# INTERIM TEST REPORT
# GENERAL ELECTRIC 20-AMPERE HOUR
# NICKEL-CADMIUM BATTERY

by

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(NASA-CR-120748) GENERAL ELECTRIC 20-AMPERE HOUR NICKEL-CADMIUM BATTERY Interim Test Report (Sperry Rand Corp.) 22 p HC $3.25 CSCL 10C
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SPERRY RAND CORPORATION

For

Electrical Power Branch
Electrical Division
Astrionics Laboratory

GEORGE C. MARSHALL SPACE FLIGHT CENTER

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LIST OF ILLUSTRATIONS
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## 1. PURPOSE

The purpose of this test was to observe, record, and become familiar with the General Electric (GE) 20-ampere-hour, 24-cell nickel cadmium battery. Of major concern was the interaction, effect, and controllability of the various performance parameters.

## 2. CONCLUSIONS AND RECOMMENDATIONS

2.1 The following conclusions can be drawn after 620 cycles of operation on the GE battery.

(a) The battery capacity decreases after a high initial charge, as a function of cycles. This may be the result of a memory effect, or the battery achieving a state of equilibrium. Whether the battery is achieving a state of equilibrium or not has not been determined.

(b) The required overcharge cannot be achieved because of excessive cell divergence. This also can cause a capacity loss.

(c) Parameter variations, such as temperature or load, have no apparent effect on reversing the reduction in battery capacity.

The overall performance of the battery to date has been marginal for application with the Apollo telescope mount (ATM) power system. Voltage matching of individual cells is required to permit recharge. The causes of capacity loss must be determined.

2.2 The purpose of the following test recommendations is to acquire further data on capacity losses, equilibrium, and battery charge parameters. It is recommended that testing be performed in the following areas:

(a) A 100-cycle test should be conducted starting with a fully charged battery.

(b) A second 100-cycle test should be performed starting with a completely discharged battery to which normal cycling is applied.

(c) A series of tests should be performed where any individual cell voltage, during the charge cycle, is allowed to rise to 1.51 volts.

(d) Tests should also be completed to determine the relationship between the maximum individual cell charge voltage, the percentage of overcharge, and the steady state capacity of the battery.

## 3. PROCEDURE

3.1 Test plan. The basic test plan was to cycle the battery under simulated orbit conditions. As data was accumulated, it was analyzed and evaluated in terms of battery parameters and performance characteristics. An attempt was then made, during subsequent tests, to acquire more specific information on particular characteristics and parameters.

3.2 Test conditions. The battery was tested under "worst case" ATM orbit conditions as follows:

| | | |
|---|---|---|
| (a) | Charge time | 58 minutes |
| (b) | Discharge time | 36 minutes |
| (c) | Temperature | 25 $\pm$ 5 degrees Celsius (C) |

All individual cell voltages and the total voltage were monitored with a data scanner. The current, total voltage, and controlling third electrode were monitored by a strip chart recorder. An additional strip chart recorder was used to record two other third electrode signals. Orbit simulation was provided by a timing unit composed of an oscillator and an electronic counter. A 700-watt power supply simulated the solar source. The system load was simulated with a hand controlled wire wound rheostat. Constant power was supplied throughout the charge/discharge cycle.

The battery was charged with a breadboarded ATM charger/regulator. During charge, the maximum battery current was limited to 10 amperes until a preset maximum voltage level was achieved. At this point, charging current was limited to prevent exceeding maximum battery voltage. Charge cutoff occurred when any one of three third electrode signals exceeded their preset levels.

The 24 cells were mounted in the restrainer provided by GE. Heat sinks, also supplied, were positioned as a spacer between individual cells and extended beyond the bottom of the battery to decrease temperature gradients among the cells. Temperature was maintained within $\pm$ 1 degree C with a thermal chamber.

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All standard battery capacity tests were performed with the battery load maintained at a constant 8 amperes. The discharge was terminated when the voltage of any cell decreased below 1 volt.

## 4. TEST RESULTS

### 4.1 GE battery no. 1.

4.1.1 Procedure. The GE battery no. 1 was received in a discharged condition having been previously conditioned in accordance with the National Aeronautics and Space Administration (NASA) recommended procedure in Appendix A. The recommended GE conditioning cycle, as noted in Appendix A, was immediately applied to the battery. At the completion of this cycle, the total open circuit battery voltage was 31.32 volts with the maximum individual cell voltage divergence at 8 millivolts (mV). Following the above conditioning, the battery was placed on automatic orbit cycling using the previously noted orbit conditions. Control parameters for this portion of the test were determined by GE as follows:

(a) Temperature was maintained between 25 $\pm$ 5 degrees C.

(b) Maximum battery voltage was not to exceed a particular value, as noted in figure 1, corresponding to a given battery temperature.

(c) The third electrode load resistor value was to be between 1 and 3 ohms.

(d) No third electrode cutoff information was given. It was, however, maintained at 125 mV during this test.

A typical charge/discharge cycle is shown in figure 2. As shown, no third electrode cutoff occurred during the charge cycle. With no cutoff, the charge was 150 percent of the capacity taken out during discharge. An additional undesirable factor was the individual cell divergence, or voltage spread, at the end of charge. This divergence exceeded 39 mV. The NASA conditioning procedure was applied to the battery as a result of the 39-mV divergence compared to the post conditioning divergence of 8 mV. A 2.3 mV maximum divergence was noted on the final conditioning charge.

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The battery was placed on simulated orbit cycling following the special conditioning. After two days, the divergence had increased to 45 mV. A final discharge of this battery resulted in a measured capacity of 27 ampere hours.

4.1.2 Summary. The performance information obtained from the preceding test is as follows:

(a) The battery was cycled according to ATM conditions 30 times during this test.

(b) No third electrode cutoff occurred during normal cycling.

(c) Excessive cell divergence occurred at the end of a charge cycle.

Subsequent information received from GE indicated a 7-ohm third electrode resistor was preferred instead of the 1-ohm unit that had previously been used. In addition, the third electrode cutoff criteria was established to be the signal level necessary to permit 20 percent overcharge of the battery.

Since the excessive cell divergence of GE battery no. 1 was not necessarily typical of GE cells, it was decided to use a second 24 cell GE battery (GE battery no. 2) specimen during subsequent tests.

4.2 GE battery no. 2 (phase 1, cycle 0-138).

4.2.1 Procedure. The second GE battery was received in a discharged state, having previously been preconditioned using the recommended NASA procedure in Appendix A. After reconditioning the battery using the GE procedure, the unit was placed on the 94-minute simulated orbit cycle. However, a change was incorporated in this test. The third electrode resistor was increased from 1 to 7 ohms, and the third electrode cutoff was set to permit 20 percent overcharge. The battery was continuously cycled 138 times following the conditioning cycle.

4.2.2 Summary. The performance characteristics are shown in figures 3, 4, 5, 6, and 7. Figure 4 indicates the loss in capacity after 138 cycles of operation. Figure 5 illustrates the increase in cell divergence from 8 to 38 mV. Two typical charge/discharge cycles are shown in figure 3.

Detailed charge characteristics for cycles 30 and 134 are illustrated in figures 6 and 7.

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The evaluation of the phase 1 test resulted in the following conclusions:

(a) Individual cell voltage spread (divergence) increases to a maximum value as a function of cycle time.

(b) Capacity decreases over the cycle life.

(c) Third electrode performance is consistent. However, there are questions concerning nonlinear "jumps" in the signal (figure 3).

(d) The percent of overcharge is self limited to 10 percent because of excessive cell divergence.

4.3 GE battery no. 2 (phase 2, cycle 138-230).

4.3.1 Procedure. Since the low value of overcharge may have caused the loss in capacity during phase 1, the third electrode cutoff was increased from 130 to 140 mV. Normal simulated orbit cycling was then continued for 90 cycles. At cycle 230, figure 4, the battery capacity was again measured and found to have decreased to 14.6 ampere hours.

4.3.2 Summary. Evaluation of the battery performance resulted in three possible causes for battery capacity loss.

(a) The battery was not charged completely.

(b) The battery was not discharged completely.

(c) Effective battery capacity had been reduced.

4.3.3 Capacity test (cycle 230-254). The questions of improper charge were tested by continued simulated orbit cycling for 12 cycles. During the 12th cycle, however, third electrode cutoff control was removed. The measured overcharge during this cycle was 59 percent and is shown in figure 8. The capacity test immediately following the 58 percent overcharge indicated 16 ampere hours of capacity.

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As a result of the last two tests, it was concluded that the effective battery capacity had been reduced. Another attempt was made to completely charge the cell. On the initial charge, 23.5 ampere hours were placed in the cell. Nine cycles of simulated orbit conditions followed with no third electrode control. The overcharge during each charge was 20 percent. Assuming 100 percent battery efficiency, approximately 30 ampere hours of charge were added to the battery. The subsequent discharge resulted in a 22 ampere hour battery capacity.

Two basic problems emerge as a result of the phase 2 test. One is the individual cell divergence at the end of each charge cycle. The other is the loss in battery capacity as a function of cycling.

4.4 GE battery no. 2 (phase 3, cycle 254-540).

4.4.1 Procedure. The loss in battery capacity could have been caused by a memory effect. If this were the case, any change in operating parameters, such as temperature or load, should reverse this apparent memory. Based on the foregoing, the battery was cycled under simulated orbit conditions for one week. At cycle 350, after an apparent memory effect had taken place, normal cycling was continued. The temperature, however, was varied from 20 to 30 degrees every 24 hours.

4.4.2 Summary. A capacity test at 20 degrees C was performed at cycle 460 after one week of temperature cycling. The results indicated a decrease from 18.5 to 16 ampere hours. Immediately thereafter, the battery was again charged and [illegible]ed for 16 hours at 30 degrees C. The subsequent discharge resulted in an additional loss in capacity to 14.5 ampere hours.

From cycle 475 to 540, cycling was continued with the battery load being varied from 8 to 2 amperes every 12 hours. At cycle 540 the battery capacity was 14 ampere hours.

The test results during phase 3 can be tabulated as follows:

(a) Battery capacity decreases as a function of cycling.

(b) Capacity appears to decrease as the temperature increases (figure 4).

(c) Cell divergence at maximum charge is not affected by temperature (figure 5).

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(d) The third electrode signal varies approximately 8 mV per degree C.

(e) Excessive cell divergence limits the battery overcharge capability.

4.5 GE battery no. 2 (phase 4, cycle 540-620). Phase 4 was begun by discharging individual cells with 1-ohm resistors for 72 hours. The subsequent charge was at a 2-ampere rate for 20 hours in accordance with GE recommendations. Normal cycling followed the high overcharge. The battery was cycled for one week prior to a capacity test. The results of the capacity test are shown in figure 4. Cell divergence is noted in figures 5 and 9.

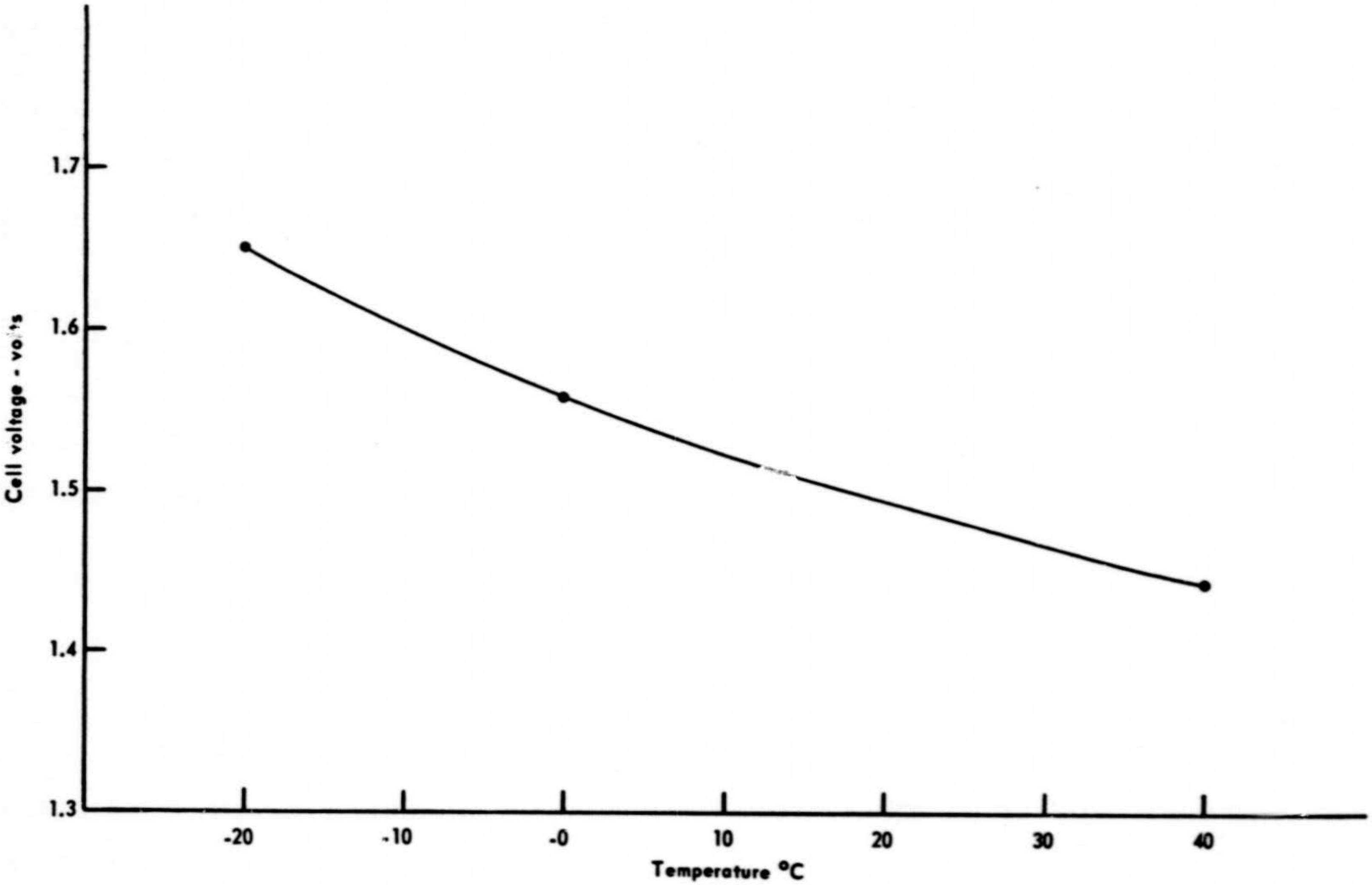


Figure 1 Maximum cell voltage vs. temperature.

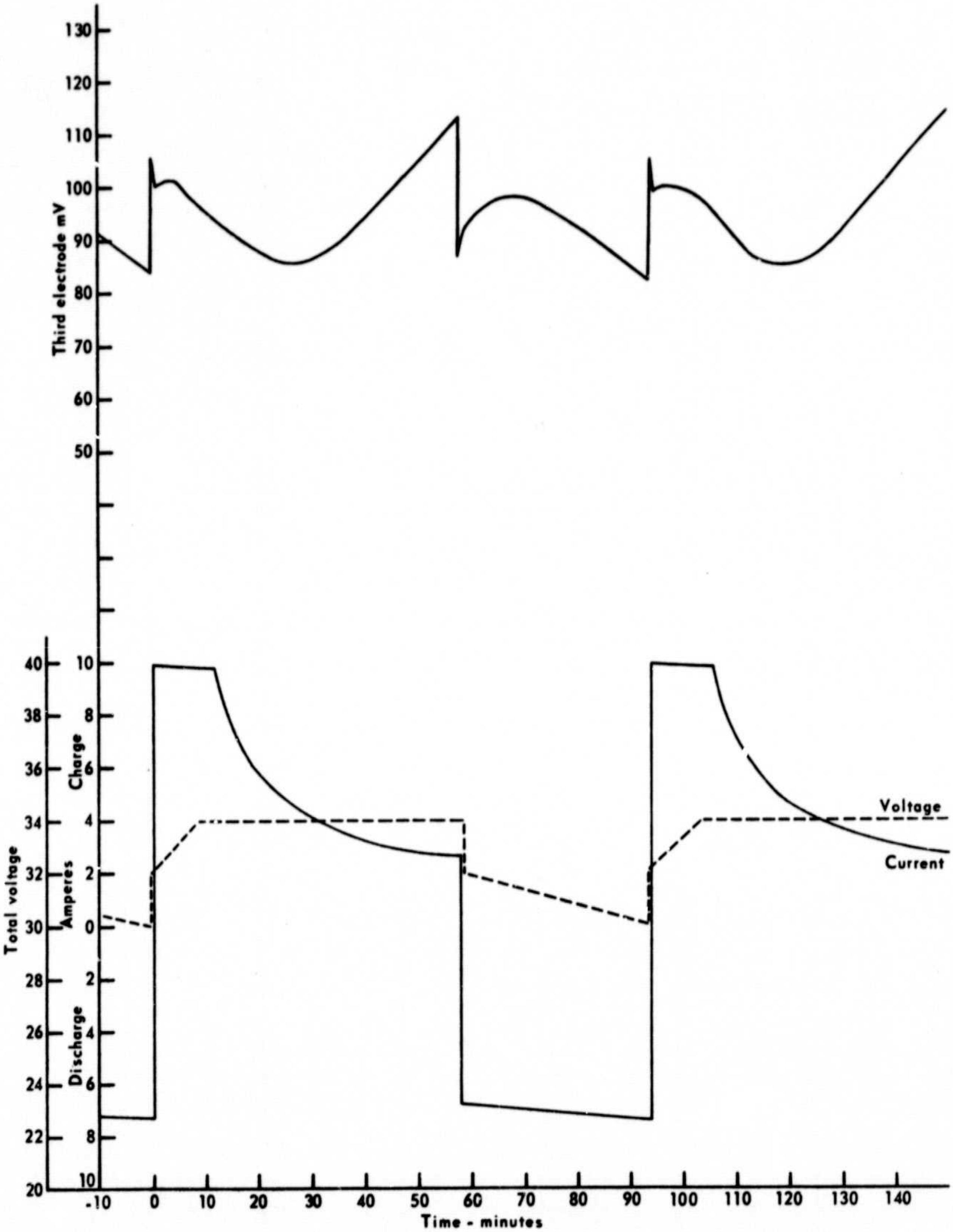


Figure 2 GE battery no. 1, cycles 12 and 13 characteristics



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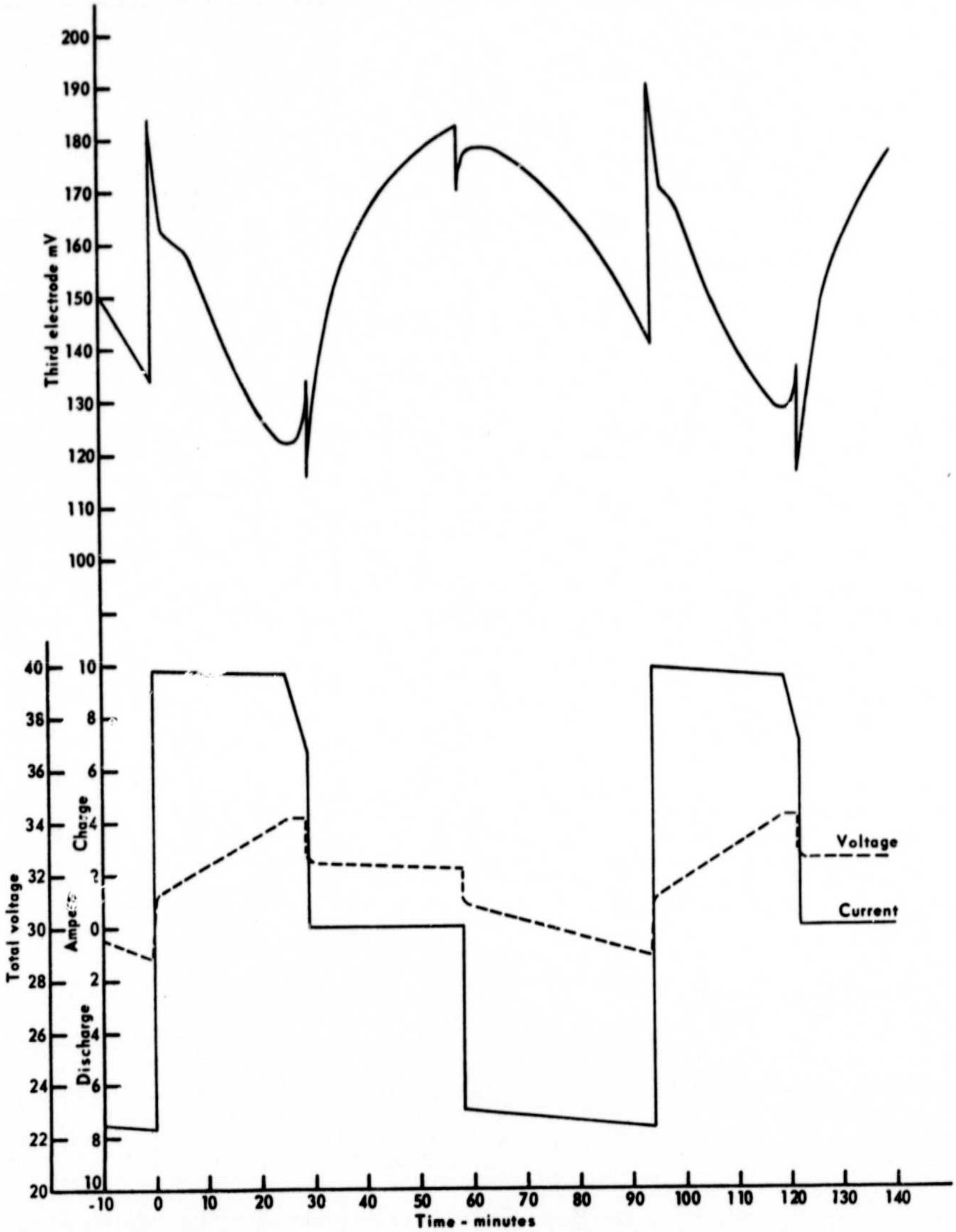


Figure 3 GE battery no. 2, phase 1 cycle characteristics



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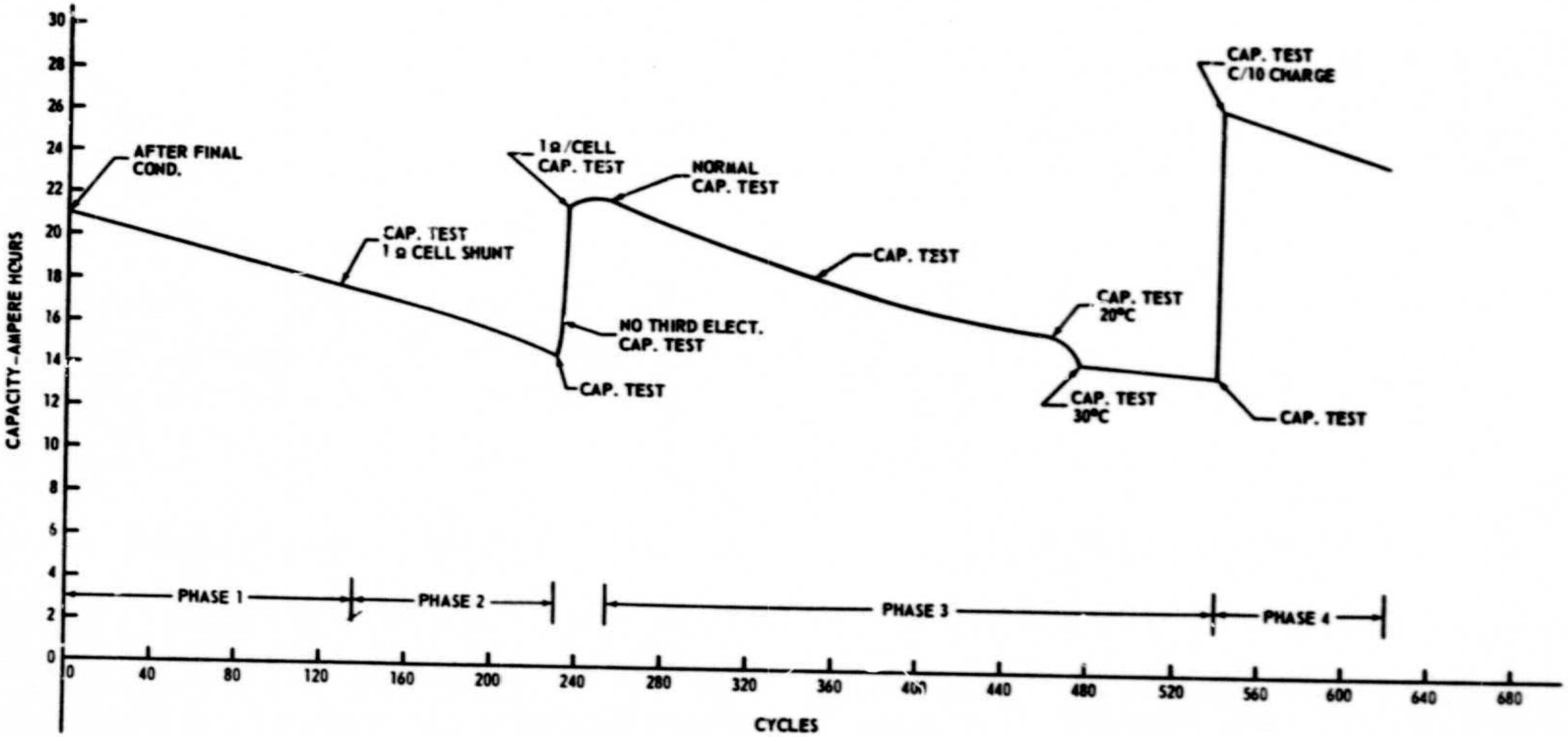


Figure 4. GE Battery No. 2 Capacity Characteristics.



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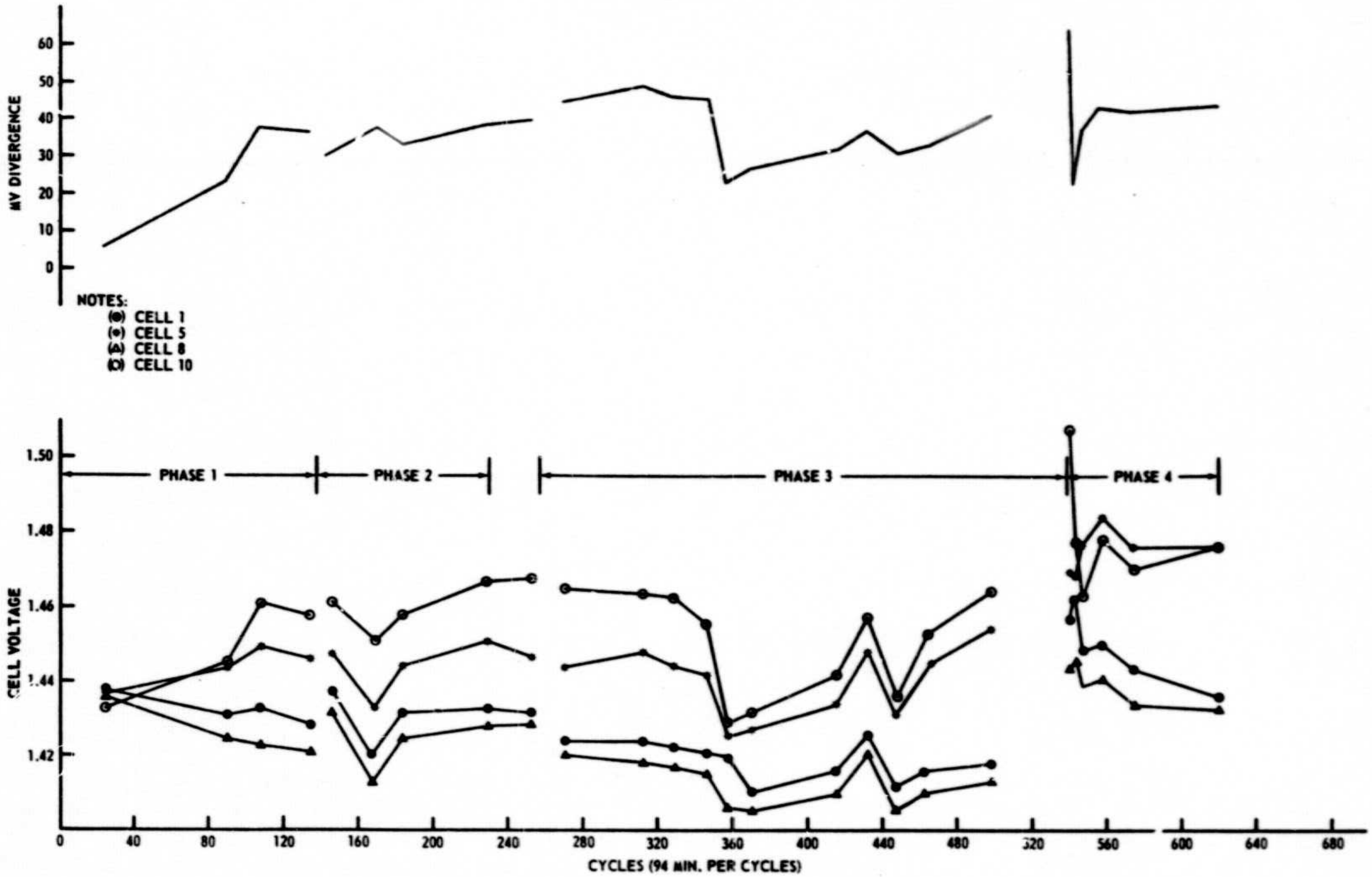


Figure 5. GE Battery No. 2 Cell Divergence Characteristics.

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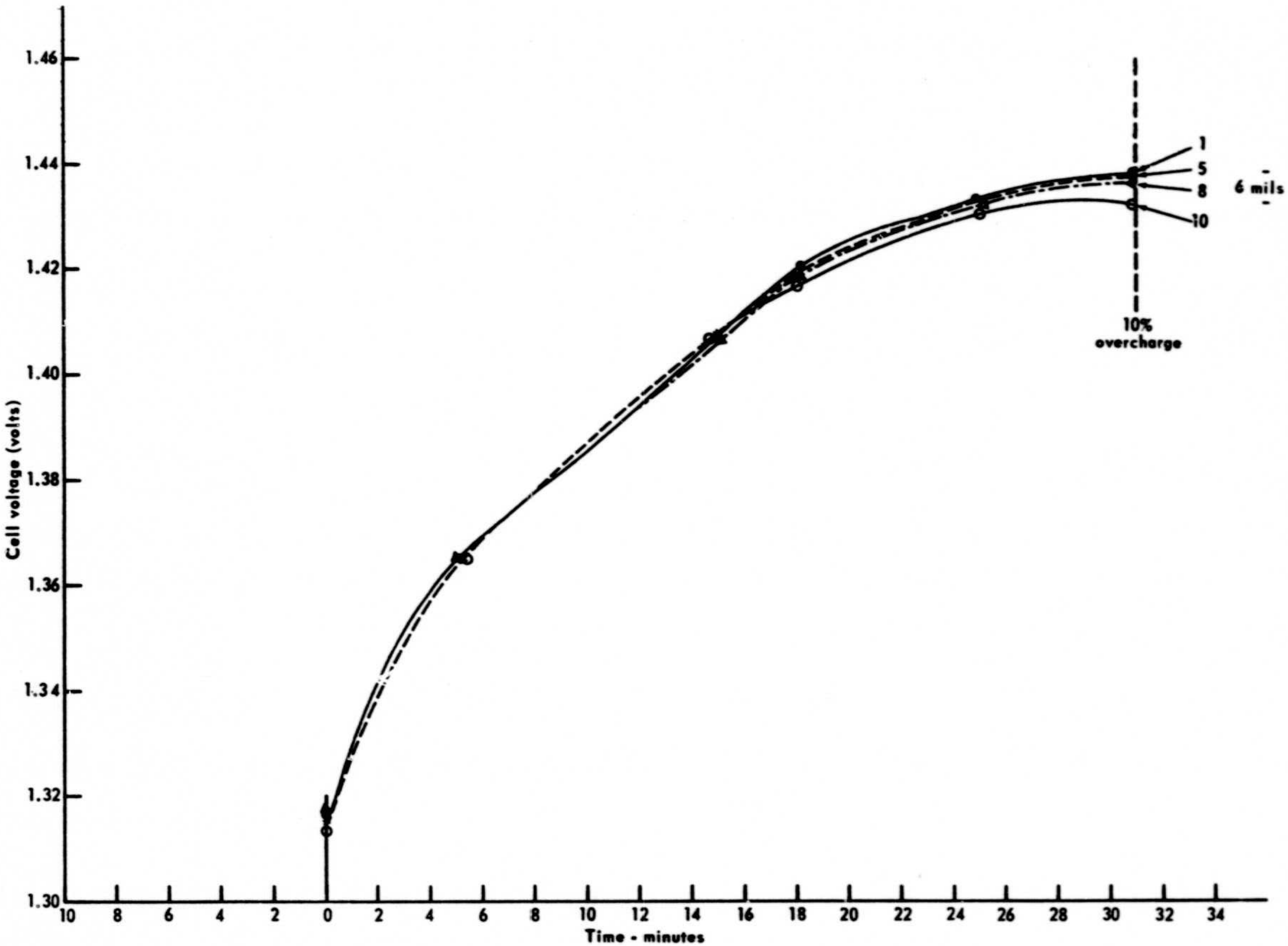


Figure 6 GE battery no. 2, cycle 30, phase 1 (8-24-67, 15:05)

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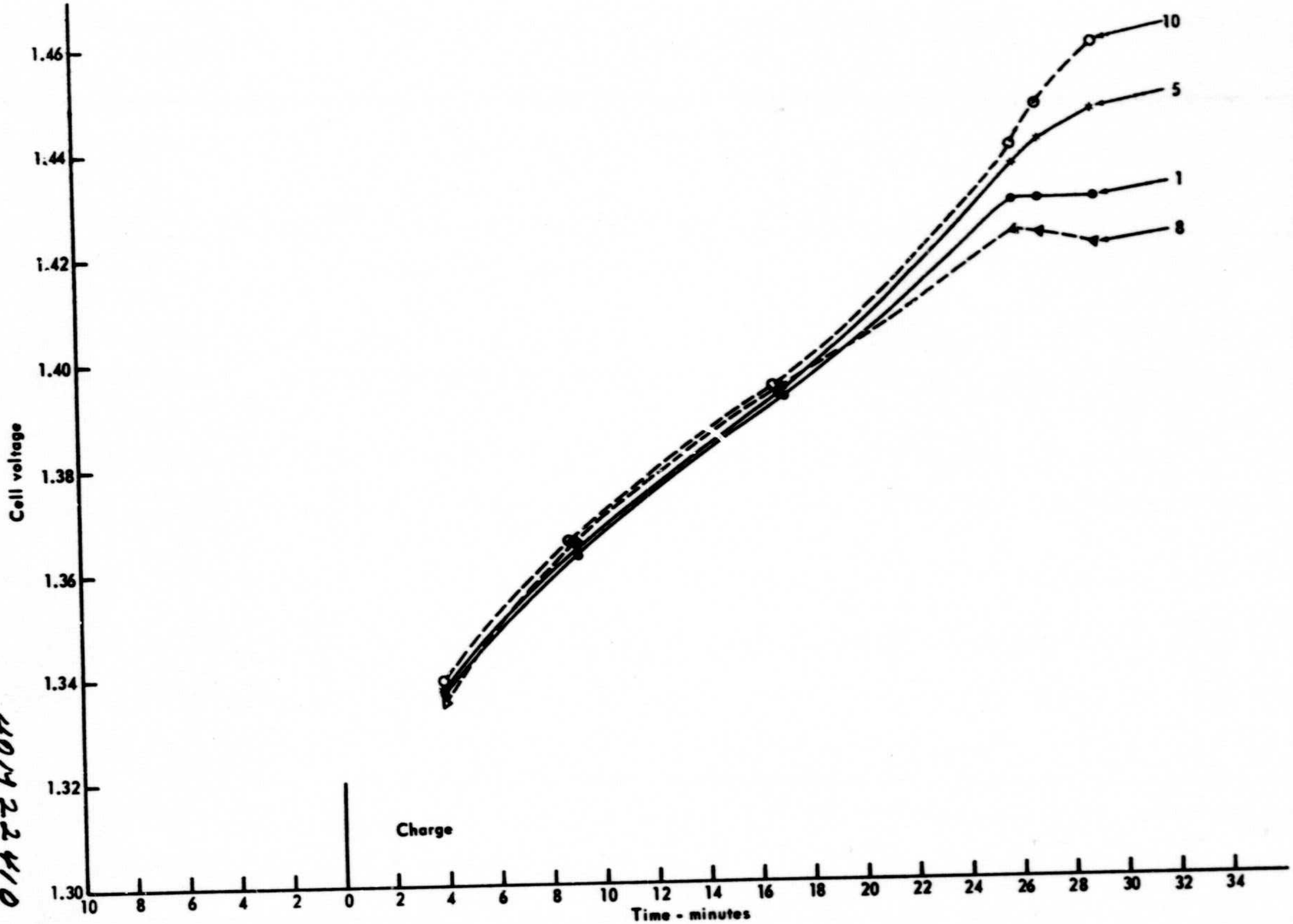


Figure 7  GE battery no. 2, cycle 134, phase 1 (8-31-67, 8:43, 6% overcharge).

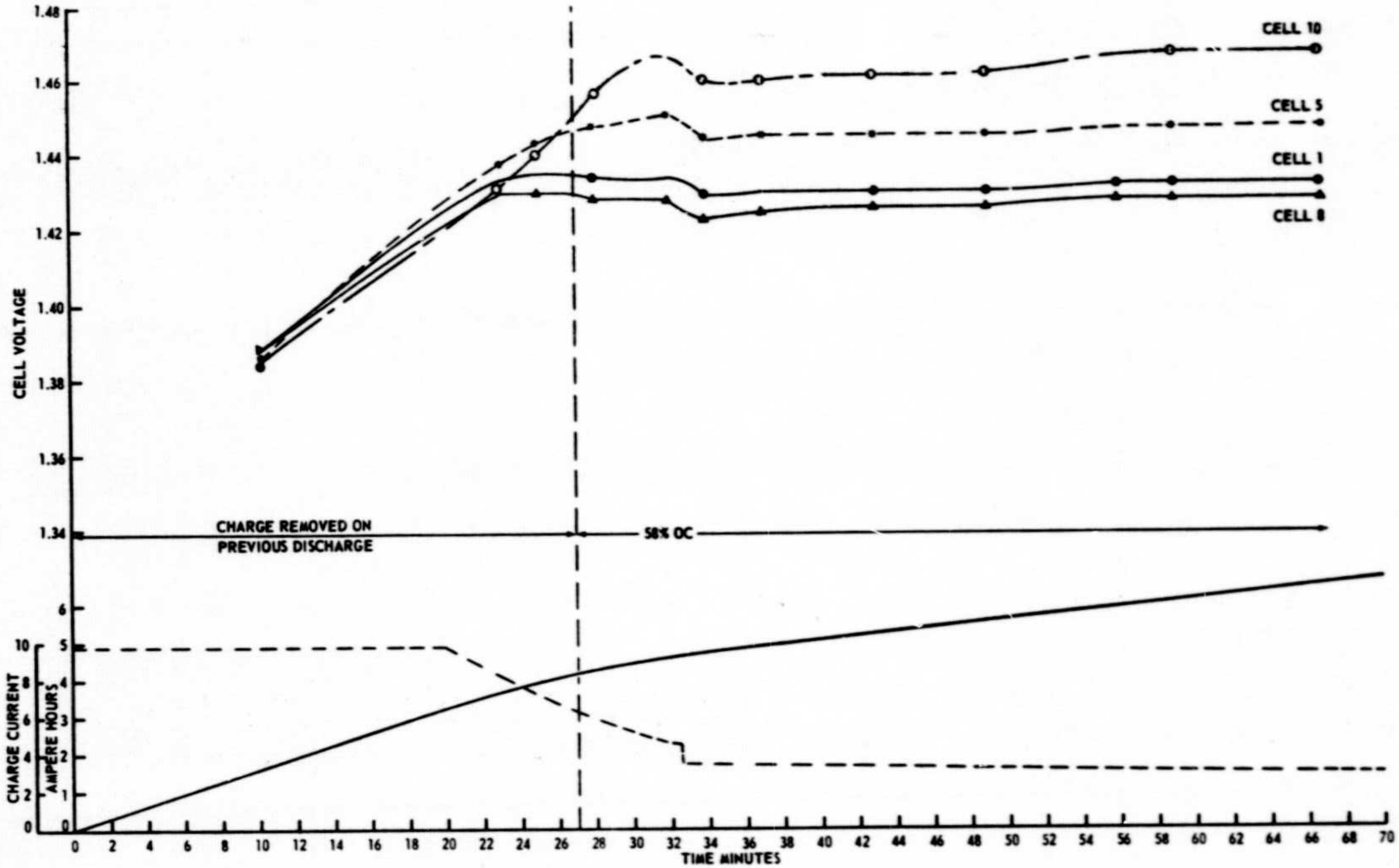


Figure 8. GE Battery No. 2 Charge Characteristics, Cycle 247 (9-12-67, 58% Overcharge).

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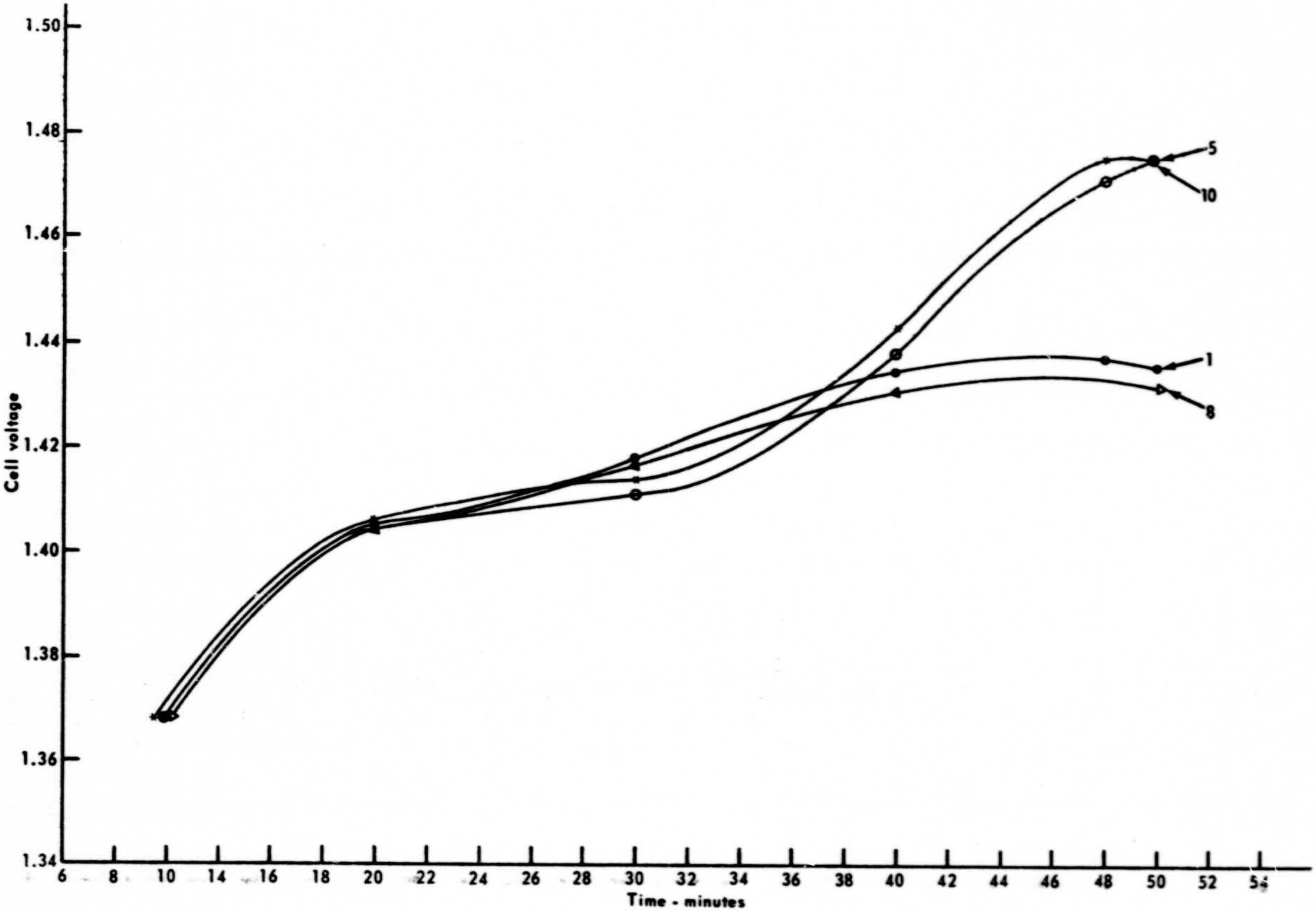


Figure 9 GE battery no. 2, cycle 620, phase 4 (10-16-67, 12:00).

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# APPENDIX A

## NASA AND GE RECOMMENDED PROCEDURES

## 10. INTRODUCTION

The following two procedures are conditioning cycles which are to be performed on GE 20-ampere-hour, 24-cell nickel cadmium batteries after they have been inactive or in storage for more than 20 days.

### 10.1 Conditioning cycle reco mended by NASA.

(a) Place battery in an appropriate restrainer.

(b) Charge the battery at 2 amperes for 13 hours.

(c) Discharge the battery at 2 amperes until the voltage on any cell decreases to 1 volt.

(d) Charge the battery at 5 amperes for 5 hours.

(e) Discharge the battery at 5 amperes until the voltage on any cell decreases to 1 volt.

(f) Charge the battery at 10 amperes for 2.25 hours.

(g) Discharge the battery at 10 amperes until the voltage on any one cell decreases to 1 volt.

Conditioning is complete.

### 10.2 Conditioning cycle recommended by GE.

(a) Place the battery in an appropriate restrainer.

(b) Charge the battery at 0.5 ampere for 50 hours.

(c) Discharge the battery at 4 amperes until the voltage on any one cell decreases below 1 volt.

(d) Charge the battery at 1 ampere for 25 hours.

Conditioning cycle is complete.

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| C H | D S | DRAWING PART/ NUMBER | DWG REV | DASH NO REV | DESCRIPTION | UNIT WEIGHT | CHANGE CONTROL NO | QUAN | NEXT ASSEMBLY | EFFECTIVITY | CONF CODE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| * | | 10439999 | N/A | 324 - | N/A | | | AR | N/A | ZA01 | |

| C H | DWG ZONE | ITEM NO | CODE IDENT | DWG SIZE | PART NUMBER | DWG REV | DA | SPL | QUAN | UNIT WEIGHT | NOTES | DESCRIPTION |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | | A | 40M22410 | - | | | AR | | | INTERIM TEST RPT GEN ELECT 20-AMPERE HOUR NICKLE CAD BATTERY |
| | | 2 | | A | 40M22411 | - | | | AR | | | SUMMARY TEST RPT NICKLE-CAD BATTERIES FOR ATM |
| | | 3 | | A | 40M22412 | - | | | AR | | | EXP INVESTIGATION + MODEL DEV SKYLAB ATM SECONDARY NICKEL CAD BATTERIES |

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