PERFORMANCE ANALYSIS OF THE TYPE IC AND IE PRIMARY BATTERIES WITH RESPECT TO THE 1170 PROBLEM

1011-2

SUMMARY

The design and performance history of the unit are presented, followed by a detailed analysis of observed and predictable failure modes. Curves are included showing battery voltage response after surge loads are applied and then removed.

Current battery testing has been reviewed with respect to the possible implementation of any tests which might contribute to this particular failure mode analysis.

An analysis is made of the 1170 battery failure and recommendations are submitted for the improvement of the Acceptance Test Specification.

DESCRIPTION

The Type IC primary battery consists of 16 series - connected, vented silver oxide - 40% KOH - zinc cells contained in a neoprene-lined magnesium case. The case is fitted with a pressure relief valve designed to relieve below 15 psi and positively reseat above 5 psi. The battery is rated to deliver 11,250 watt-hours at a nominal voltage of 25. The unit is 118 pounds maximum and the dimensions are 15.95" x 11.31" x 8.03" overall. The operating temperature range is 30 to 100°F. The Type IE battery differs from the IC only in external case details - the cells are identical.

HISTORY

The Type IC Battery was developed by the [redacted] as an improved version of the Type I battery which was qualified 31 October 1958. Of the 102 units (IC and IE) flown, the only two instances where battery malperformance was noted occurred under conditions of excessive temperature. This is the first legitimate flight failure attributed to the Type I series batteries.

DOCUMENTATION

1. Final Reliability Design Review Report, [redacted] 19 March 1964. This document reviews battery reliability data for Gemini Program use and finds the unit acceptable.

2. Final Report: Test Program, [redacted] under LMSC Purchase Order No [redacted] This report documents successful completion of dynamic tests on the Type IC battery to levels of [redacted] The battery case has been subjected to static loads prescribed by stress and burst testing to over four times maximum operating pressure. Marginal tests for wet-stand and temperature extremes were also conducted.

3. Qualification Test Report for the Type IE Primary Battery, [redacted] The report documents successful completion of qualification testing of the Type IE battery. Since the Type IC and IE units are electrically identical and use the same cells, the IC was qualified by similarity.

4. Cell Test Data Sheets. These are copies of performance data from battery cells, two of which are tested by [redacted] for every battery manufactured.

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FAILURE MODE ANALYSIS

A formal FMA has not been prepared for the IC battery; therefore the observed and predictable failure modes will be listed below.

1. Observed failure modes.

1.1 The shorting of a cell is the most common mode and will occur on a predictable basis if wet-stand or temperature limitations are exceeded. The shorts will occur whether the unit is being discharged or standing at no-load. Shorting of cells also occurred in overage (22 and 26 month) Type I batteries after activation and partial discharge; the present shelf-life limit is one year. There is no record of Type IC cells shorting within the specified storage or activated environmental limits.

1.2 Spillage of electrolyte on activation can cause electrical leakage or shorting paths between cell terminals or from cell terminals to the battery case.

1.3 Low voltages under load on similar cells have been reported by [redacted] with insufficient electrolyte attributed as the cause. These cells also fell short on ampere-hour capacity. [redacted] noted that while electrolyte volumes for this particular cell type had been kept constant, electrode densities had slightly increased allowing more voids for electrlyte. This allowed the tops of the electrodes to remain comparatively dry.

2. Predictable failure modes.

2.1 Cell shorting remains the most probable failure mode since integrity of the separators is essential to restrict the migration of ionic silver to the zinc electrode. The solubility of silver oxide in the electrolyte is a fact of life to be accepted in this electrochemical system. Care must be taken to eliminate all defective separator materials and chances for improperly installing separators.

The electrodes must be inspected for burrs or sharp edges which could go through or get around the separator. Foreign particles could also penetrate a separator.

2.2 Loss of the battery pressure seal can expose the vented cells to a vacuum environment and gradual loss of water from the electrolyte. A loss of water or increase in electrolyte concentration will cause the internal cell resistance to increase with a corresponding drop in operating voltage. And, for a given current, heat dissipation will increase. Ampere-hour capacity will also be degraded.

The battery Acceptance Test calls for the maintenance of the reseating pressure of the case relief valve for five minutes within 0.1 psi. It would be difficult to read a normal pressure gauge to greater accuracy. Admittedly the test would permit very small leaks to go undetected, but

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a leak allowing the 0.1 psi drop in five minutes would only pass about 0.1 gram of water vapor per hour at an average case pressure of 0.5 atmospheres. If the hydrogen evolved were taken into account, the water loss rate would be even less. The above water loss rate is not critical to IC battery usage. Other primary batteries of much longer life, such as the Type XV which must last 90 days, employ relief valves on the individual cells as well as the battery case.

2.3 A cracked cell case would allow electrolyte to leak out causing a possible dielectric leak to the battery case and low voltage under load.

BATTERY VOLTAGE CHARACTERISTICS

Figure 1 attached shows the very rapid recovery of voltage seen when cell loading is increased from c/100 (about 4.5 amps) to c/10 (about 45 amps) and decreased to c/100. These discharges were on the lower plateau.

Figure 2 attached shows loading profiles from the upper plateau open circuit voltage. It is noted that a recovery to the lower plateau O.C.V. is a gradual asymptote.

TEST PLAN REVIEW

One question keeps coming up, that is, how long would operation be normal if the battery case were left unsealed or with a gross leak to vacuum? [redacted] may be able to give us some data of this nature in a few weeks; if not, testing should be considered at LMSC.

The testing going on presently to determine the effects of intermediate wet-stand over a range of temperatures and stand times does not lend itself to the incorporation of additional variables. Further, at this time this writer cannot suggest a test program to define the 1170 battery failure mode.

ANALYSIS OF 1170 BATTERY FAILURE

The Type IC batteries used on 1170 were S/N 105, 106, and 107 which were manufactured in May of 1964 and activated 23 September 1964. The production control at [redacted] calls for making a capacity check on two cells of the eighteen cells manufactured for each sixteen battery. The capacities of recent cells tested for S/Ns 100 through 107 are as follows:

S/N	Capacity, Amp-Hours Cell #1	Capacity, Amp-Hours Cell #2
100	492	492
101	484	471
102	486	465
103	465	459
104	469	469
105	469	476
106	469	483
107	479	478

The electrodes used to manufacture 104, 105, and part of 106 were of the same lot. 104 and 106 performed to specification.

The loss of approximately 3 volts on the pyro battery, S/N 105, at the time it assumed the bulk of the main bus loading and its falling short of predicted capacity by an estimated 79 ampere-hours is the failure. The failure modes possible will be examined in an attempt to isolate the most probable explanation for the failure.

The following factors are known with reasonable assurance:

1. Battery temperatures were not excessive and the rise noted as the pyro battery delivered about 10 amperes was termed normal by Thermodynamics, with respect to past flight experience.

2. Wet-stand time at the temperatures known was not excessive for the battery.

3. No anomalies were reported on battery handling or activation. The open circuit voltage of 29.6 and the surge values of 88 amperes at 21.8 volts were normal. No electrolyte was spilled. The battery was installed with ease.

If one of the cells had a little more free volume than normal, the electrolyte used could have left dry spots which would have resulted in a shortage of capacity. Small variations in electrode density have accounted for volume changes. As this cell depleted early it would lose its voltage and possibly reverse - accounting for the voltage drop of two cells. The argument against this proposition is that the voltage drop occurred before much capacity had been removed from the pyro battery.

A similar circumstance could happen if the case seal is broken and the cells are exposed to vacuum; however, in this case water would be evaporated from the electrolyte causing its concentration to increase, thereby increasing internal resistance. This would account for additional IR or battery voltage drop and heat generation. A calculation to determine the rate of battery temperature rise which would account for this additional quantity of heat gave 5°F per hour. Only 1.5°F per hour was observed, which was normal. Hence, this failure mode is not probable.

A cracked cell case could leak electrolyte and thereby yield low voltage and capacity, but this would be likely to short to the battery case. And, no evidence has been presented showing stray shorting currents.

The most probable failure mode then remains to be the random manufacturing problem where the separators may be defective or improperly installed; burrs or sharp edges may exist on electrodes; or foreign particles may have been built into a cell. [redacted] has changed one manufacturing step since this series of units was built. Electrodes had been hand cut, sometimes leaving sharp edges which conceivably could contribute minute shorting paths. Such small shorts would rob us of both voltage and capacity. [redacted] now uses a punch to cut electrodes, leaving a much cleaner and smoother edge.

CORRECTIVE ACTION:

If at all possible, attempts sould be made to monitor the pyro battery prior to demand to assure its "health". Perhaps the unit could be periodically surge tested or loaded hard on the main bus, by passing the pyro bus diode. Unfortunately, a positive gauge of remaining capacity is not available, and to some degree is a theoretical impossibility.

The present Acceptance Test Specification is being examined in an attempt to implement any possible tests which may improve reliability. One definite procedure to be added is the individual cell check for open circuit voltage after activation. Heretofore we have tested only the overall battery open circuit voltage, which is valid but may not catch the statistical chance that fifteen cells might all give maximum open circuit voltage readings and one cell may be up to 0.5 volts low, still giving 29.5 volts for the battery.

It is not felt that the surge test should be applied to each cell at a time. The present 20 volt minimum in the ATS is deemed adequate; however, the Design Specification calls out 18.5 volts minimum at 100°F.

Concurrence will be requested from [redacted] to increase this value to 20.0.

[redacted]
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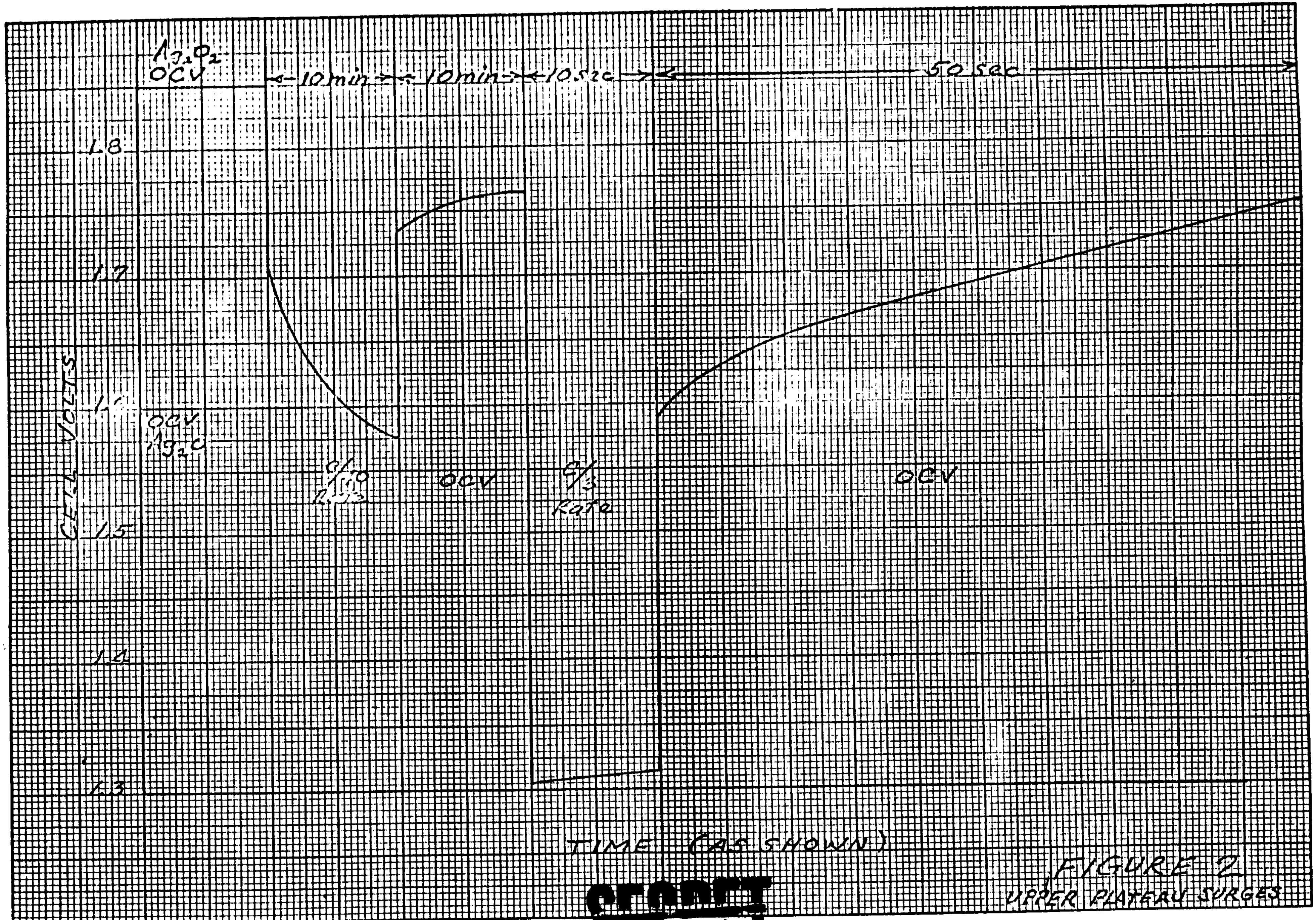

FIGURE 2
UPPER PLATEAU SURGES

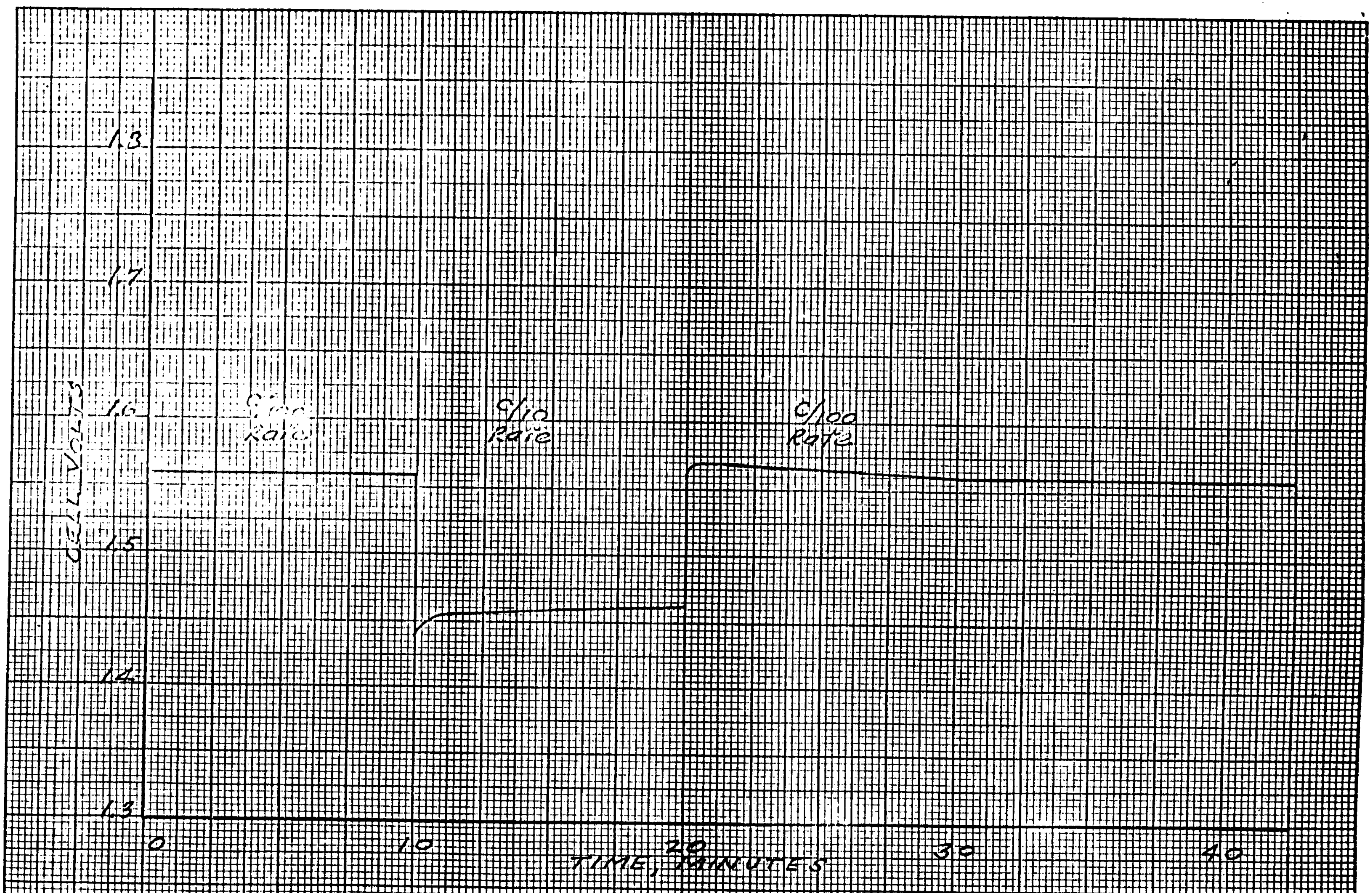

FIGURE 1
LOWER PLATEAU DISCHARGE

HANDLING PROCEDURE OF THE TYPE IC PRIMARY BATTERIES WITH RESPECT TO THE 1170 PROBLEM

The batteries are shipped direct from the vendor to the test base in sealed containers complete with measured quantities of electrolyte for each cell. The containers are stored in a suitable environment until activation is required. At activation time the batteries are removed from the shipping containers, inspected, filled with electrolyte, tested and then stored for a brief time at 40°F until time for vehicle installation.

The batteries are normally activated about two days prior to need to allow adequate soak time for the separators to absorb the electrolyte and adequate reaction time to activate another battery should any of the original batteries be defective. On the 75 pad complexes, batteries are installed on R-2 day. The sole exception for the [redacted] program occurs on the older series of vehicles with forward auxiliary racks (such as 1170). One battery must be installed at R-4 days, just prior to booster mating. On the PALC pads, the batteries are installed at R-4 days just prior to booster mating, booster mating in this case being a vertical mate.

For transportation from the MAB to the pad, the batteries are installed in a special padded carrier to avoid damage.

On pre 1609 vehicles, the batteries are removed from the carriers and manually installed in the vehicle structure. Installation on 1609 and up type vehicles is accomplished by use of special handling "spatula" since access for manual installation is marginal. The "spatula" is inserted in the vehicle and provides a surface to set a battery on. The battery is then pushed into position, mounting bracketry secured, and then the "spatula" removed.