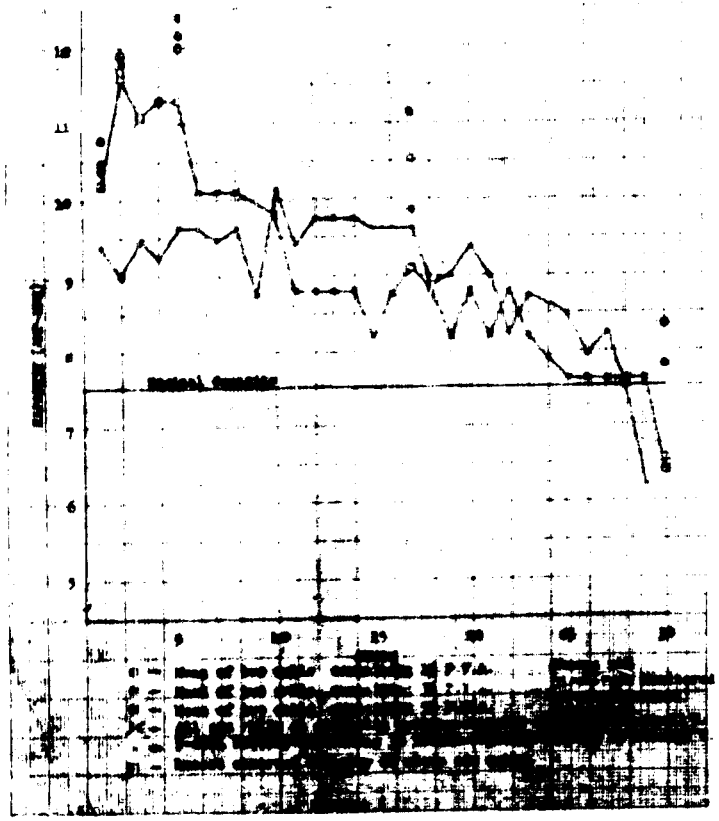

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FIGURE 9

MODEL 216 DISCHARGE CURVES AT 20-HOUR RATE

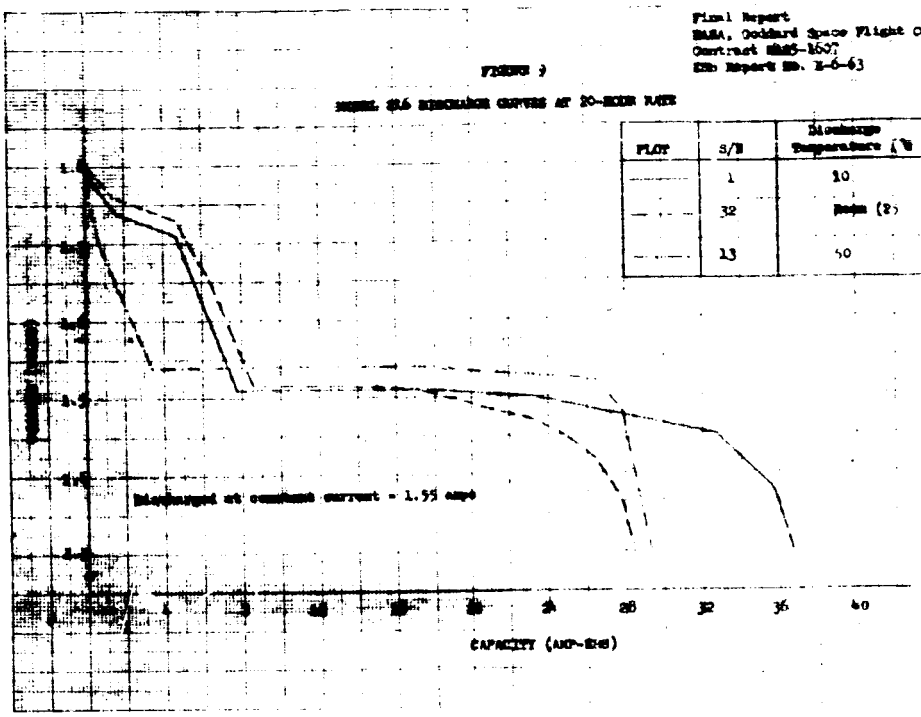


FIGURE 10

MODEL 216 DISCHARGE CURVES AT 100-HOUR RATE

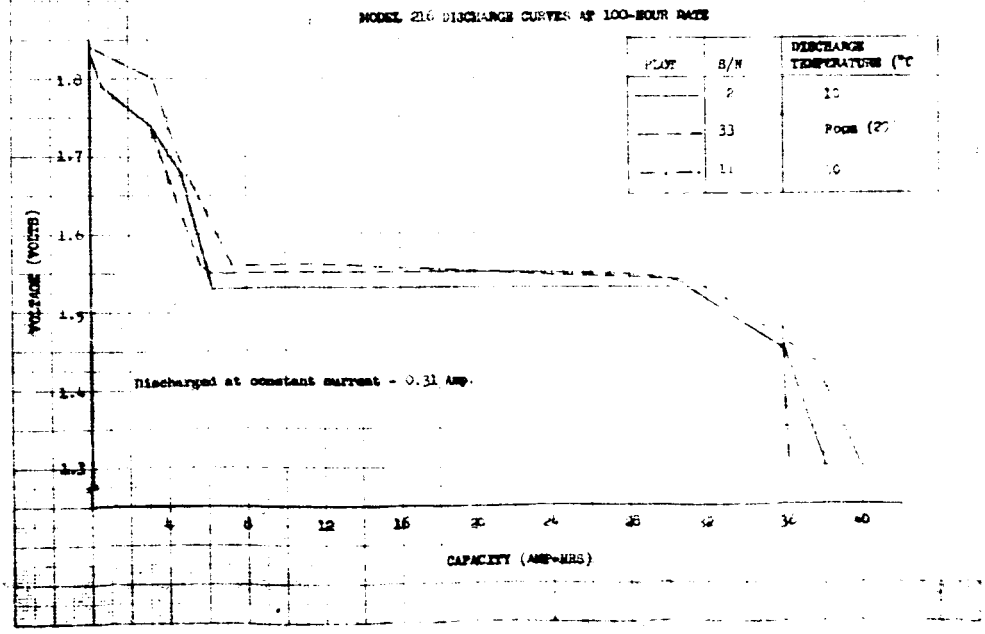


FIGURE 11

MODEL 216 DISCHARGE CURVES AT 1000-HOUR RATE

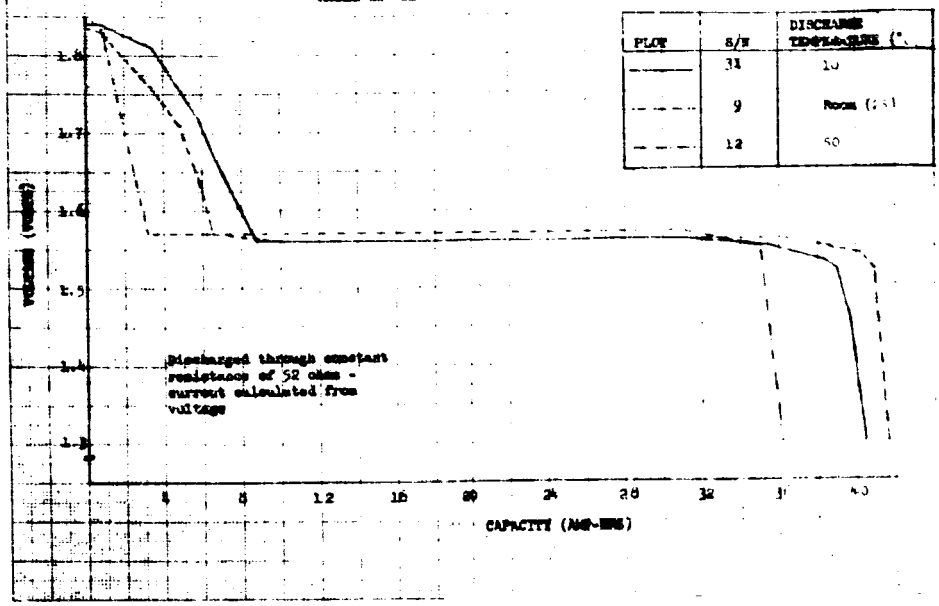
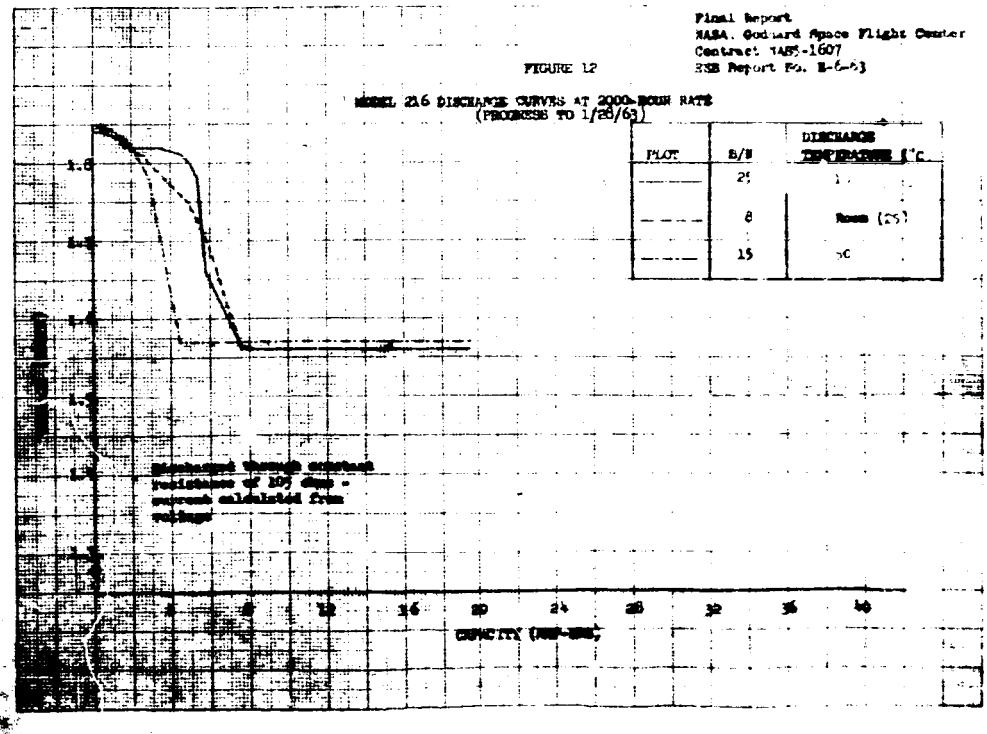
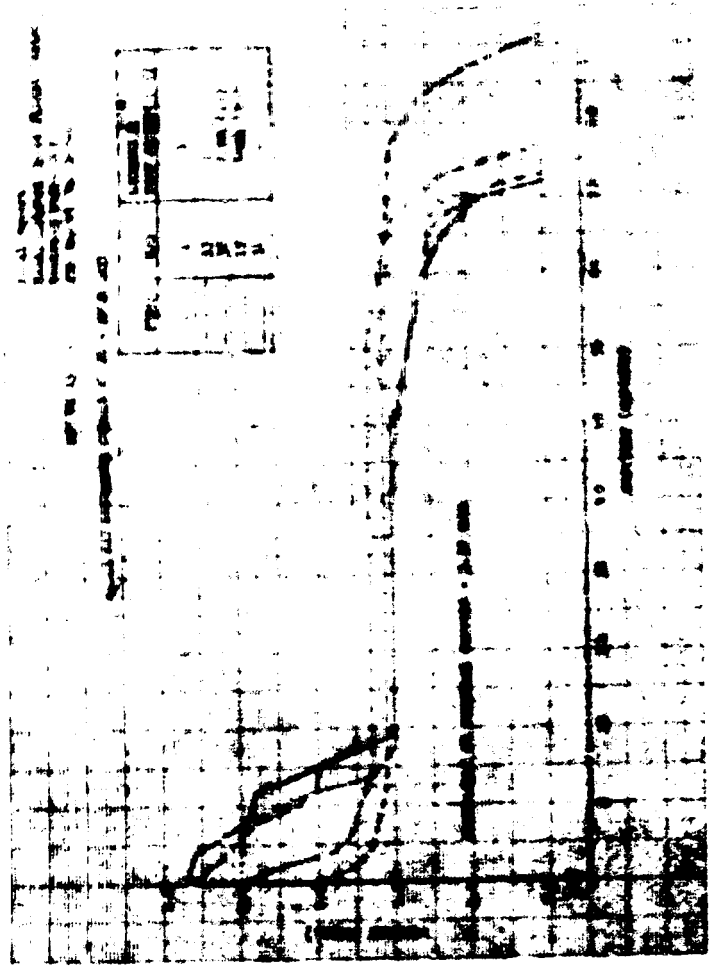


FIGURE 12

MODEL 216 DISCHARGE CURVES AT 2000-HOUR RATE
(PROGRESS TO 1/28/63)





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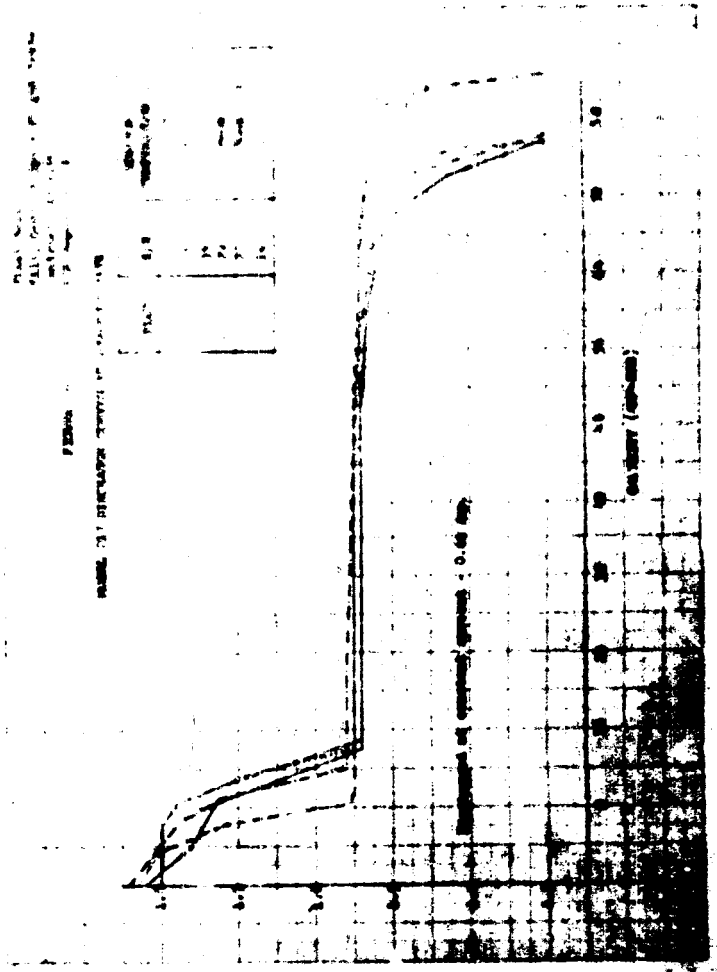

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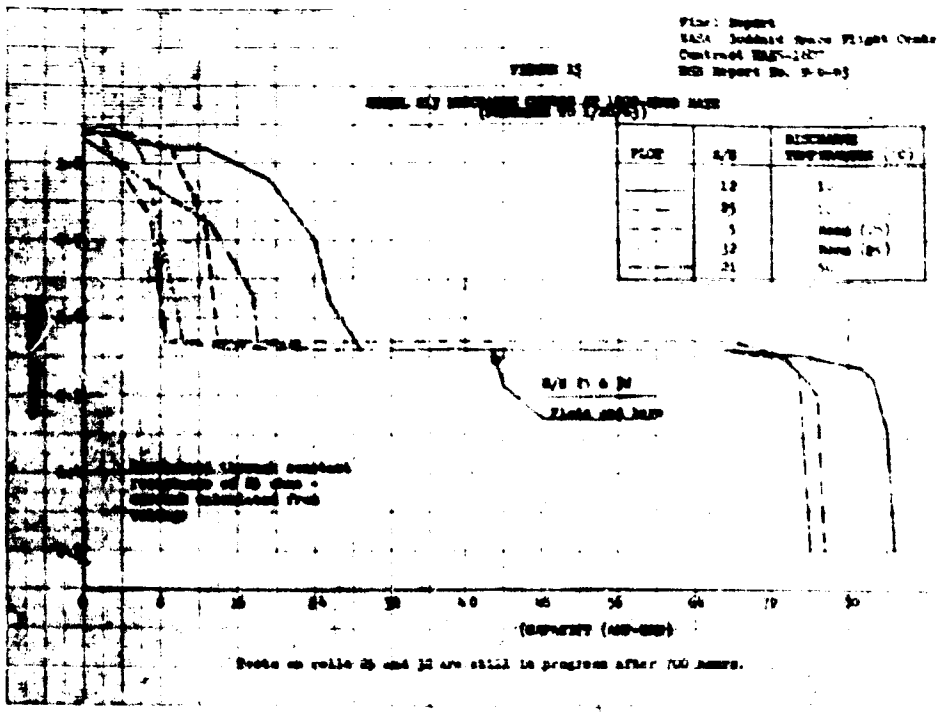

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FIGURE 15
PLOT
S/N
DISCHARGE TEMPERATURE (°C)
12
25
5
32
21
Room (25)
Room (25)
Flats and bars
Discharged through constant resistance of 25 ohms - current calculated from voltage
0
8
16
24
32
40
48
56
64
72
80
(DEPTH (MM-HG))
Tests on rolls 25 and 32 are still in progress after 700 hours.

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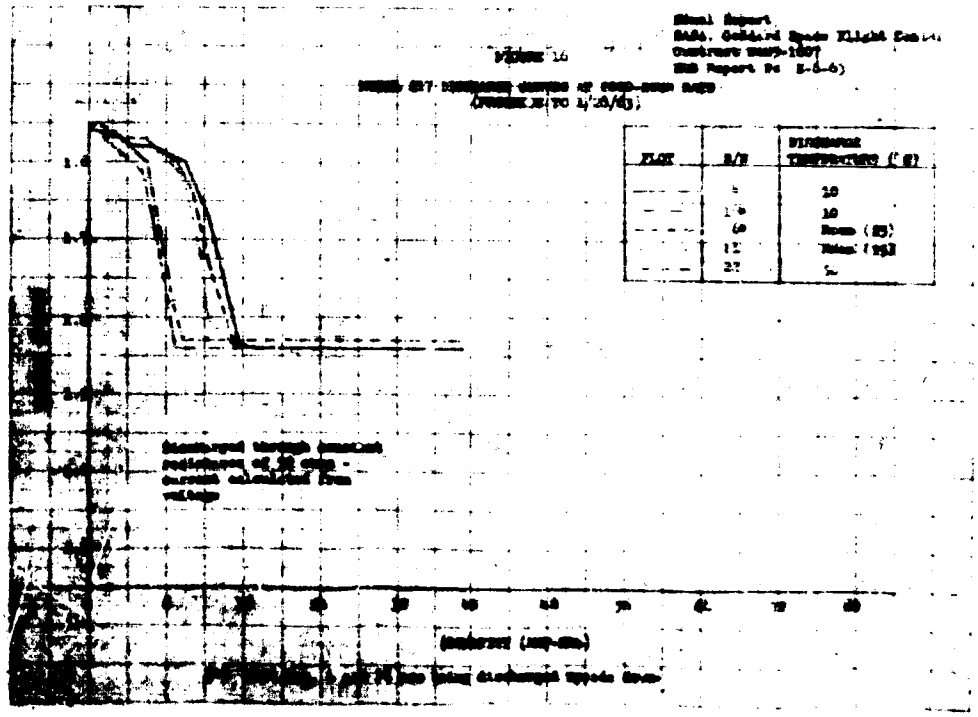

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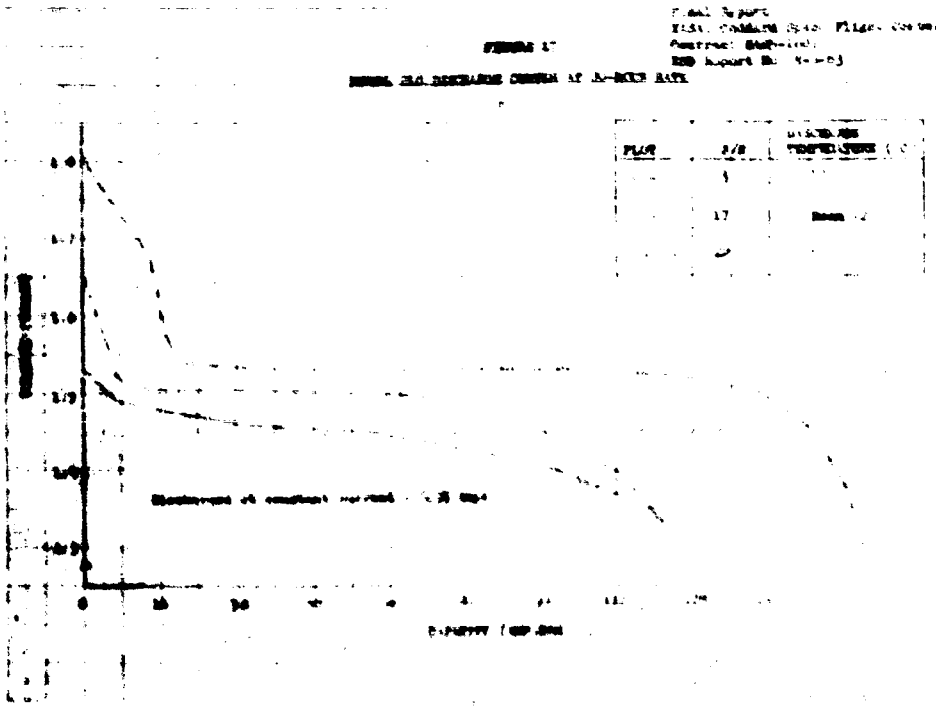
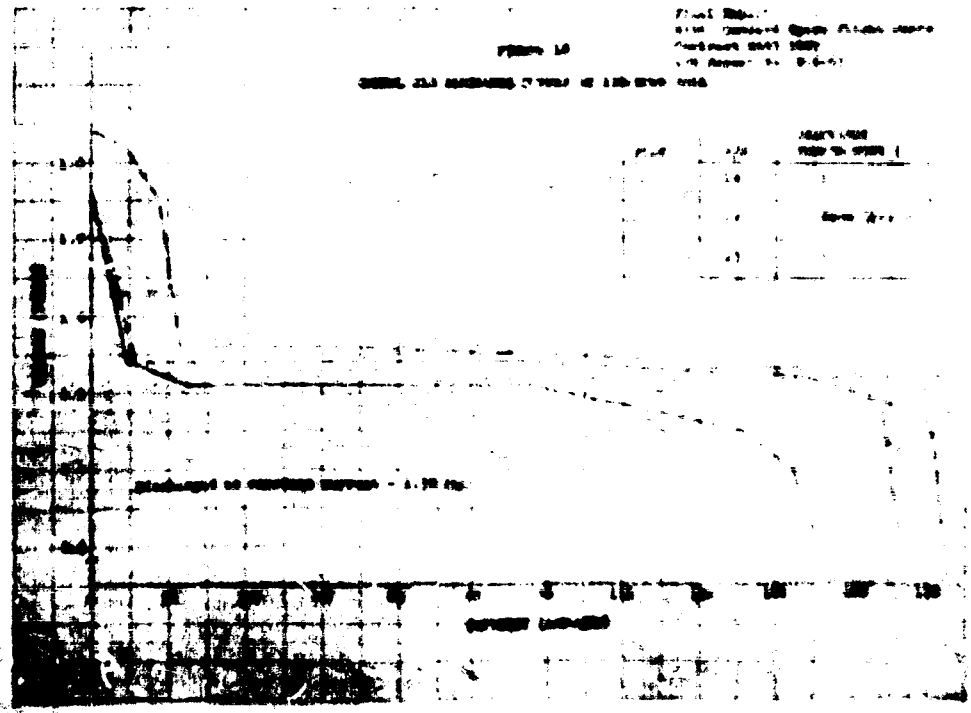
FIGURE 16
PLOT
S/N
DISCHARGE TEMPERATURE (°C)
10
10
60
Room (25)
Room (25)
Discharged through constant resistance of 25 ohms - current calculated from voltage
0
8
16
24
32
40
48
56
64
72
80
(DEPTH (MM-HG))





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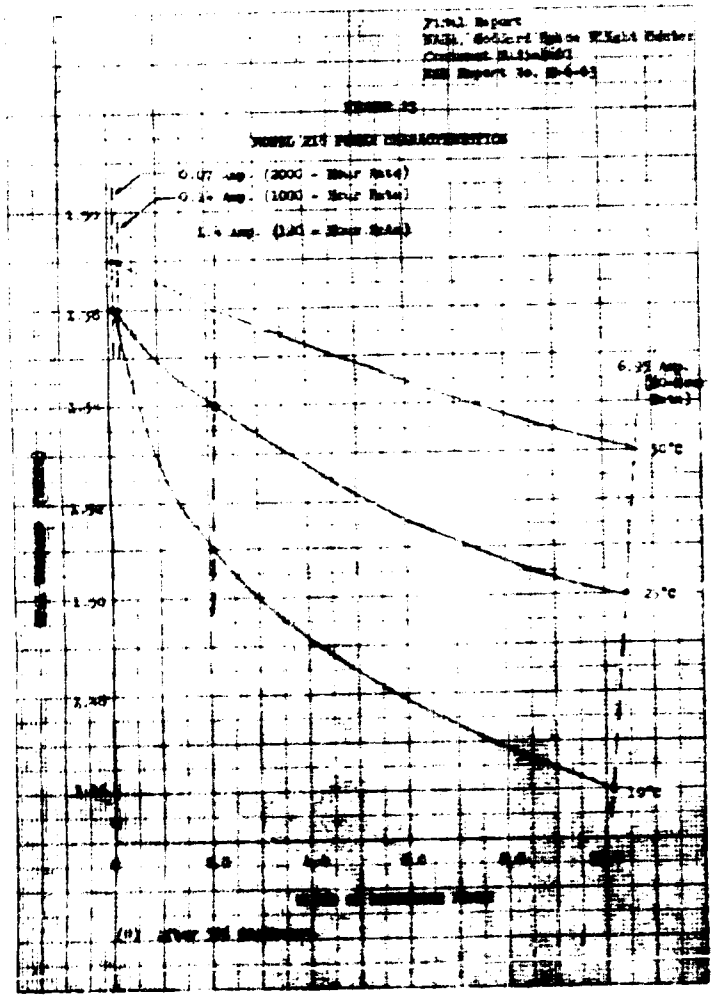
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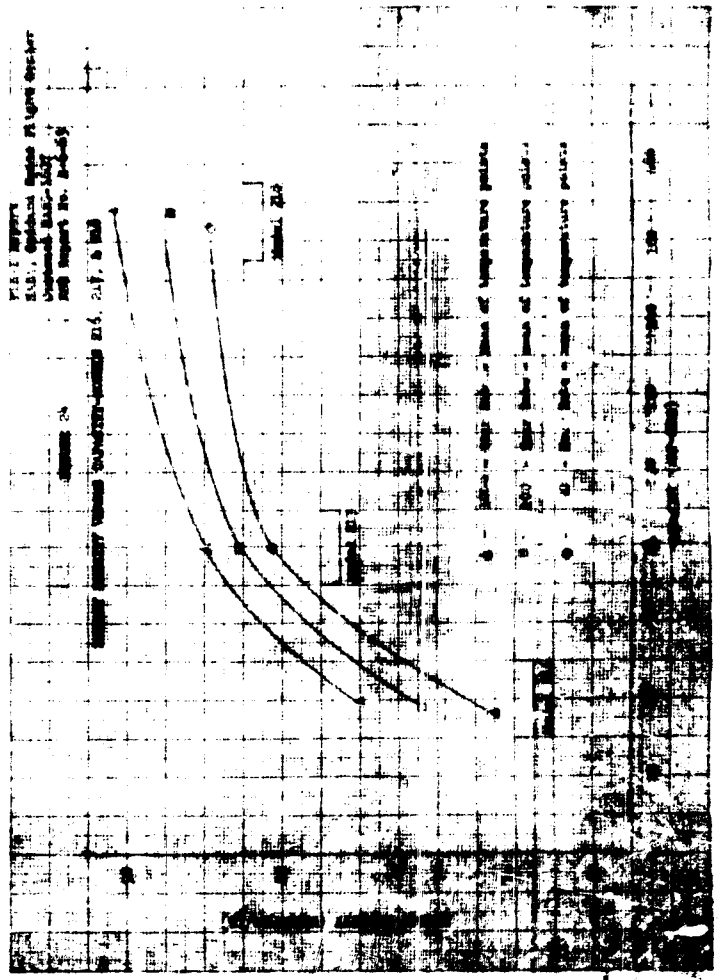
0.07 Amp. (2000 - Hour Rate)
0.14 Amp. (1000 - Hour Rate)
1.4 Amp. (120 - Hour Rate)
6.95 Amp.
50°C
25°C
10°C



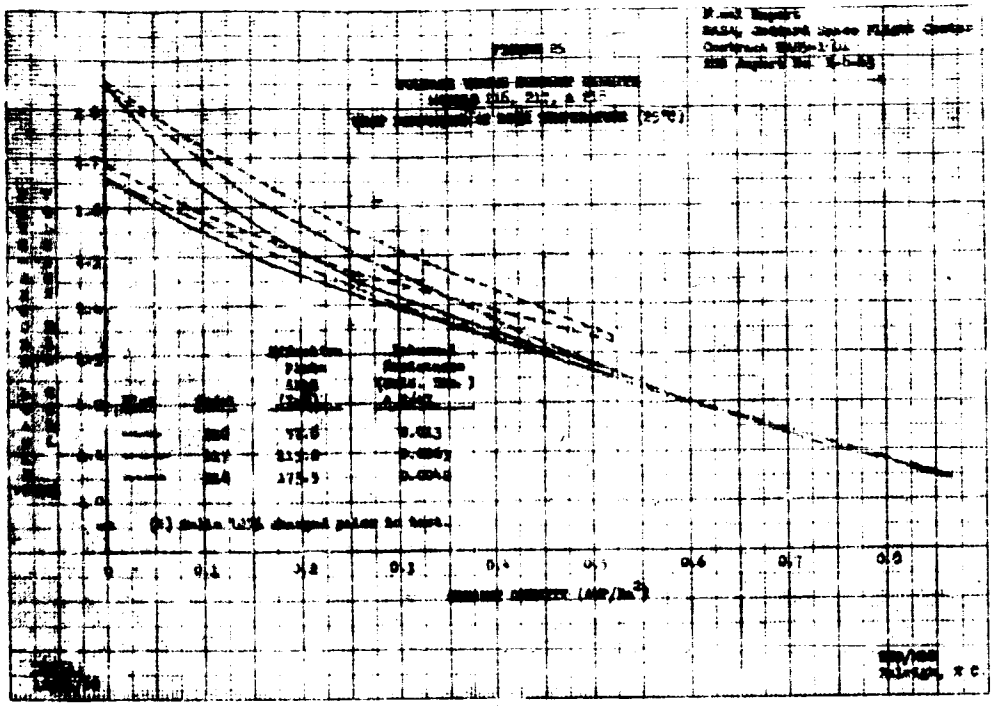


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FIGURE 25
(25°C)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8

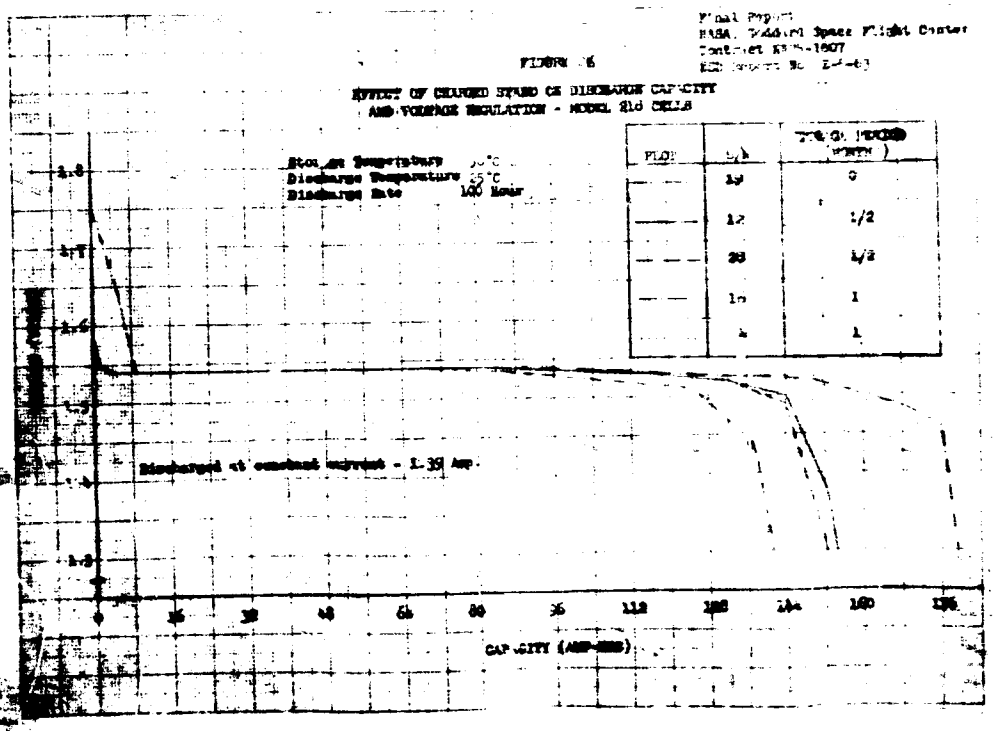

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FIGURE 26
EFFECT OF CHARGED STAND OF DISCHARGE CAPACITY
AND VOLTAGE REGULATION - MODEL 21d CELLS
Storage Temperature
Discharge Temperature 25°C
Discharge Rate 100 Hour
PLOT
19
0
12
1/2
28
1/2
1
1
Discharged at constant current - 1.39 Amp.
0
16
32
48
64
80
96
112
128
144
160
176
CAPACITY (AMP-HRS)

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Service and Operating Instructions No. 47a

15 March 1963
Superseding
Service and Operating Instructions No. 47b
16 February 1963

SERVICE AND OPERATING INSTRUCTIONS

FOR

SEALED SILVER-ZINC BATTERIES

ESB MODELS 216, 217, AND 218

THE ELECTRIC STORAGE BATTERY COMPANY
MISSILE BATTERY DIVISION
RALEIGH, NORTH CAROLINA

15 March 1963

SERVICE AND OPERATING INSTRUCTIONS
FOR
SEALED SILVER-ZINC BATTERIES
ESB MODELS 216, 217, AND 218

FOREWORD

These instructions contain physical and electrical descriptions for preparing and maintaining The Electric Storage Battery Company sealed silver-zinc Type 216, 217, and 218 batteries. Before performing maintenance procedures, battery servicemen shall first become fully acquainted with the contents herein, paying strict attention to all WARNINGS and CAUTIONS.

1. GENERAL

1.1 Battery Description. - The Electric Storage Battery Company sealed silver-zinc batteries Type 216, 217, and 218 have nominal capacities of 30, 60, and 140 ampere-hours, respectively, at the 20 hour rate. They have inherent energy densities in excess of 55-watt-hours per pound at the 10-hour to 1 year rates as calculated on the basis of first cycle output. Nonmagnetic cell case materials are used to prevent field intensities greater than 10^{-5} gauss at a point three feet from the cells. CAUTION: Discharge and recharge these batteries in strict accordance with the operating instructions contained herein.

1.2 Shipment. - Each battery shipped by ESB has been fully charged prior to shipment.

1.2.1 Open-Circuit Voltage. - Upon receipt and prior to discharging, the batteries should be tested for open-circuit voltage.

1.2.1.1 Fully Charged Battery, As Received. - The terminal voltage of the battery should be in the range 1.83 to 1.86 volts during the first month after manufacture as shown on the battery label WHEN STORED AT ROOM TEMPERATURE (25°C) OR BELOW. If the open-circuit voltage falls below 1.83 volts during this period, charge the battery according to the charging instructions herein, and then recheck the open-circuit voltage of the battery. If the battery open-circuit voltage is restored to the range 1.83 to 1.86 volts per cell, the battery is considered reliable and may be placed in service. If the recharged battery fails to charge to the desired voltage or fails to hold the desired voltage over a 24-hour period, the battery shall be considered unreliable and the directions of Section 5 apply. All voltage measurements should be made with a voltmeter having an impedance of at least 5000 ohms per volt.

1.3 Storage. - Optimum storage life will be obtained when these batteries are stored in the charged state at temperatures between 20 and 60 degrees F. Under these conditions little loss of capacity increases with increases in storage temperature. The estimated maximum percent capacity lo[illegible] month is 0.1% at [illegible]°C, 0.2% at 15°C, 4% at 32°C, and 20% at 50°C based on observations [illegible] AH cells for periods up to 6.0 months. CAUTION. Long time storage should be at a temperature of 40 to 60 degrees F. The cells should be reinforced by clamping across the short length of the cell to prevent cell expansion and warpage of plates.

1.4 Electrolyte Leakage. WARNING. Electrolyte (KOH) solution is highly dangerous. Extreme care shall be exercised at all times if any solution is detected. Electrolyte leakage may occur as a result of internal pressures developed. Any detected electrolyte must be immediately wiped up with a cloth or paper towel. Discard the wiping material. Immediately after wiping thoroughly wash the area with water, then neutralize with a weak solution of acetic acid and wash with water. CAUTION. Do not allow spilled electrolyte to come in contact with skin or clothing. If this does occur, follow the above steps.

2 DISCHARGING INSTRUCTIONS

2.1 Discharging. - These batteries may be discharged at rates up to the 5-hour rate but under no circumstances shall the depth of discharge exceed the lower limit of [illegible] volt per cell. Below this voltage, cells may reverse and gas causing damage to the unit. These batteries must be reinforced by clamping across the cell length while discharging to achieve maximum performance.

3 TYPICAL DISCHARGE PERFORMANCE

3.1 Performance. - Typical discharge performance of the Model 216, 217, and 218 batteries is shown in Table I and Figure 1. The loss of performance, if any, as the number of cells in series increases is not accurately known at the present time.

4. CHARGING INSTRUCTIONS

4.1 General. - For maximum performance these batteries should be charged at the constant currents tabulated in paragraph 4.2 to a voltage cut-off of 1.96 ± 0.01 volts/cell. WARNING: Under no condition shall the charge cutoff voltage be exceeded as this might lead to gassing and high internal pressures causing subsequent electrolyte leakage. These batteries must be clamped across the short dimension while charging

and should be enclosed in a protective box to shield equipment and personnel in the unlikely event that electrolyte is sprayed from the unit. Typical charge performance is shown in Figure 1.

4.2 Charging [illegible]. - These batteries should be charged at the full Currents tabulated below until the voltage reaches 1.96 ± 0.01 volts per cell. The charge current should then be reduced to the half currents tabulated below and charge continued until the cell voltage again reaches 1.96 ± 0.01 volts:

Model No.	Full Current (amperes)	Half Current (amperes)	Formation Charge Input* (AH)
216	0.58	0.29	40
217	1.15	0.58	80
218	2.50	0.29	170

*: Minimum acceptable input on formation charge at ESB

5 BATTERY FAILURE

5.1 General. ESB requests that if batteries fail prematurely the customer inform ESB through proper channels in order to receive instructions for return of batteries.

A full disclosure of test routines and the circumstances attending the failure should accompany the battery. Post mortems conducted by ESB engineers yield useful information on the cause of failure and will result in improved future designs. Full details of post mortems will be mailed to the customer.

(15 March 1963)

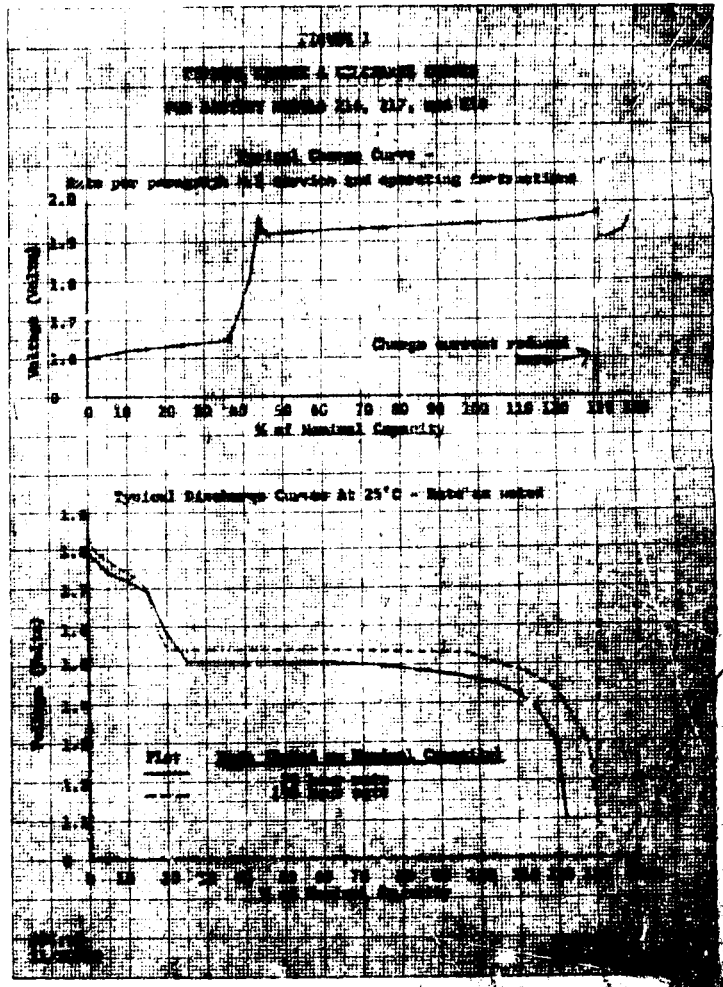
TYPICAL DISCHARGE CHARACTERISTICS* OF SEALED SILVER-ZINC CELLS
MODEL 216, 217, AND 218

Model No.	Nominal Rate (Hrs)	Current (Amperes)	Capacity (Ampere-Hrs)	Mean Voltage (Volts/Cell)	Energy Density Watt Hrs/Lb	Energy Density Watt Hrs/In³
216	20	1.55	37	1.5[illegible]	66	5.[illegible]
217	100	0.31	38	1.[illegible]	71	5.4
218	1000	0.03	[illegible]	1.5[illegible]	75	5.8
217	20	3.10	[illegible]	1.[illegible]	81	7.2
217	100	0.62	79	1.[illegible]	83	7.4
218	1000	0.05	79	1.[illegible]	85	7.6
218	[illegible]	0.9[illegible]	[illegible]	1.[illegible]	85	7.3
218	100	1.39	16[illegible]	1.5[illegible]	87	8.0
218	1000	0.14	168	1.5[illegible]	91	8.4

*Average Performance 10°C to 50°C based on limited data now available and may be revised later

TABLE II

DIMENSIONS OF SEALED SILVER-ZINC CELLS
MODEL 216, 217, AND 218

Model No.	Cell Case Dimensions (Inches) Height (Max.)	Width (Max.)	Length (Max.)	Cell Weight (Lb.) (Mean)
216	5.830	2.385	0.775	0.83
217	5.830	2.385	1.205	1.49
218	5.858	3.448	1.562	2.95

-4-