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LITHIUM-ORGANIC ELECTROLYTE BATTERIES FOR
SENSOR AND COMMUNICATIONS EQUIPMENT

Honeywell, Incorporated

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Research and Development Technical Report
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**LITHIUM-ORGANIC ELECTROLYTE BATTERIES FOR SENSOR
AND COMMUNICATIONS EQUIPMENT**

Honeywell Inc.
Power Sources Center
104 Rock Road
Horsham, PA. 19044

AUGUST 1975

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Lithium Batteries	Low Temperature Batteries									
Organic Electrolyte	Long Term Storage									
Vanadium Pentoxide	Safety Vent System									
Sulfur Dioxide	Non-Hermetic Seal									
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Lithium-organic electrolyte cells and batteries were developed and fabricated for use in powering sensor and communications equipment. During the initial phase of the contract, Honeywell effort resulted in the development of a lithium disc cell design, employing vanadium pentoxide as the cathode material. Cell corrosion problems causing random failures and preventing battery delivery to ECOM are discussed. A battery safety study was also conducted. (continued on reverse)										

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Item #20. Abstract (continued)

The second contract phase centered on the fabrication of lithium-sulfur dioxide batteries in the 15 volt BA-5386()/U configuration for Radio Set AN/PRC-25 and -77 and other electronics applications. Incorporation of a safety venting system (Tefzel rupture disc) in the cell design and the conducting of a safety program comprised a significant portion of contract effort. Cell leakage through the non-hermetic seal and corrosion problems which precluded delivery of batteries are discussed. Battery test results and post mortem analyses are included.

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TABLE OF CONTENTS

	<u>Page</u>
I. INTRODUCTION	I-1
II. RESULTS AND CONCLUSIONS	II-1
III. RECOMMENDATIONS	III-1
IV. DEVELOPMENT OF A $\text{Li/V}_2\text{O}_5$ ORGANIC ELECTROLYTE BATTERY	IV-1
A. ELECTROCHEMICAL SYSTEM	IV-1
1. Reactions	IV-3
2. Electrolyte	IV-3
B. CELL DESIGN	IV-3
1. General Description	IV-3
2. Cell Specification	IV-6
3. Cell Assembly	IV-6
C. FABRICATION METHODS	IV-7
1. Cell Cup	IV-7
2. Glass - NE-T-70	IV-8
3. Cup and Terminal Plate Assembly	IV-8
4. Cathode Grid	IV-8
5. Cathode Grid and Lead Assembly	IV-9
6. Cathode Mix	IV-9
7. Cathode and Grid Assembly	IV-9
8. Lithium Anodes	IV-11
9. Separators	IV-11
10. Case	IV-11
11. Ball	IV-12
D. CELL DEVELOPMENT	IV-12
1. 2M LiBF_4 :MA Electrolyte	IV-12
2. Addition of SO_2	IV-12
3. Aluminum Grids	IV-15
4. 2M LiAsF_6 + 0.4M LiBF_4 :MF Electrolyte	IV-15
5. Production Cells	IV-17

TABLE OF CONTENTS (continued)

	<u>Page</u>
E. SAFETY CONSIDERATIONS	IV-23
1. Study Approach	IV-23
2. Test Results	IV-26
3. Conclusions	IV-33
4. Safety Mechanism Design	IV-35
F. BATTERY DESIGN	IV-36
1. General Requirements	IV-36
2. Cell Acceptance Criteria	IV-43
3. Battery Design Details	IV-47
G. BATTERY TESTS	IV-47
V. DEVELOPMENT OF A Li/SO ₂ ORGANIC ELECTROLYTE BATTERY	V-1
A. ELECTROCHEMICAL SYSTEM	V-1
1. Reactions	V-2
2. Theoretical Capacity	V-2
3. Electrolyte	V-3
4. Cathode	V-3
B. CELL DESIGN	V-7
1. Baseline Cell Design	V-7
2. G2686-C Design	V-7
3. Discussion	V-15
C. SAFETY FEATURE DESIGN	V-16
1. Requirements	V-16
2. Approach	V-16
3. Leakage	V-17
D. FABRICATION METHODS	V-18
1. Cells	V-18
2. Batteries	V-22
3. Cell and Battery Inspection Methods	V-22

TABLE OF CONTENTS (continued)

	<u>Page</u>
E. CELL CAPACITY TESTS	V-24
F. SAFETY TESTS	V-37
G. BATTERY DESIGN	V-38
1. Electrical Requirements	V-38
2. Other Considerations	V-43
H. BATTERY TESTS	V-43
1. General	V-43
2. Post Mortem Analysis	V-53
3. Additional Tests	V-53

APPENDIX

- A - Engineering Test Report PTL-1242-1, BA-5386 Qualification Test
- B - Engineering Test Report 4509-3(#1) , Post Mortem of Qualification Batteries
- C - Engineering Test Report PTL-1338-1, Four Additional BA-5386 Battery Tests
- D - Battery Tests PTL-1225-1 , Six Additional BA-5386

LIST OF FIGURES

	<u>Page</u>
IV-1 G2655 Cell - Exploded View	IV-5
IV-2 G2655 Cathode Die	IV-10
IV-3 Discharge Performance of Li/V ₂ O ₅ Laboratory Cells	IV-13
IV-4 Cycle and Load Profile for G2655 Cell	IV-14
IV-5 Performance of a G2655 Cell Containing Five Percent SO ₂	IV-16
IV-6 G2655 Cell Discharge Performance After Eight Days at +165°F	IV-18
IV-7 G2655 Cell Discharge Performance after Eight Days at +165°F	IV-19
IV-8 Discharge of Fresh G2655 Cell at +130°F	IV-20
IV-9 Discharge of Fresh G2655 Cell at +75°F	IV-21
IV-10 Discharge of Fresh G2655 Cell at -22°F	IV-22
IV-11 Discharge Comparison of G2655 Cells - Fresh and Stored Nearly Two Years at +75°F	IV-24
IV-12 Battery Using Eight G2655 Cells - Exploded View	IV-25
IV-13 Temperature Rise of Short Circuited G2655 Cell	IV-28
IV-14 Current Profile of Short Circuited G2655 Cell	IV-29
IV-15 Expansion Characteristics of G2655 Cell Case Under Pressure	IV-30
IV-16 G2655 Cell Safety Valve Assembly	IV-37
IV-17 G2655 Valve Components	IV-38
IV-18 G2655 Battery Valve and Cell Assembly	IV-39
IV-19 Battery - Dimensional Outline, Honeywell Dwg. No. 72003066	IV-40
IV-20 Constant Current Discharge Test of G2655 at +125°F	IV-44
IV-21 Constant Current Discharge Test of G2655 at +75°F	IV-45
IV-22 Constant Current Discharge Test of G2655 at -20°F	IV-46
IV-23 Minimum Pulse Voltage for Battery During Storage at +130°F	IV-48
IV-24 G2655 Battery Discharge Performance at -20°F After 30 Days Storage at +130°F	IV-49
IV-25 G2655 Battery Discharge Performance - First Hour at -20°F After 30 Days Storage at +130°F	IV-50

LIST OF FIGURES (continued)

	<u>Page</u>
V-1 Conductivity Vs. Temperature for LiBr/AN/SO ₂ Electrolyte	V-4
V-2 Density Vs. Temperature for LiBr/AN/SO ₂ Electrolyte	V-5
V-3 Vapor Pressure Vs. Temp - LiBr/AN/SO ₂ Electrolyte	V-6
V-4 Baseline Design - G2686	V-8
V-5 Cross-Sectional View of Elastomer Crimp Seal and Pin	V-9
V-6 Discharge Performance as a Function of Rate - G2686	V-10
V-7 Discharge Performance as a Function of Temperature for G2686 at a Rate of Approximately 0.5 Ampere	V-11
V-8 Cross-Sectional View of the G2686C Closure and Vent	V-13
V-9 Discharge of G2686C Cells, BA-5386 Loads, -20°F, No Storage	V-25
V-10 Discharge of G2686C Cells, BA-5386 Loads, -20°F, After 7 Days Storage at +165°F	V-26
V-11 Discharge of G2686C Cells, BA-5386 Loads, -20°F After 14 Days Storage at +165°F	V-27
V-12 Discharge of G2686C Cells, BA-5386 Loads, -20°F, After 21 Days Storage at +165°F	V-28
V-13 Discharge of G2686C Cells, BA-5386 Loads, -20°F, After 30 Days Storage at +165°F	V-29
V-14 Discharge of G2686C Cells, BA-5386 Loads, -40°F, No Storage	V-30
V-15 Discharge of G2686C Cells, BA-5386 Loads, -40°F, After 7 Days Storage at +165°F	V-31
V-16 Discharge of G2686C Cells, BA-5386 Loads, -40°F, After 14 Days Storage at +165°F	V-32
V-17 Discharge of G2686C Cells, BA-5386 Loads, -40°F, After 21 Days Storage at +165°F	V-33
V-18 Discharge of G2686 Cells, BA-5386 Loads, -40°F, After 30 Days Storage at +165°F	V-34
V-19 Discharge of G2686B2 Cells, BA-5386 Loads, -20°F, After 20 Days Storage at +160°F	V-35
V-20 Discharge Performance of G2686B2 Cells, BA-5386 Loads, -40°F, After 30 Days Storage at +160°F	V-36

LIST OF FIGURES (continued)

		<u>Page</u>
V-21	BA-5386 Battery and G2686C Cell	V-44
V-22	BA-5386 Outside Design Dimensions	V-45
V-23	BA-5386 Circuit Diagram	V-46

LIST OF TABLES

	<u>Page</u>
IV-1 Characteristics of G2655 Cell Under High Rate Discharge	IV-31
IV-2 Reverse Discharge Test of G2655 Cell	IV-34
IV-3 Battery Voltage Before and After Vibration	IV-51
V-1 Weight After 30 Days Storage at +160°F	V-48
V-2 Voltage After Drop	V-49
V-3 Voltage After Vibration	V-50
V-4 Voltage, Weight, and Insulation Resistance After T&H	V-51
V-5 BA-5386 Cyclic Load Test	V-52
V-6 Summary of Test Results of Six BA-5386 Batteries	V-55
V-7 Analysis of Defective Cells and Stacks Vs. Delivered Capacity	V-55

I. INTRODUCTION

The advantages of electrochemical systems employing lithium as the anode material have been recognized for several years. The main advantages over the more traditional electrochemical systems, such as mercury, alkaline, magnesium, or carbon zinc, include higher energy density, superior cold temperature performance, and longer shelf life.

Contract DAAB07-71-C-0191 was one of several contracts entered into by ECOM and various lithium battery suppliers for the purpose of conducting research and development leading to the design and production of a lithium organic electrolyte battery to satisfy the technical requirements specified in ECOM's Technical Guidelines for Sensor Batteries dated 28 December 1970. Activity under this particular contract was conducted by Honeywell Power Sources Center between the period 14 June 1971 to 15 March 1975.

During the initial period of the contract, Honeywell conducted research and development activity leading to a button cell design having a 2.24 inch diameter and an 0.5 inch thickness. Of the various electrochemical systems analyzed for this application, $\text{Li}/2\text{M LiAsF}_6 + 0.4\text{M LiBF}_4:\text{MF}/\text{V}_2\text{O}_5:\text{C}$ appeared to be the best on the basis of long term stability, energy density, and cold temperature performance. The battery design consisted of eight of these cells connected in series.

Although the battery of the final design demonstrated the capability of meeting all electrical discharge performance requirements of the contract, random failures due to corrosion of the positive electrode grid prevented delivery of reliable batteries to ECOM. Since that time, Honeywell has identified the mechanism of collector corrosion; however, at that time, it was determined to be in the best interest of ECOM and Honeywell to modify the contract to call for delivery of

batteries using the Li/SO₂ electrochemical system to meet the ECOM Technical Guidelines dated 15 April 1974 for the BA-5386 battery. An additional task was incorporated into the contract to conduct cell safety tests in accordance with ECOM Technical Guidelines for Non-Hazardous Primary Lithium-Organic Electrolyte Batteries dated 30 January 1973.

Cells were design in "C" diameter (1.0 inch) and 3.5 inches long to fit within the BA-5386 battery configuration. A cell safety feature was designed using a rupture disc incorporated in the cell seal. The battery was designed using five stacks in series with each stack having three cells in parallel. Cells were built in pilot production facilities at Horsham, Pennsylvania. Cell tests indicated sufficient capacity to meet the battery requirements both before and after storage with some excess. Cell safety studies, documented with slow motion moving pictures, were conducted and indicate that the design protects users against cell case rupture under expected conditions of abuse.

Battery tests, conducted under full environmental conditions, provided performance significantly short of the requirements. The fact that individual cell tests indicated a design capable of meeting the electrical discharge performance requirements, yet the battery tests showed otherwise, is attributable to an inadequate design of the cell closure and terminal hardware. Post mortem analysis has shown that the major cause of battery failure was the failure of a substantial number of cells to discharge. This has been traced to a high resistance developing between the interior positive lead and the exterior positive terminal of the cell. Corrosion of an aluminum contact ring due to a combination of SO₂ leakage and ambient humidity conditions causes this high resistance condition when cells are exposed to moisture. Soldering of leads to the cell terminal during battery assembly further degrades the integrity of the cell seal, increasing the SO₂ leak rate. This, in addition to the exposure of the batteries to humidity over longer periods of time and - in the case of the

qualification batteries - to more severe environmental stresses, is the basic reason that batteries did not perform as well as the individual cells.

Final post mortem and design analyses have concluded that the Li/SO₂ electrochemistry is inherently suitable for these applications and that the specific cell designs evolved in this program are capable of demonstrating this fact. These final results from this program have indicated a need for an improved design for the Honeywell cell in the seal and positive conductive path areas and work in those areas has been initiated.

II. RESULTS & CONCLUSIONS

Li/V₂O₅ ELECTROCHEMISTRY

- A Li/2M LiAsF₆ + 0.4M LiBF₄:MF/V₂O₅ cell was designed and tested to meet the requirements of the technical guidelines for organic electrolyte sensor batteries dated 28 December 1970. Eight cells connected in series were used in the battery.
- Batteries were designed, built and tested according to ECOM specifications.
- Safety tests were conducted to assess the potential hazards of the cells under conditions of electrical, thermal and mechanical stress. A proposed pressure relief mechanism was designed for the cell based on the safety tests.
- Random cell failure due to corrosion of the positive electrode collector prohibited the delivery of 100 batteries to ECOM.
- Batteries containing cells which did not show the corrosion problem were capable of meeting all requirements of the technical guidelines.
- Cells not exhibiting the corrosion phenomena (initially, approximately 600 units out of a 1200 unit build) continued to be stable (indetectable loss in capacity) after 2 years of storage at room temperature - over 200 units remain in storage.
- Excessive amounts of water at the positive electrode grid/V₂O₅:C interface is the cause of grid corrosion.
- The Li/2M LiAsF₆ + 0.4M LiBF₄:MF/V₂O₅ electrochemical system is a viable candidate for high energy, long life, low temperature batteries requiring rate capabilities similar to those required for sensor operation (500 mA to 1A pulses).

- High single cell voltage, and high power density capability and low internal pressures are the most significant advantages of the $\text{Li/V}_2\text{O}_5$ cells while material costs and voltage regulation (voltages of each half of the two electron discharge of the system are at approximately 3.2 and 2.4 volts) are the most significant disadvantages.

Li/SO₂ ELECTROCHEMISTRY

- A Li/SO_2 cell was designed and tested to meet the BA-5386 battery requirements with a total of 15 cells consisting of 5 stacks in series with 3 cells in parallel in each stack.
- Batteries were designed, built and tested according to ECOM specifications.
- Safety tests were conducted to assess potential hazards of vented design Li/SO_2 cells under conditions of electrical, thermal, and mechanical stress. The tests were documented with motion pictures. No hazardous cell behavior was observed during the tests.
- Battery test failure was traced to the development of a high resistance in the cell terminal assembly that prevented discharge of cells in the parallel stacks. This can be corrected by design modification.
- The non-hermetic cell design which features a roll-crimp closure, was tested and found to leak at a rate of approximately 30 mg/day (total electrolyte weight is approximately 28 grams) at +160°F.
- A modified seal was designed, built and tested. Its leakage rate is 1.5 - 2.0 mg/day at +160°F. A hermetic design is recommended to achieve significantly lower leakage rates.

- The $\text{Li}/\text{SO}_2:\text{AN}:\text{LiBr}/\text{SO}_2:\text{C}$ electrochemical system is a low cost system featuring good voltage regulation and is a viable candidate for long life, low temperature, high rate applications. Leakage of the SO_2 must be eliminated before wide spread acceptance of this system can be expected.

III. RECOMMENDATIONS

- The development of the Li/SO₂ system should be continued to take advantage of its high cell voltage, high energy density, excellent low temperature performance (to -60°F), and potential for long active shelf life.
- Electrochemistry and manufacturing methods research should be continued to improve cell-to-cell uniformity.
- Major effort should be devoted to improved seal design. A true hermetic seal should be the goal.
- The safety requirements and capabilities of new electrochemical systems should be continuously reviewed and re-evaluated. This will require continuing interaction between users and producers.

IV. DEVELOPMENT OF A $\text{Li}/\text{V}_2\text{O}_5$ ORGANIC ELECTROLYTE BATTERY

The initial contract objective was to conduct the research and development leading to the design of a lithium active primary organic electrolyte battery for sensors. This battery was to meet the USA-ECOM Technical Guidelines dated 28 December 1970 for "An Organic Electrolyte Battery for Sensors."

Honeywell chose to use the $\text{Li}/\text{V}_2\text{O}_5$ system as it had the energy density, stability and cold temperature capability required to meet the specification.

A cell design was established which met the performance requirements. However, a corrosion problem associated with the positive electrode collector material during the final cell build resulted in a decision not to make the required contract deliveries.

This section describes the $\text{Li}/\text{V}_2\text{O}_5$ cell and battery development activities conducted by Honeywell including cell testing and safety studies.

A. ELECTROCHEMICAL SYSTEM

The electrode couple chosen by Honeywell to meet the requirements for the organic electrolyte battery for sensors was Lithium (Li)/vanadium pentoxide (V_2O_5). Several organic electrolyte solutions were evaluated during the program with $2\text{M LiAsF}_6 + 0.4\text{M LiBF}_4:\text{MF}^*$ providing the best electrical and storage characteristics. This solution was chosen for the final cell build.

The $\text{Li}/2\text{M LiAsF}_6 + 0.4\text{M LiBF}_4:\text{MF}/\text{V}_2\text{O}_5$ electrochemical system has undergone considerable investigation at Honeywell.

*Methyl formate

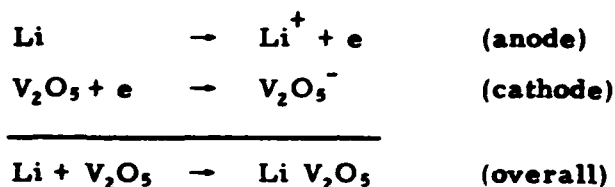
The overall system provides the following advantages as related to the battery of this contract.

- High voltage per cell, therefore, fewer cells per battery
- Adequate energy density
- Minimal passivation during high temperature storage
- Electrolyte which provides one of highest conductivities of all organic electrolyte solutions known, therefore, minimum active electrode area to meet specific current/voltage requirements.
- Low solubility of electrodes in the chosen electrolyte solution, therefore, minimum capacity loss during storage due to a solubility mechanism.
- Discharge products are not electronic conductors, are not catalysts for side reactions and are insoluble
- Moderate cost

A careful comparison of the capabilities of the $\text{Li}/2\text{M LiAsF}_6 + 0.4\text{M LiBF}_4\text{:MF}/\text{V}_2\text{O}_5$ electrochemical system with the electrical requirements for the sensor battery of this contract showed that the chosen system was a highly desirable choice for the intended application. Therefore, work was initiated to design and build the cells for delivery to USA-ECOM using the $\text{Li}/2\text{M LiAsF}_6 + 0.4\text{M LiBF}_4\text{:MF}/\text{V}_2\text{O}_5$ electrochemical system.

1. Reactions

The cell discharge reaction to the cutoff voltage used in the battery of this contract is:



The reactants and products are essentially insoluble in the electrolyte solution at +165°F. Therefore, self-discharge during storage through electrode solubility is not anticipated.

2. Electrolyte

Typical properties of the 2M LiAsF₆ + 0.4M LiBF₄/MF electrolyte system at +75°F are:

Viscosity	-	1.419	
Specific Gravity	-	1.300	
L _s	-	44.2 mmho/cm	
pH	-	3.06	
Refractive Index	-	1.354	
Vapor Pressure	-	<u>Temp., °C</u>	<u>V. P., psig</u>
		75	45
		85	60
		95	70

B. CELL DESIGN

1. General Description

The cell is a large button type approximately 0.50 inch thick by 2.24 inches in

diameter. The case material is 304 SS and is the negative terminal of the cell. The cell is hermetically sealed and uses a glass-to-metal seal to insulate the positive terminal (a titanium metal pin) from the negative case. This design provides a cell capable of storage and use over the temperature range specified in the contract technical guidelines. Figure IV-1 shows the cell components and how they are arranged in the cell. The Honeywell item identification code assigned to this cell is G2655.

The cell design capacity is 3.5 Ahr to a cutoff of 2.5 volts. The requirement is for a capacity of 2.25 Ahr. A cathode reduction efficiency of 64% is required to meet the energy specified in the contract. At currents up to 0.25 amp, the average voltage for the cell is above 3.00 volts above -20°F . Typical output capacity at the above rates is greater than 3 Ahrs.

The internal electrode structure of the cell consists of eleven plates, five cathodes each 0.05 inch thick and six anodes totaling 0.06 inch thick. Between each pair of electrodes are two micro porous polypropylene separators each 0.001 inch thick. This gives an electrode stack thickness of less than three eighths of an inch.

The positive plates are connected via a terminal strap of 316L SS welded to the titanium pin. The anode plates likewise are connected via a nickel strap welded to the case. The plate surface area for the cathode is 23.6 cm^2 giving a total cell surface area of $23.6\text{ cm}^2 \times 10\text{ sides} = 236\text{ cm}^2$. The high surface to volume ratio for this cell makes it suitable for high power applications where many other lithium cells would not be suitable.

Figure IV-1 G2655 Cell - Exploded View

2. Cell Specifications

a. Physical Characteristics - The following describe the physical characteristics of the G2655 cell:

Diameter	2.24 inches	5.69 cm
Thickness	0.50 inches	1.27 cm
Flange Diameter	2.40 inches	6.10 cm
Volume	1.97 cubic inches	32.29 ml
Weight	0.17 pound	78.50 grams

b. Electrical Characteristics - The following describe the theoretical electrical characteristics of the G2655 cell:

Open Circuit Voltage	3.4 Volts
Capacity	3.5 amp hours (2.5V cutoff)
	7.0 amp hours (2.0V cutoff)
	11.9 Whr (2.5V cutoff)
	23.8 Whr (2.0V cutoff)
Energy Density	6.04 Whr/in ³ (2.5V cutoff)
	12.08 Whr/in ³ (2.0V cutoff)
Energy Density	70 Whr/lb (2.5V cutoff)
	140 Whr/lb (2.0V cutoff)

3. Cell Assembly

The assembly of the cell begins with the terminal plate which includes the glass-to-metal seal. A polypropylene cup is placed on the terminal plate which has two leads welded to it - one lead for the negative and one for the positive. The electrode

stack is then assembled in the cup, welding each plate to its appropriate strap as it is placed in the cell. The cell stack starts and ends with a negative electrode thereby using both sides of the five positive plates. Upon completion of the stack, the case is then pressed over the electrodes. Each of the positive electrodes is insulated from the case by an oversize separator which folds down over the edge of the cathode (positive plate) and the poly cup wall as the case is pressed on the stack.

Case closure is completed by projecting (resistance) welding the perimeter flange of the case and cover. This flange extends beyond the case approximately 0.08 inch. At this stage, the cell is ready for activation.

The cell terminal plate has a ball seal flange welded to it prior to cell assembly. This flange has a precision hole which is used to evacuate the air from the cell and then to fill the cell with electrolyte. Honeywell has built a special device to fill the active lithium cells in this manner. This insures a dry system as well as minimizing any contaminants. When the cell has been activated, it is removed from the fixture in the dry room (less than two percent relative humidity) and immediately the hole is sealed by pressing an oversize hardened stainless steel ball into the hole. The resulting seal has proven to be a very effective hermetic seal under extreme environmental shock, vibration and storage temperature conditions.

C. FABRICATION METHODS

The fabrication for each of the critical operations of the cell for the sensor battery of this contract was conducted as described below.

1. Cell Cup

Polyethylene cups are molded and finished by a machining process. The cup holds

the anodes, cathodes and separators of the cell and insulates the active ingredients from the cell case. The cups are cleaned by washing in an ultrasonic cleaner using methyl ethyl ketone as the solvent. The cups are then air dried and stored in a dry room atmosphere.

2. Glass - NE-T-70

The glass insulating material of the terminal plate of the cell is designated by the vendor* as NE-T-70. This glass is used to accomplish a hermetic seal between the terminal plate and the positive pin. It also serves as the dielectric between its positive and negative terminals. The terminal plate is used as purchased with no further processing.

3. Cup and Terminal Plate Assembly

The negative (anode) lead of the cell is a nickel strap and is welded (with a Model HRW 250B Hughes Parallel Gap Welder) to the case which is isolated from the positive terminal pin by a glass-to-metal seal. The other terminal of the header is titanium and is welded to the lead, also with a Parallel Gap Welder. A plastic cup (polyethylene) holds the cell stack in place. In addition, a rubber cement is used to insulate the lithium electrode from the positive electrode, and to insure that paths of potential dendritic shorting are minimized.

4. Cathode Grid

The cathode grid is 316L stainless steel fully annealed expanded metal having the designation 5-SS-7 2/0. The grids are circular and are blanchied in a Model 1 DiAcro Press. The press simultaneously punches even equidistant holes in the grid to insure satisfactory adherence of the cathode mix to the grid. The grid also has a cutout 0.250 inch deep which provides clearance for the negative electrode lead of the cell. The grids are flattened, pickled and passivated, and dried in a vacuum chamber for a minimum of 12 hours before use.

*Northeast Electronics, 83 Erna Avenue, Milford, Connecticut 06463

5. Cathode Grid and Lead Assembly

A strip of 316L stainless steel is spot welded to an expanded 316L stainless steel grid material cut to the shape of the cathode. The grid and lead assembly is stored in a dry room atmosphere until the cathode is prepared.

6. Cathode Mix

The cathode mix consists of 87% vanadium pentoxide (yellow air dried) 9% graphite (Dixon #200-44) and 4% microthene (grade FN500). The vanadium pentoxide is dried for 16 hours at 230°C, the graphite is vacuum dried at 150°C for 16 hours and the microthene is vacuum dried for a maximum of 16 hours at 25°F. The dried components are combined and passed through a #48 sieve in a dry atmosphere. The sieved mix is ball milled at 60 RPM for 16 hours. The ratio of chemical volume to jar volume is not less than 1:2. The final mix is sealed in glass containers until ready for use.

7. Cathode and Grid Assembly

The cathodes are prepared in a die as shown in Figure IV-2. A preweighed quantity (2.50 g) of the cathode mix is placed into the die which fills the die slightly less than half and is leveled. The grid and lead assembly is then positioned in the mold on the mix. The second premeasured portion of the mix (2.95 g) is placed over the grid and is leveled. Since mix can fill the holes in the grid, the larger quantity of material for this operation is necessary to insure that the grid is properly centered. The entire assembly is placed between the plates of a press and pressed to 25,000 pounds. The cathodes are heat formed by applying a current of 300 amperes through the die until the pressure on the

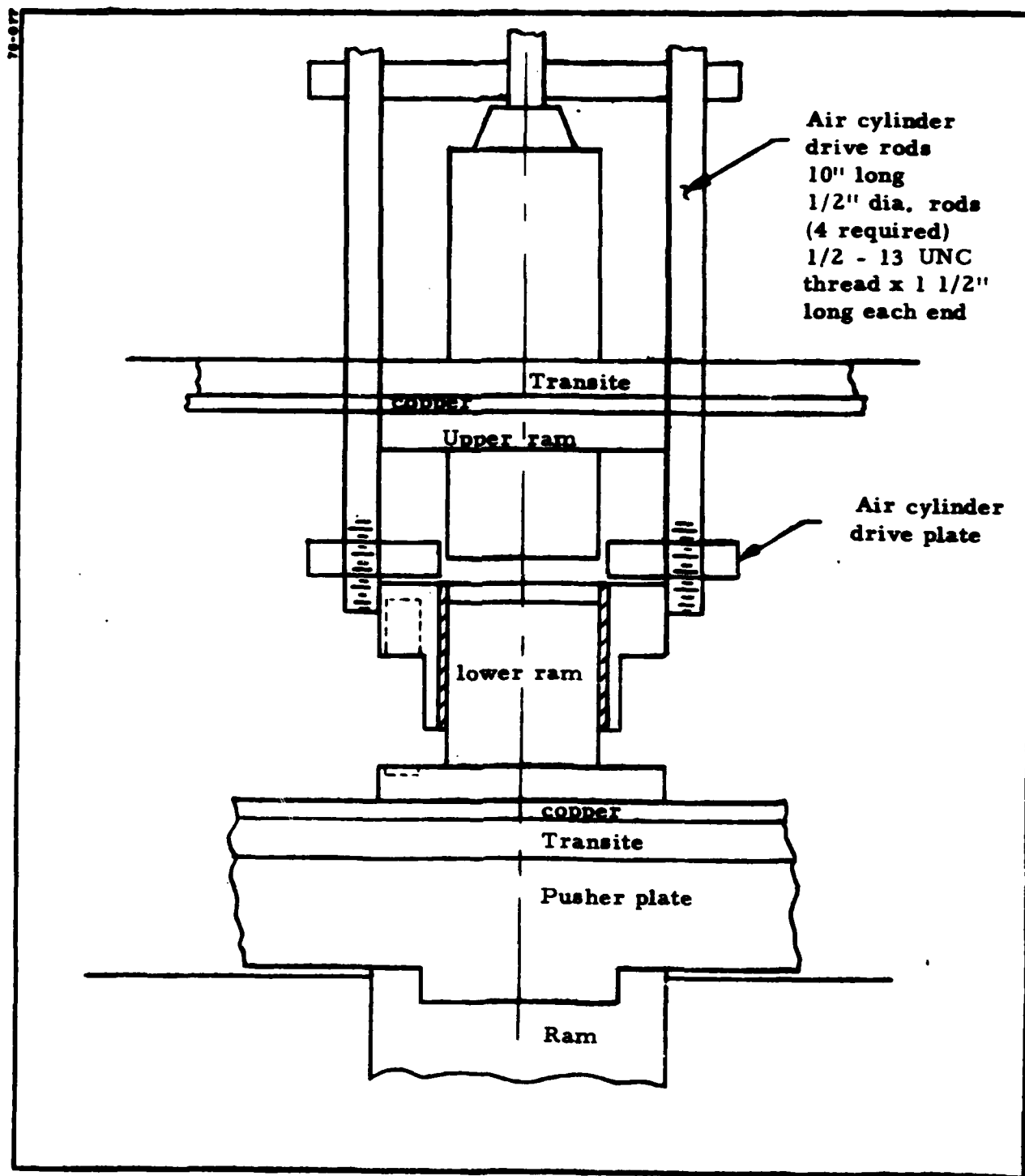


Figure IV-2. G2655 Cathode Die

gauge released to 24,000 pounds (approximately 7 seconds). The current is stopped and the assembly allowed to cool for 1 minute. The pressure is completely released and the cathode and grid assembly removed from the die. The assemblies are stored in dry room conditions. Each of the five cathodes of the cell has a theoretical capacity of approximately 697 mAh to a 2.5 volt cutoff.

8. Lithium Anodes

The six lithium anodes of the cell are attached to a nickel grid having design characteristics similar to the grid used in the cathode. The lithium grid assembly is purchased from a vendor and used "as received" with no further processing. The theoretical capacity of each of the two end anodes of the cell is approximately 1600 mAh, while the remaining four internal anodes each have a theoretical capacity of approximately 3200 mAh.

9. Separators

The separator material is Celgard* #2400. Discs are press punched to size using a steel rule die. Three different size separators were used to insure maximum protection from internal shorting and maximum volume for active components. The separators are cleaned by immersing them in methyl ethyl ketone (MEK). The separators are air dried and stored in a dry room atmosphere until used in assembling the cell.

10. Case

The cell case is a drawn can machined to finish and is made of 304 stainless steel.

*Registered Trade Mark - Celanese Plastic Company, P.O. Box 828, Hood Rd., Greer, South Carolina 29651.

11. Ball

The small ball which seals the cell activation hole is made of 440C stainless steel and is used as received from the vendor after passing the quality requirements. The seal is accomplished by forcing the ball into a flange which is resistance welded in the cell case.

D. CELL DEVELOPMENT

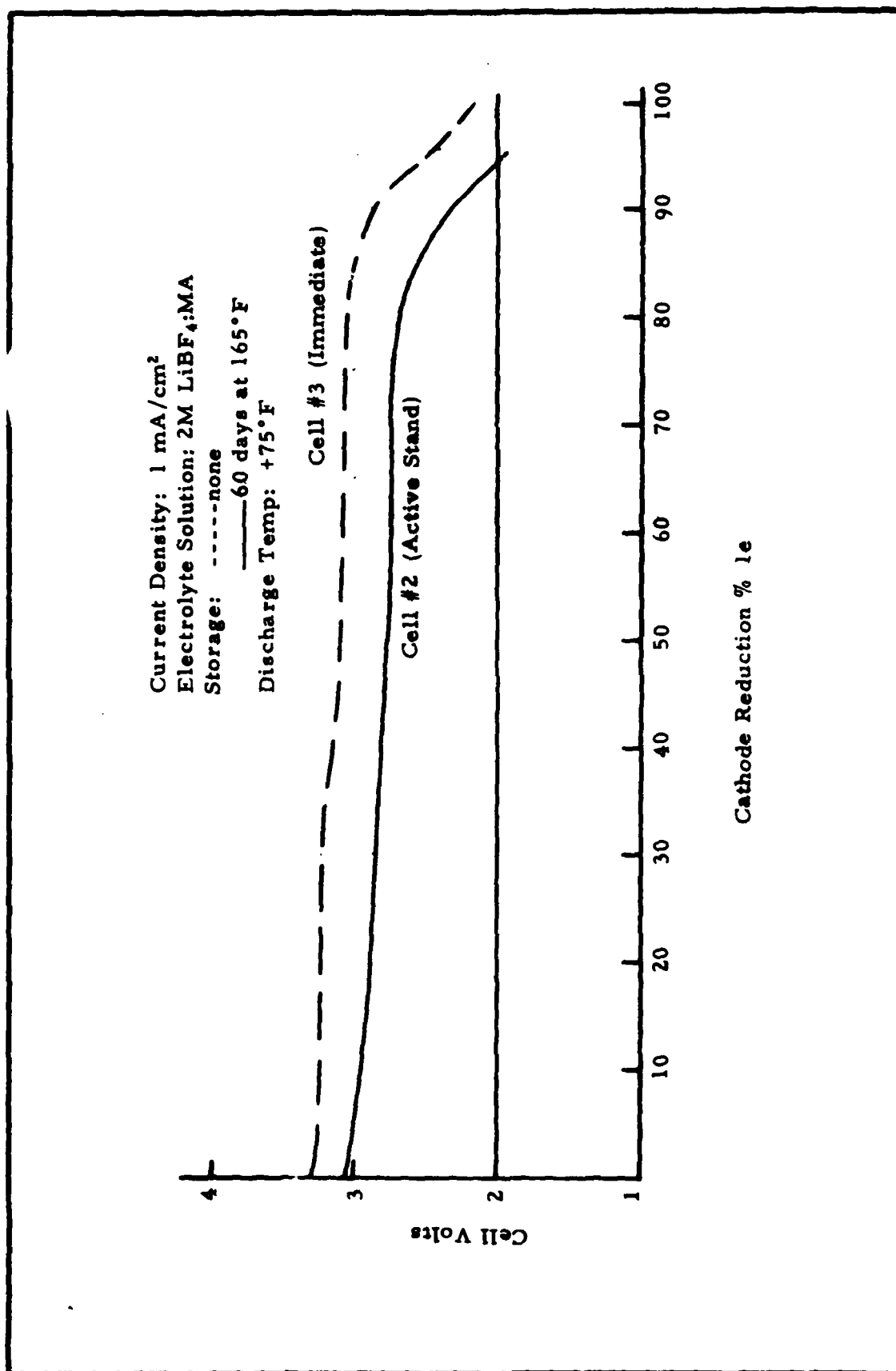
1. 2M LiBF₄:MA Electrolyte

During the earlier phases of the development work, the Li/2M LiBF₄:MA*/V₂O₅ electrochemical system demonstrated that it could meet the electrical requirements of the contract. However, due to severe corrosion of the positive grid material (304 stainless steel) at elevated temperatures, this system could not meet the storage requirements. Impurities in the system, particularly acetaldehyde and acetic anhydride were found to be at least in part responsible for the positive grid corrosion even when present in the electrolyte in concentrations of as low as 25 ppm. In laboratory cells where extreme measures were taken to control purity, dramatic improvements in cell performance were achieved. Figure IV-3 shows good cell performance after 60 days storage at +165°F. The precautions used in these cells were, however, not practical for the production of low cost cells.

2. Addition of SO₂

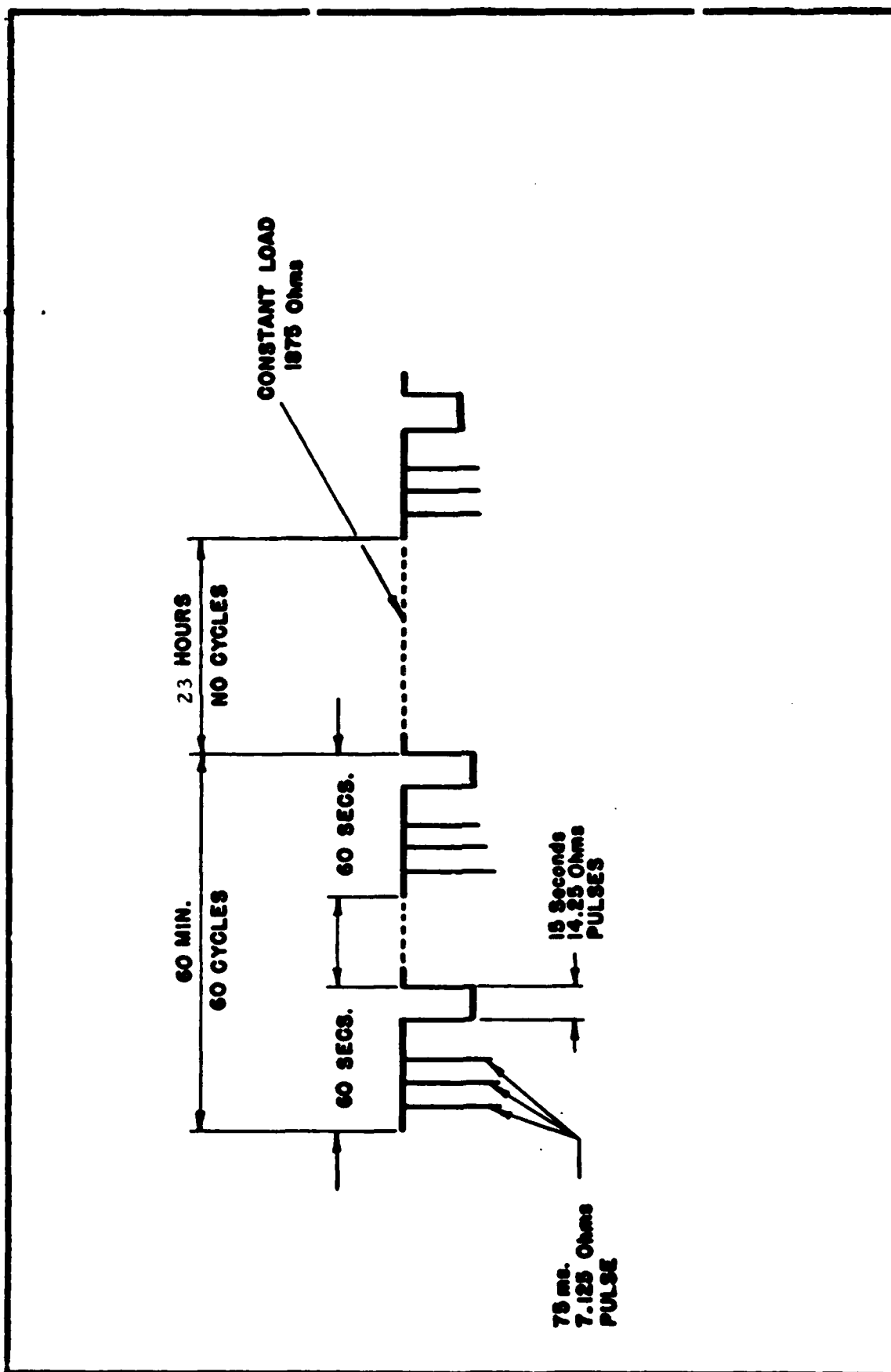
Under the cycle and load pattern of Figure IV-4, cells of the above system could be stabilized at high temperatures by adding five percent SO₂ to the electrolyte solution. The SO₂ apparently passivated the surfaces of the corroding grid material

*Methyl acetate



FORM FM-101

Figure IV-3. Discharge Performance of Li/V₂O₅ Laboratory Cells



FORM FM-101

Figure IV-4. Cycle and Load Profile for G2655 Cell

such that it could not be oxidized by the V_2O_5 . Figure IV-5 shows that under an accelerated storage temperature ($+165^\circ\text{F}$ rather than $+130^\circ\text{F}$) and discharge cycle (8* days rather than 20) this cell system has the capability to meet the storage and electrical performance requirements of the contract. At the low temperature (-22°F) cell polarization during discharge was excessive and performance was unacceptable. It is believed that this was due to passivation (resistive film) of the cathode grid and anode surface due to reaction with SO_2 .

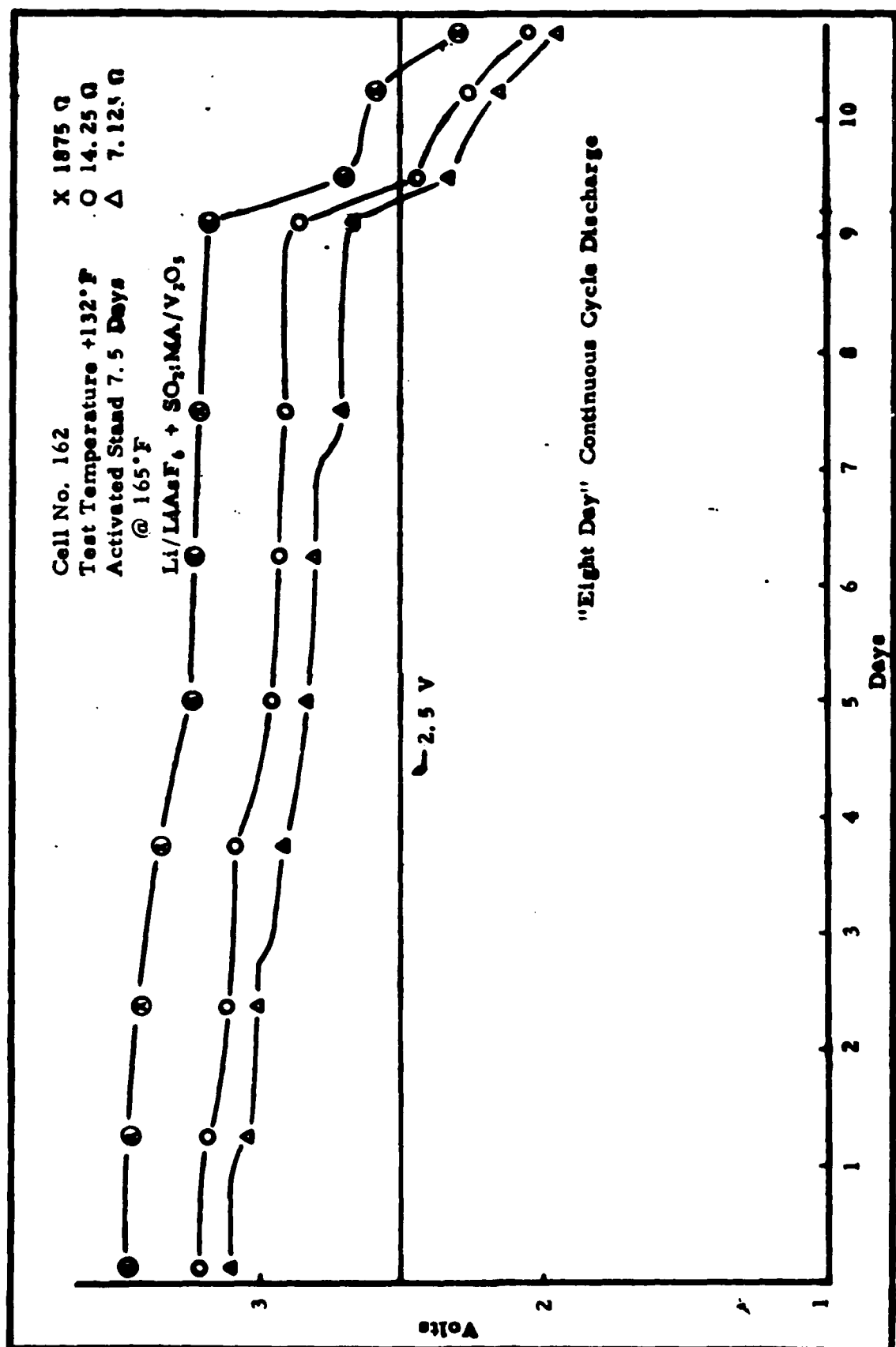
3. Aluminum Grids

Using Al grids in the positive electrode (replacing stainless steel), results similar to adding SO_2 were obtained; i. e., grid corrosion was not observed, but after storage, severe polarization during discharge prevented meeting the -22°F electrical requirement.

4. 2M LiAsF_6 + 0.4M LiBF_4 :MF Electrolyte

Through an extensive effort to understand the corrosion of the stainless steel positive electrode grids, the problem was solved by using the $\text{Li}/2\text{M } \text{LiAsF}_6 + 0.4\text{M } \text{LiBF}_4\text{:MF}/\text{V}_2\text{O}_5$ electrochemical system and pickled and passivated 316L stainless steel positive electrode collectors. During the course of this contract, the 2M LiAsF_6 + 0.4M LiBF_4 :MF electrolyte had been developed and proved stable for other Honeywell devices. Since acetaldehyde and acetic anhydride were not impurities of this solution its usefulness was evaluated in the cells being built for this program. Also, Carpenter Steel Corp. recommended that for solutions containing halogen ions, 316 stainless steel should be used. This steel has two to three percent molybdenum which apparently forms insoluble molybdic halides which prevents corrosion. Also 316L contains low amounts of carbon. High carbon steels produce

*The accelerated load profile is identical to that of Figure IV-4 except that no-cycle period is 5 hours instead of 23 hours.

Figure IV-5. Performance of a G2655 Cell Containing Five Percent SO₂

carbides which can be leached out to initiate corrosion. Pickling and passivating of the stainless steel surface was expected to provide further protection. Nine cells in full hardware were evaluated using the above double salt solution and positive electrodes using 316L collectors. These cells provided satisfactory electrical and storage performance. Figure IV-6 shows the discharge performance of one of the cells under the worst case discharge conditions (8 days storage at +165°F followed by discharge at -22°F under the cyclic load profile of Figure IV-4).

Due to slight passivation during storage, the first three 75 ms pulses applied to the above cell fell slightly below the 2.5V minimum voltage. (See Figure IV-7.) The voltages during the remainder of the discharge were satisfactory. Figures IV-8, 9, and 10 show fresh cell discharge performance under identical loads at +130°, +75° and -22°F respectively.

Based on the promising data from the initial 9 cells, 40 more cells were built for further discharge and storage evaluation in batteries and cell safety evaluation. Twelve of these cells were provided to ECOM. Eleven cells were used in the safety testing, eight cells were used to fabricate a battery which met the low temperature (-20°F) discharge performance requirements after 30 days storage at +130°F, and the remaining nine cells were used to obtain discharge data at -20°, +75° and +130°F.

5. Production Cells

Based on the excellent data obtained in the above tests, 1200 cells were fabricated for assembly into 124 batteries to complete the test and delivery requirements of the contract. The fresh cells throughout the build met the discharge requirements. However, after about 3 weeks storage at room temperature, severe self-discharge was occurring in 50% of the cells. The self-discharge was found to be due to positive electrode grid corrosion. Extensive analysis indicated that the humidity of the atmosphere in the area where the cathodes were formed was out of control part of

G 2655 CELL DISCHARGE PERFORMANCE

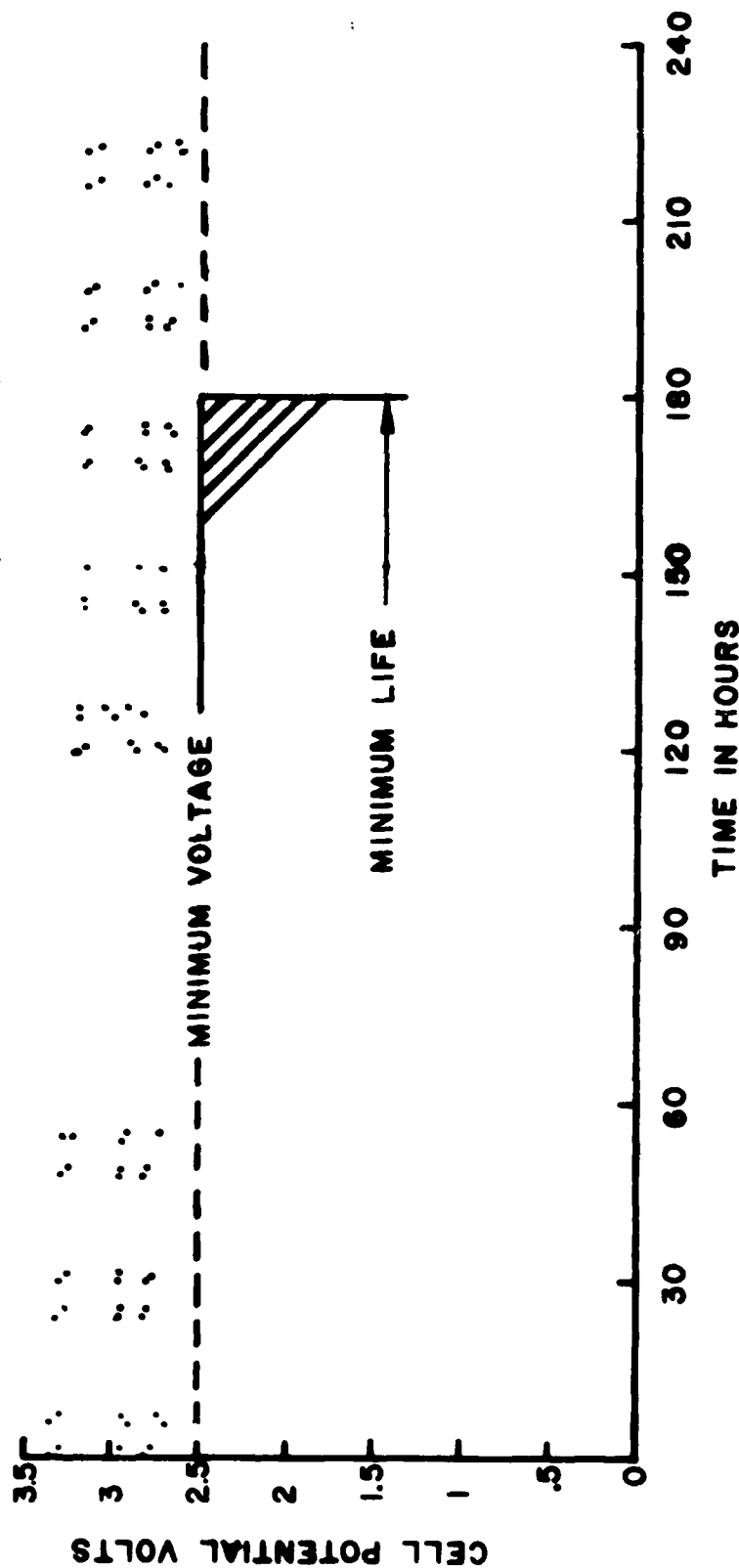
Li/2M LiAsF₆ + 0.4M LiBF₄-MF/V₂O₅:316-L SS

Cell # 369

Stand Temp 165°F (8 da.)

Test Temp -22°F

Continuous Load (top dots) - 1875 ohms
 15 Sec Pulses (middle dots) - 14.75 ohms
 75 ms Pulses (bottom dots) - 7.125 ohms



FORM FM-101

Figure IV-6. G2655 Cell Discharge Performance After Eight Days at +165°F

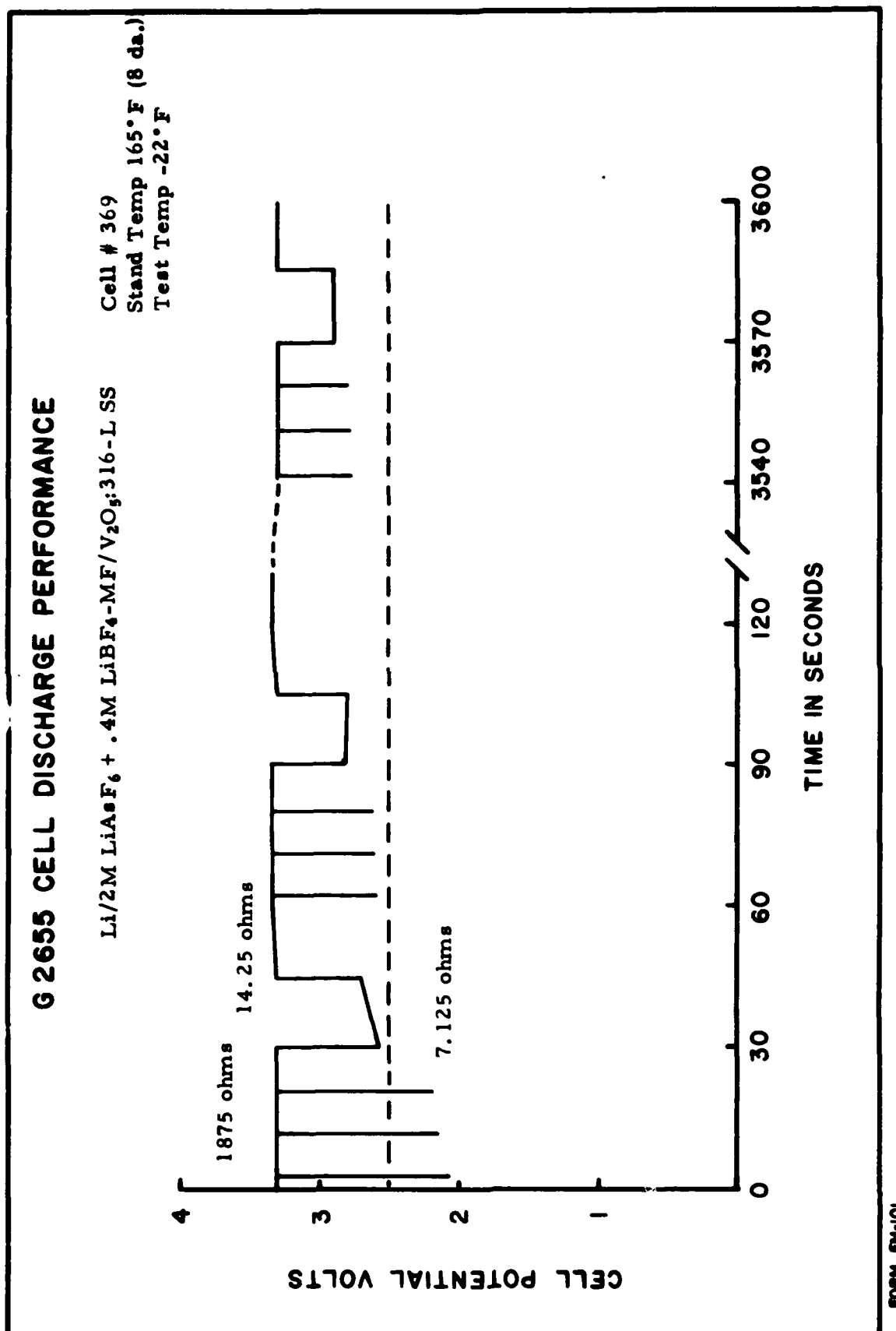


Figure IV-7. G2655 Cell Discharge Performance after Eight Days at +165° F

76-071

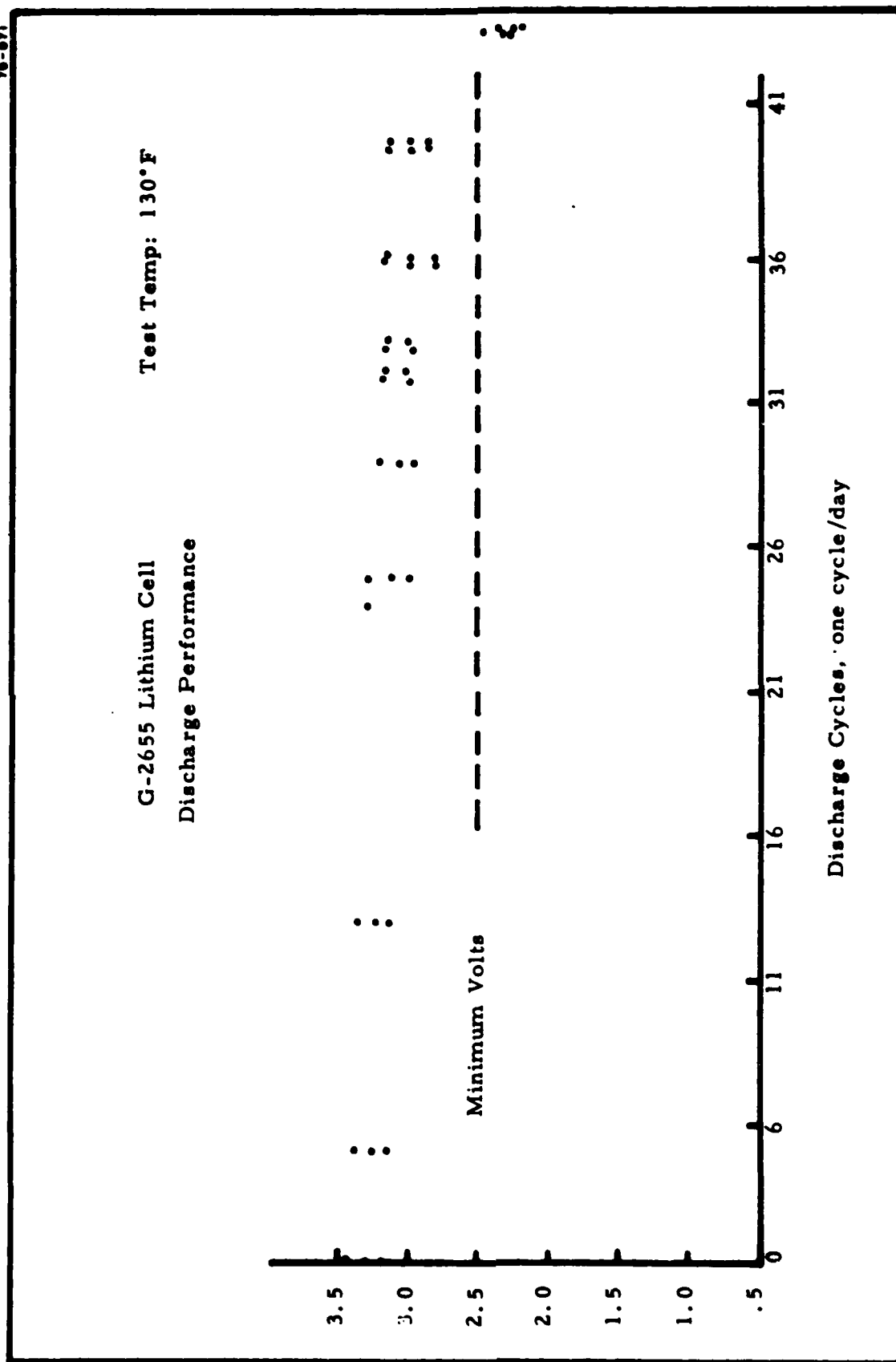


Figure IV-8. Discharge of Fresh G2655 Cell at +130°F

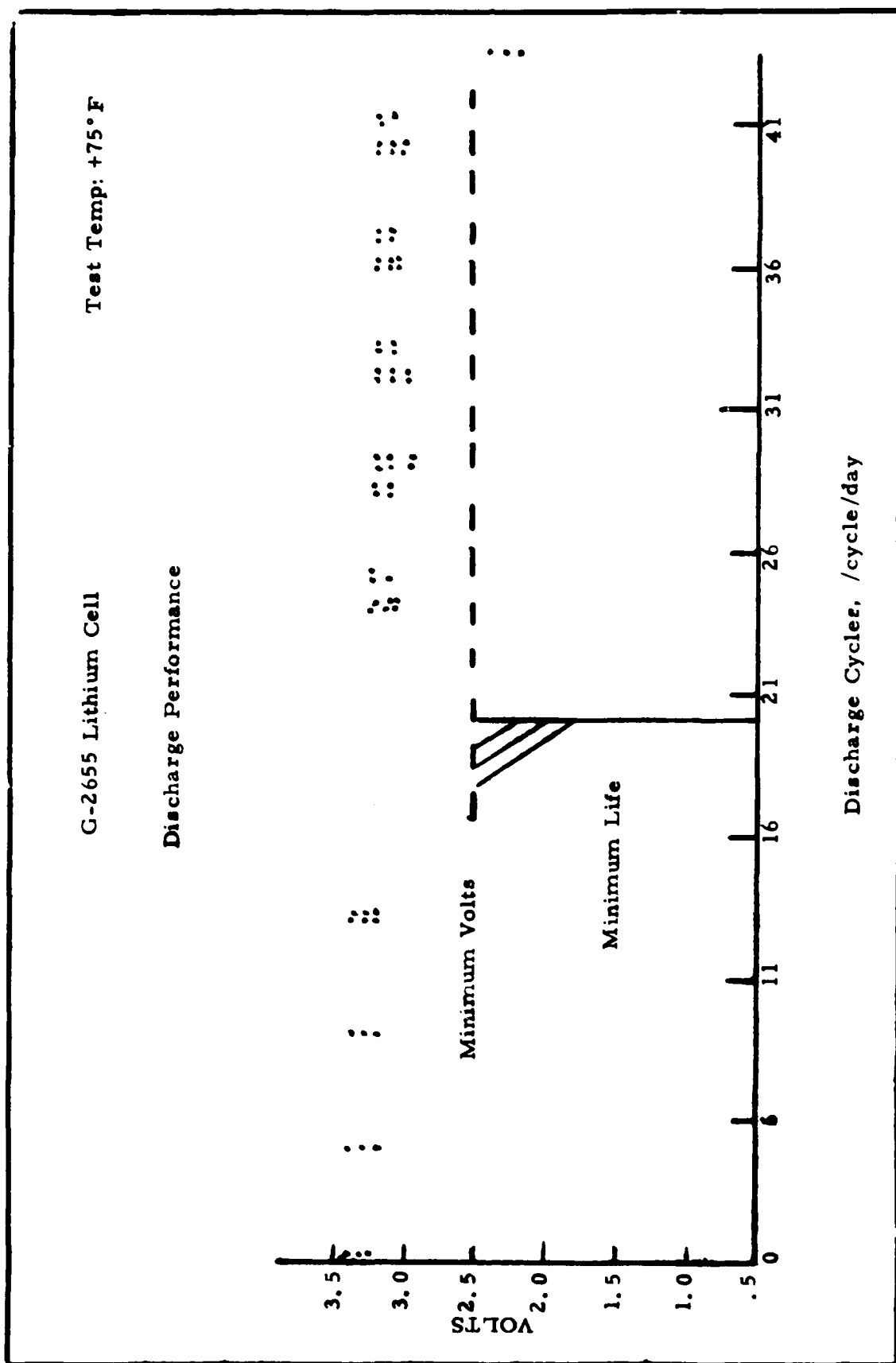
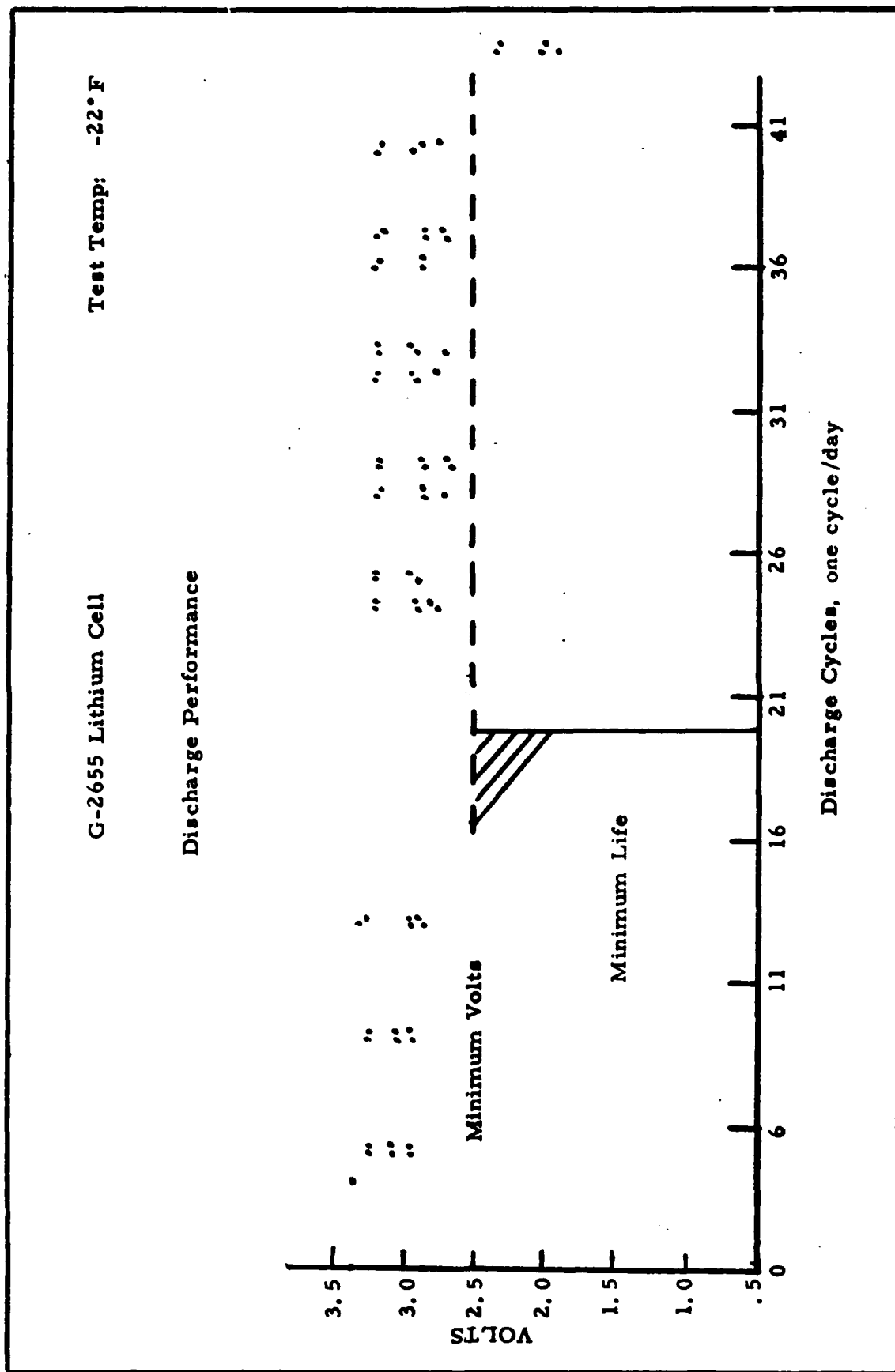


Figure IV-9. Discharge of Fresh G2655 Cell at +75°F



FORM FM-101

Figure IV-10. Discharge of Fresh G2655 Cell at -22°F

the time during fabrication and that the positive grid materials may have been improperly pickled and passivated. These are believed to be the reasons for the unexpected failures.

Not all of the 1200 cells exhibited the failure mode described above. In fact, 300 cells exhibited the expected long term storage capability and, as shown in Figure IV-11, after storage of nearly two years at room temperature, no appreciable self-discharge has occurred with these cells. It is believed that the $\text{Li}/2\text{M LiAsF}_6 + 0.4\text{M LiBF}_4\text{:MF}/\text{V}_2\text{O}_5$ electrochemical system will be capable of extremely long storage life when the critical fabrication processes and controls are defined.

E. SAFETY CONSIDERATIONS

Throughout the development program, battery safety was a paramount design consideration. The primary safety problems experienced were due to external causes such as those which occur because of heavy loading, external short circuits and cell reversal from accidental recharging. Consequently, Honeywell placed diodes across each cell in the battery and included a 10 ampere slow-blow fuse in the battery circuit. Figure IV-12 illustrates the manner in which the fuse was included in the battery package. These two devices gave a measure of safety during battery usage and handling, but did not provide adequate protection from hazards which might occur during uncontrolled storage or as a result of disposal actions.

The identification of potential hazards was determined by testing a number of cells subjected to various conditions which could render the battery unsafe.

1. Study Approach

The cells used as test vehicles for this study were a part of the battery contract production lot. Although the battery consists of eight cells, a single cell represents an appropriate unit for hazard evaluation.

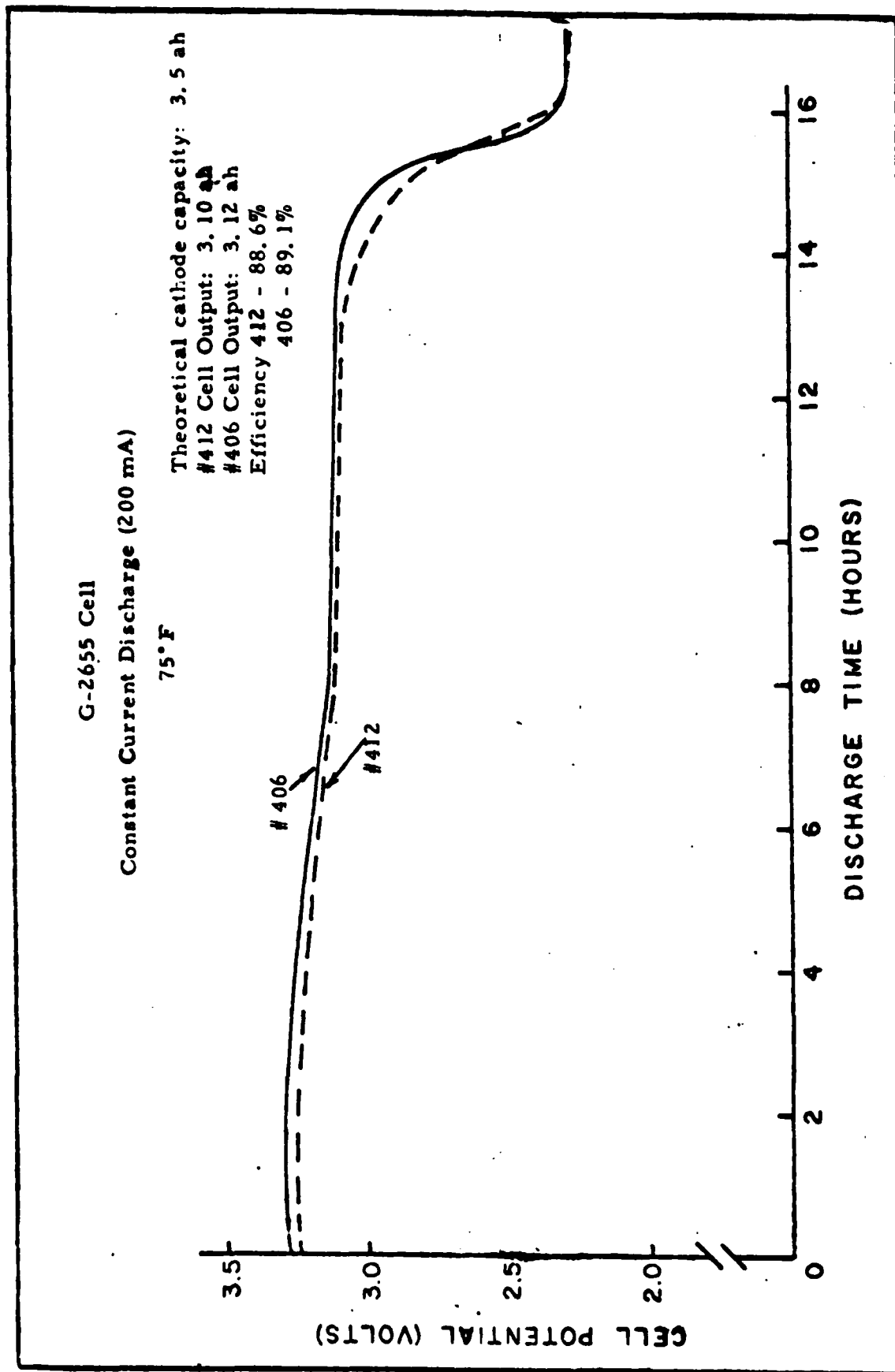


Figure IV-11. Discharge Comparison of G2655 Cells - Fresh and Stored Nearly Two Years at +75°F

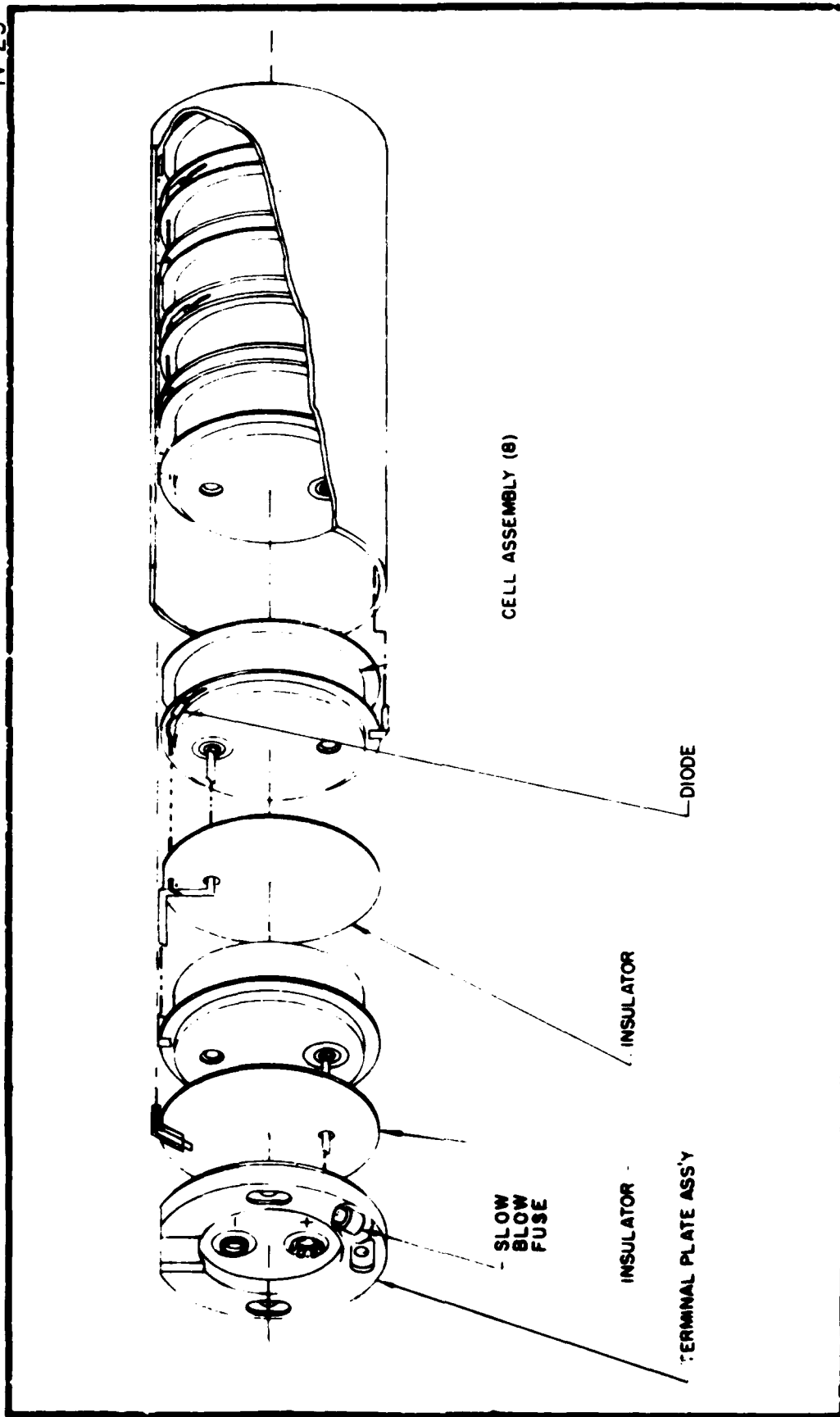


Figure IV-12 Battery Using Eight G2655 Cells - Exploded View

Considering the possible explosion hazards of the Li/V₂O₅ system during storage, use and disposal, the following test plan was formed:

<u>Cell Condition</u>	<u>Explosion Hazard Condition</u>
Storage	Extreme high temperature
Use	Short circuit, cell reversal, high rate discharge
Disposal	Incineration, case rupture, cell deformation

The above test conditions are considered representative of nearly all hazardous circumstances which could be encountered.

Cell Test Plan

<u>Cell No.</u>	<u>Type of Test</u>
392	External short circuit (124°F)
P-48	High rate discharge (increasing load)
471	Extreme high temperature (hot plate)
477	Extreme high temperature (50% discharged)
P-92	Cell deformation (crush until short circuit occurs)
481	Case rupture (drill)
480	Case rupture (drill) (50% discharge)
478	Incineration (blow torch)
479	Incineration (blow torch) (50% discharged)
P-51	Reverse discharge
P-76	Reverse discharge (diode protected)

2. Test Results

All cell tests were conducted at a temperature of 75° ± 7°F, unless otherwise indicated. All units were instrumented to record cell temperature, voltage, current and test duration.

a. Short Circuit Test - 124°F - The cell was stabilized in an oven at 124°F, then shorted with a 0.03 ohm shunt.

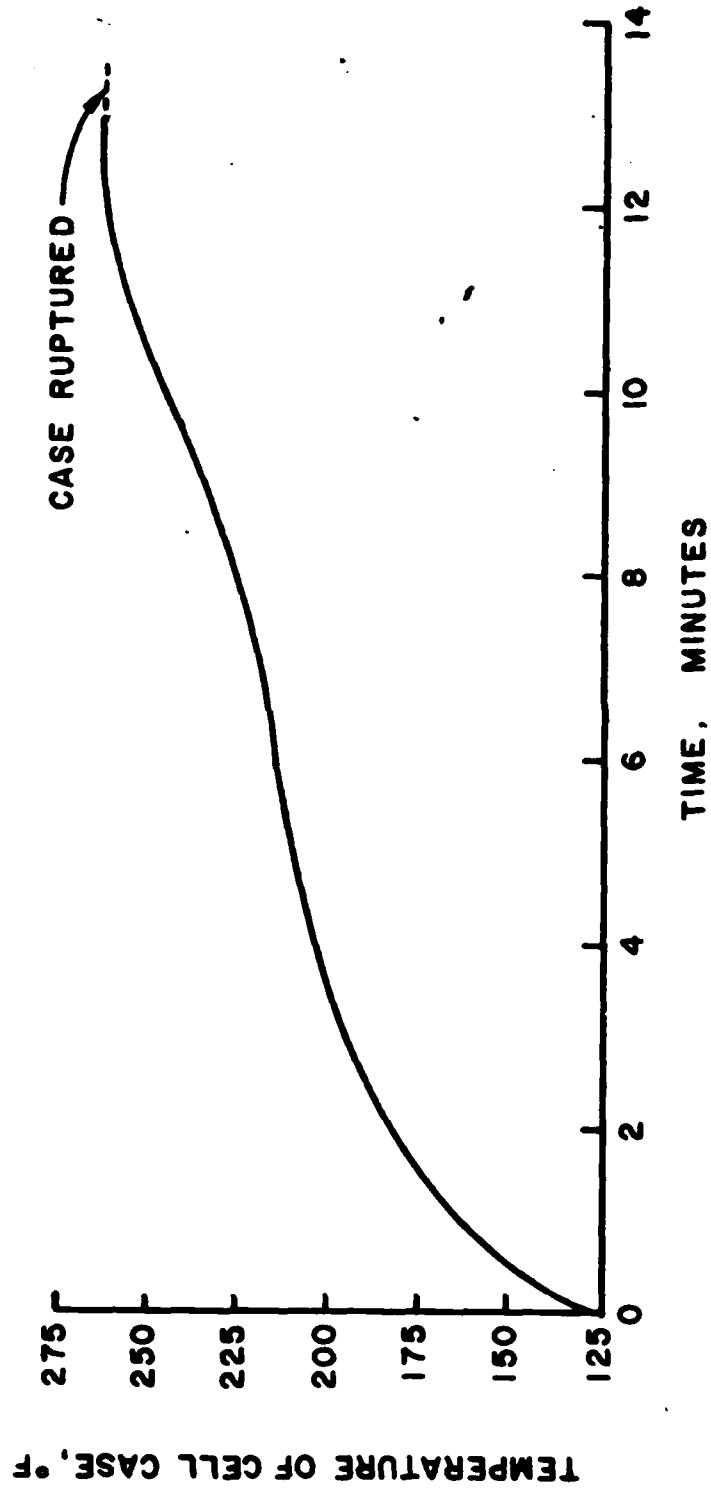
Figure IV-13 shows the rise in temperature vs. time and Figure IV-14 shows the cell current vs. time. As can be seen, cell case ruptured after 13 minutes in the shorted condition when the cell temperature had risen to 263°F. At the time of case rupture, the confined solvent gases in the oven ignited causing an explosion which scattered cell components throughout the oven. However, the cell hardware was recovered along with most of the cell parts which showed very little internal damage. Figure IV-15 shows that case rupture occurs at 400-500 psi, therefore, the internal pressure in the cell which ruptured was assumed to be greater than this value.

b. High Rate Discharge Test (Increasing Load) - This cell was placed in a safety hood with a thermocouple attached to the top center of the cell. The load resistance for the cell was slowly decreased over a period of 15 minutes, from 4 ohms to 0.08 ohm and maintained at 0.08 ohm. The case temperature reached a peak of 271°F in 32 minutes. Even though the cell temperature reached a higher level than the above short circuit test, rupture or venting did not occur. However, considerable swelling was observed and the cell appeared very close to the rupture point. Table IV-1 shows the temperature vs. time for this cell.

c. Extreme High Temperature Tests (Full Capacity and Half Discharged Cells) - Both cells were placed on a hot plate and allowed to heat until case rupture occurred. Cell #471, full capacity, vented in 14 minutes at 311°F. The 50% discharged cell vented in 8 minutes at 323°F. Venting for both cells occurred by rupturing at the weld of the case bottom to the cover. However, in the test of the partially discharged cell, the hot plate was pre-heated to 300°F in order to achieve a faster rate of temperature increase on the cells. Venting occurred in both cells at the projection

G-2655 CELL
SHORT CIRCUIT TEST
124°F

CELL NO. 392
DATE 1-12-73



FORM FM-101

Figure IV-13. Temperature Rise of Short Circuited G2655 Cell

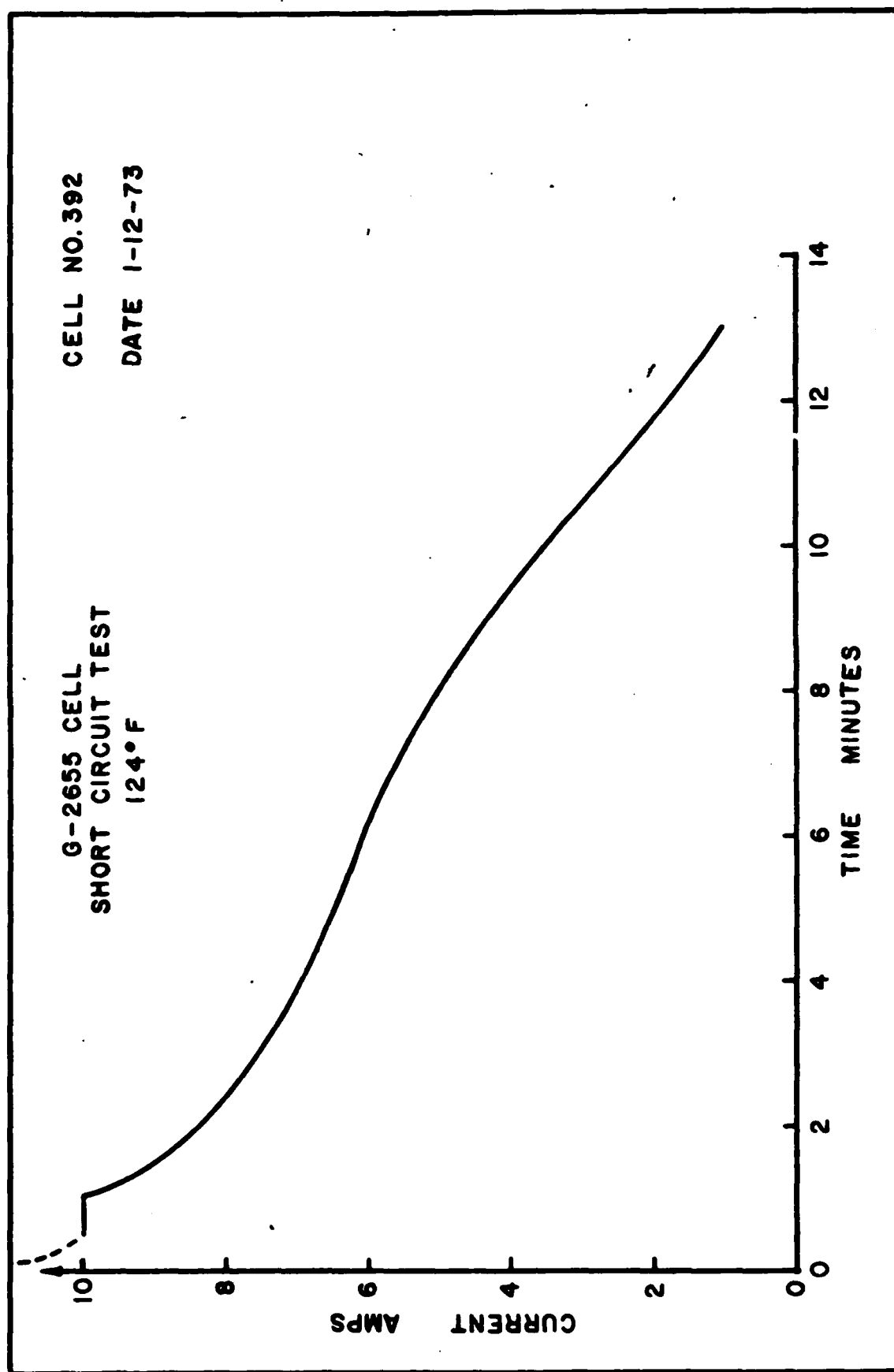
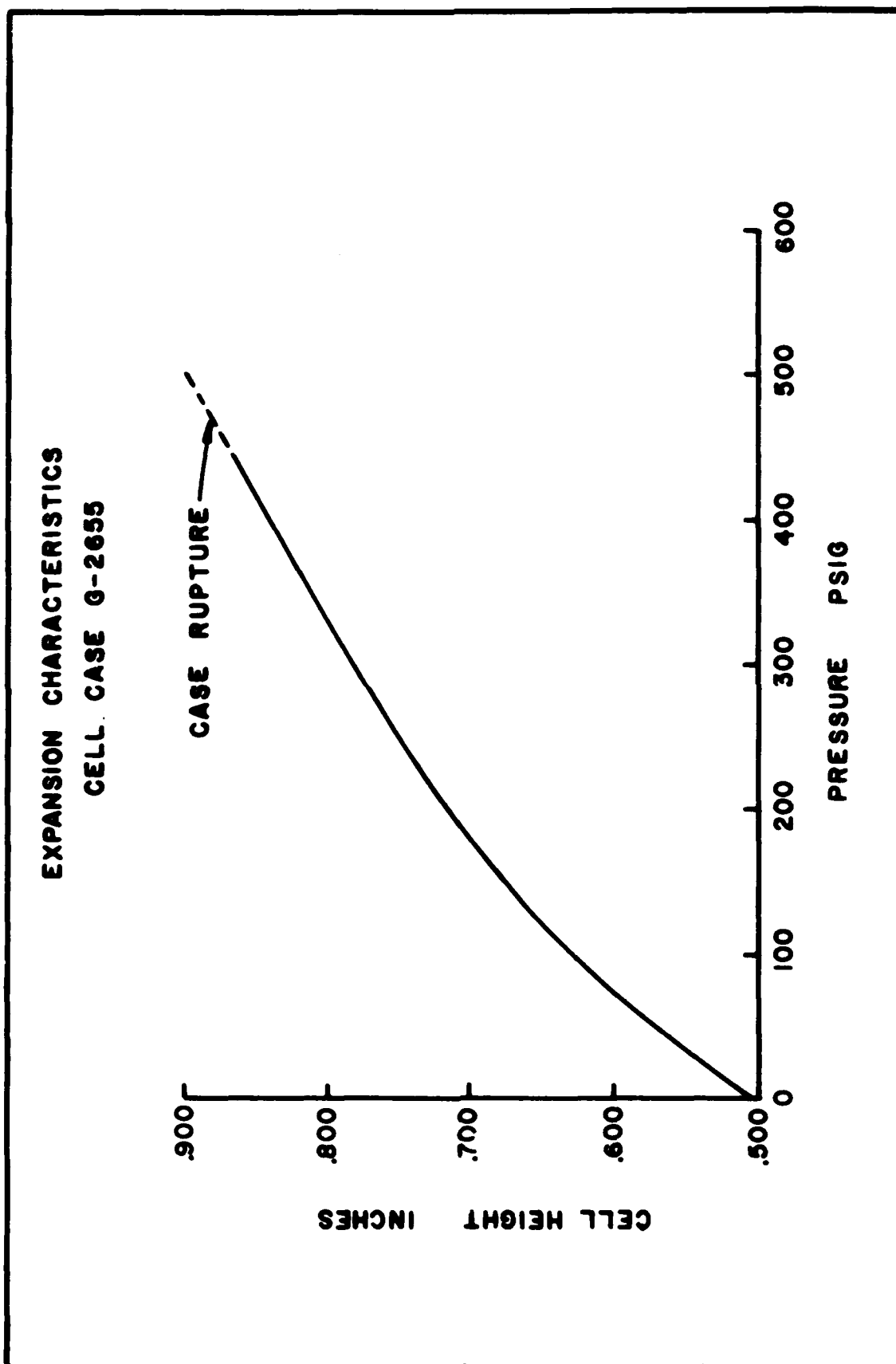


Figure IV-14. Current Profile of Short Circuited G2655 Cell



FORM FM-101

Figure IV-15. Expansion Characteristics of G2655 Cell Case Under Pressure

Table IV-1. Characteristics of G2655 Cell under High Rate Discharge**Cell No. P48**

<u>Time, min.</u>	<u>Temp., °F</u>	<u>Volts</u>	<u>Resistance, Ω</u>
0	86	3.14	4
1	88	3.19	4
2	87	3.19	4
3	88	3.13	3
4	88	3.13	3
5	89	3.03	2
6	89	3.03	2
7	90	2.49	.85
8	91	2.33	.70
9	92	1.94	.45
10	103	1.66	.37
11	110	1.47	.32
12	118	1.24	.28
13	127	0.98	.23
14	139	0.60	.19
15	150	0.025	.08
18	172	0.025	.08
20	191	0.025	.08
22	209	0.027	.08
24	225	0.005	.08
28	250	0.005	.08
32	271	0.0034	.08
34	263	0.0032	.08
38	250	0.0027	.08
45	234	0.0022	.08
50	217	0.0022	.08
55	189	0.0022	.08

Peak Temperature 274°F at 32 minutes, 20 seconds.

weld closure causing the contents to be blown out of the cases and scattering pieces up to several feet. Lithium metal remained in the undischarged cell, but the half discharged cell appeared to have practically all lithium consumed. Both cells emitted white smoke when venting. There was no sign of fire during these tests.

d. Cell Deformation Test - A cell was deformed in a hydraulic press by driving a one-inch diameter steel bar along the cell's axis until it showed a shorted condition. Within five seconds after shorting, rupture occurred at the case weld. Other than case rupture and the loss of electrolyte, the cell showed no other hazardous events. A post mortem examination showed that better than 85% of the cell components remained intact.

e. Case Rupture Test (Full Capacity and Half Discharged Cells) - For this experiment, both cells were drilled through the top (terminal side) with a 0.25 inch drill bit. In both cells, the solvent was ignited by sparks as the drill bit was being retracted. Both cells caught fire and burned for approximately 15 seconds. The 50% discharged cell did have two smaller fires which started at the completion of the solvent fire and lasted approximately one minute. A blow torch was passed over both cells after the fires were out (approximately five minutes) with no effect. During the initial burning period, the flames were as high as two feet.

f. Incineration Test (Full Capacity and Half Discharged Cells) - A propane torch was used as the heat source in this test. Both the torch and the cells were clamped in a fixture which held the cells one inch from the torch tip. The flame was concentrated on the center of the underside of the cells. Remote ignition of the torch was accomplished by an electric match. Within less than six seconds, both cells vented through a hole in the case when the flame was applied. The cells burned and smoked during the brief venting period (15 seconds). A thermocouple on the

cells indicated temperatures of 1000°F at the time of rupture and ignition. Holes approximately 0.75 inch in diameter were made by the melting of the case during burning.

g. Reverse Discharge (With and Without Diode Protection) - Two cells were discharged at a constant current of 700 mA for 15 hours. One cell was diode protected and one was not. Cell voltage reversal occurred for both cells after 6 to 7 hours of discharge. The maximum negative voltage reached was 0.62 volt. The cell temperature increased slightly, otherwise nothing abnormal was observed. Table IV-2 shows the test data for both cells.

3. Conclusions

In summary, the cells tested under extreme conditions exhibited relatively moderate reactions. For the most part, the fires and case ruptures were low order disruptions which offered little danger to personnel.

Fire was the most notable condition occurring when the cell was mishandled. This could be expected when incinerating a cell, exposing the cell to extremely high temperatures or cutting into the cell.

An explosion did occur in one test. For this to happen, it was necessary for the case to rupture, for the solvent to attain a gaseous state where the limits of flammability are reached (5.0 - 22.7% in air by volume) and for spark or hot cell particle ignition to be available.

Table IV-2. Reverse Discharge* Test of G2655 Cell

<u>Time (hrs)</u>	<u>Voltage Cell No. 51</u>	<u>Voltage Cell No. 76</u>	<u>Temp. °F Cell No. 51</u>
OCV	3.65	3.65	87
0	3.50	3.00	
.3	2.80	2.40	
.6	2.35	2.10	111
1.0	2.00	1.80	
2.0	1.50	1.15	111
3.0	1.05	.70	109
4.0	1.45	.55	
5.0	1.00	.55	111
6.0	.20	.40	113
7.0	-.45	-.15	
8.0	-.40	-.45	99
9.0	-.42	-.45	
10.0	-.42	-.45	
11.0	-.42	-.48	
12.0	-.42	-.55	
13.0	-.45	-.60	86
14.0	-.45	-.61	
15.0	-.45	-.62	

Cell No. P51 reversed potential at 377.6 minutes.

Cell No. P76 reversed potential at 409.3 minutes.

*The cells were discharged at a constant current of 700 mA.

It is apparent from this study, that the solvent must be allowed to escape when the cell is exposed to temperatures above 200°F. This must be done by a method that insures that the solvent during its release will not attain its limit of flammability.

4. Safety Mechanism Design

The objective of this study was to provide a venting feature for the Li/V₂O₅ cell developed under this contract. Such a feature would prevent the buildup of high internal pressures within the cell which creates a safety hazard. Tests have shown that when this pressure buildup occurs, cell case rupture, fire and/or explosion will result.

The problem of providing a safety vent to alleviate the above condition is influenced by the fact that under normal cell operating conditions, -40°F to +160°F, the internal cell pressure varies from 0 to 55.0 psi above atmospheric pressure. Throughout this range of operating pressures, it is desirable for the cell seal to remain intact and the quality of the seal approach a true hermetic seal with a leak rate of less than 1×10^{-8} ATM cc/sec/helium.

A design concept has been generated to provide the cell with a satisfactory seal throughout the above pressure range. This seal will also automatically vent the cell internal pressure between 80 and 100 psi. Briefly, the concept involves creating a rectangular hole approximately 0.25 inch high by 0.50 inch in arc in the circumferential wall of the cell case. This hole will be covered with a thin diaphragm on the inside of the cell case. The attachment of this diaphragm to the cell case to provide the seal will require further development; however, several approaches including welding and adhesives are under consideration. The purpose of this diaphragm will be to provide the seal only. It will be designed to rupture

at pressures significantly above the 55.0 psi required during normal high temperature cell operation. An arced flat spring will be welded to the O. D. of the cell case. This spring will back up the diaphragm, giving it the mechanical strength and support required to withstand internal pressures of over 55.0 psi.

See Figures IV-16 and 17 for cell safety valve components and assembly.

A feature of this battery safety design is a manifold venting system to allow the escape of the electrolyte from any cell to a pressure relief chamber and subsequently to a bleed hole in the battery case. Figure IV-18 illustrates this concept. As an additional precaution, a filler material can be placed in the relief chamber to absorb or neutralize the electrolyte solvent (MF). In this manner, the rapid buildup of gas pressures can be further reduced and controlled.

F. BATTERY DESIGN

1. General Requirements

The requirements for the battery are summarized below:

a. Physical

Dimensions: In accordance with Figure IV-19.

Weight: 1.75 lb maximum

Leakage: The battery shall show no loss in weight or evidence of leakage when stored for six hours at a pressure corresponding to an altitude of 50,000 feet at $75^{\circ} \pm 7^{\circ}\text{F}$.

b. Electrical - The battery will be discharged under fixed resistance load on a repeating basis as specified below:

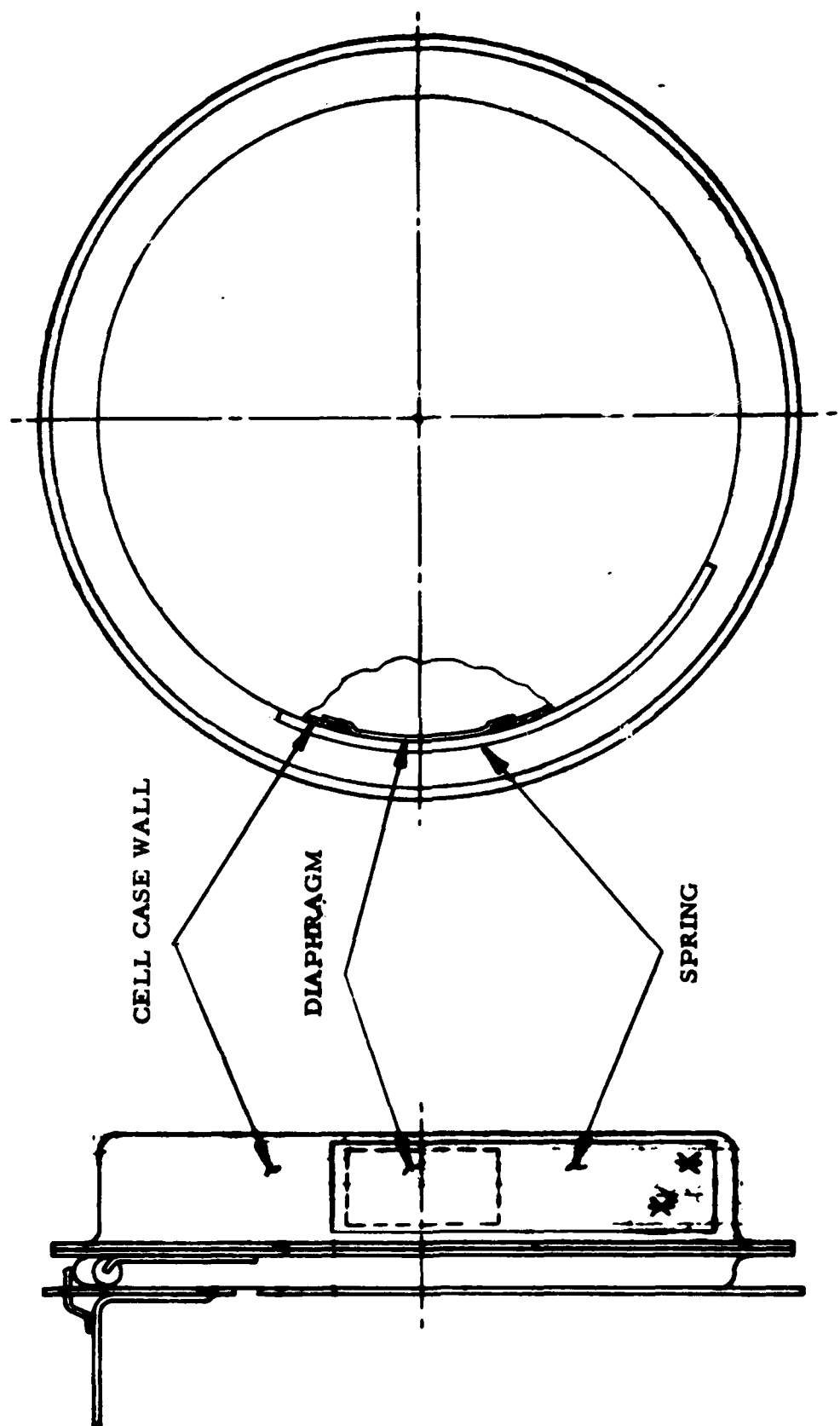


Figure IV-16. G-2655 Cell Safety Valve Assembly

MATERIAL: METALIZED PLASTIC FILM



MATERIAL: 304 STAINLESS STEEL

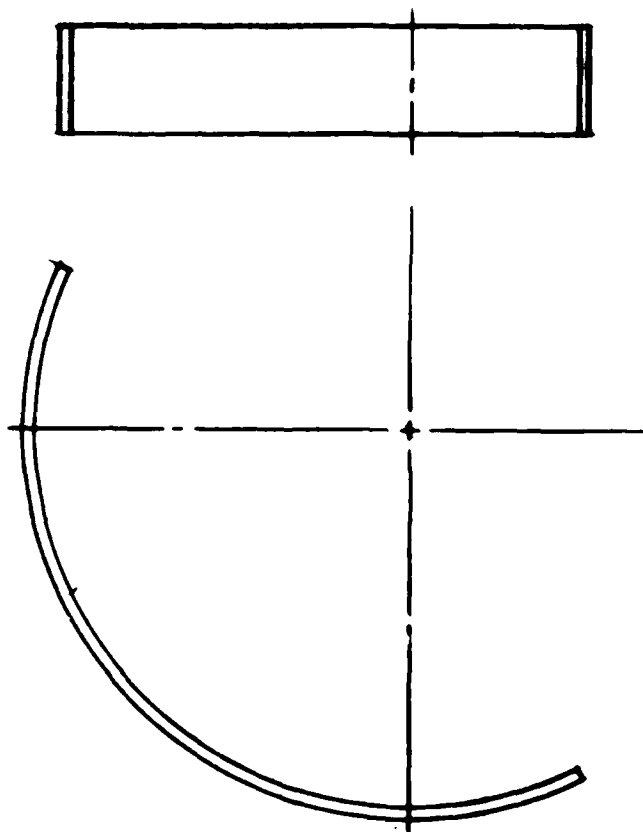


Figure IV-17. Valve Components

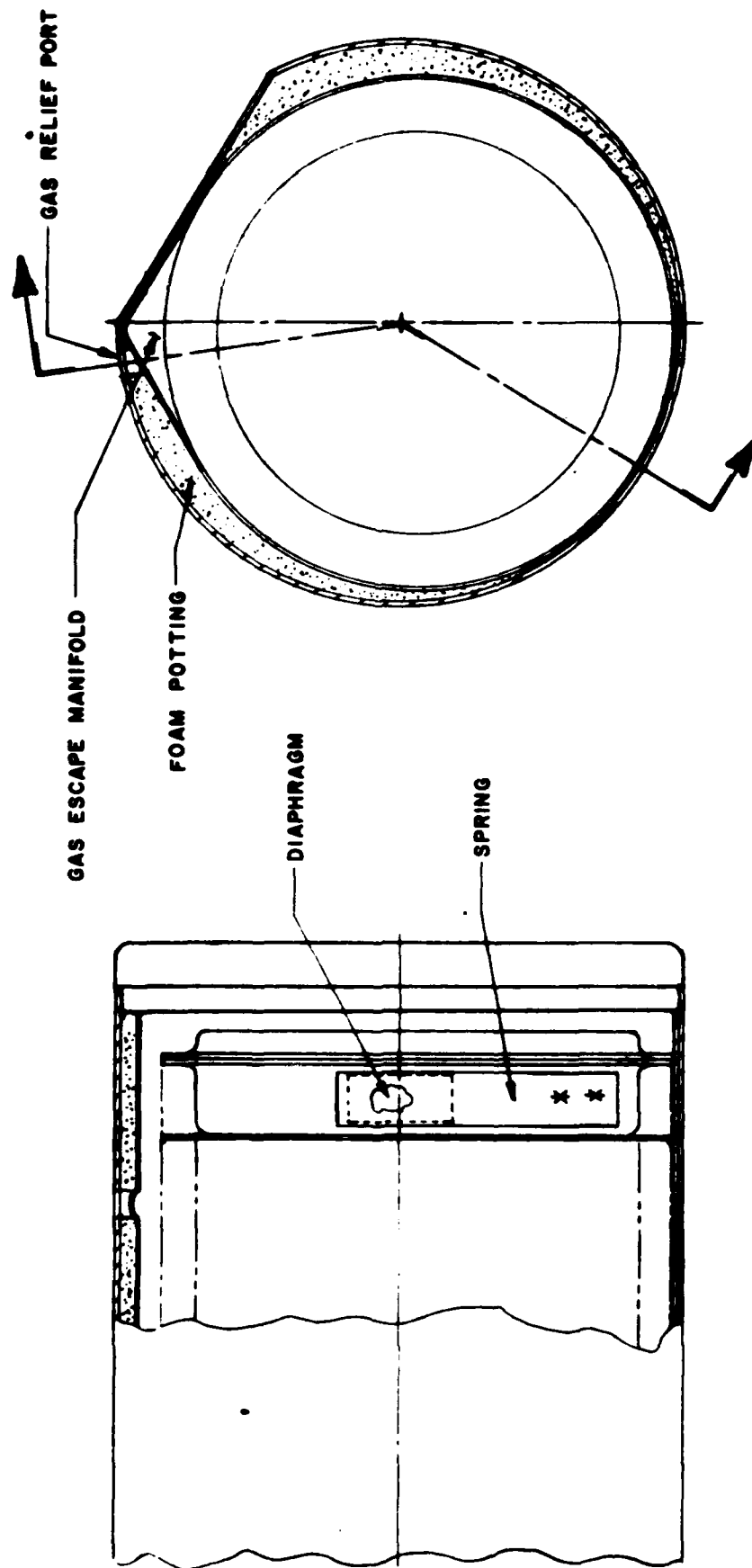


Figure IV-16 G2655 Battery Valve and Cell Assembly

↓ A | 99060021 |

IV-40

REV	DESCRIPTION	DATE	APPROVED
REL PER E072 PSC-0037		2-2-73	W J F
A REV PER E073 PSC-0012		2-2-73	W J F

PART NO.
72003065 -001

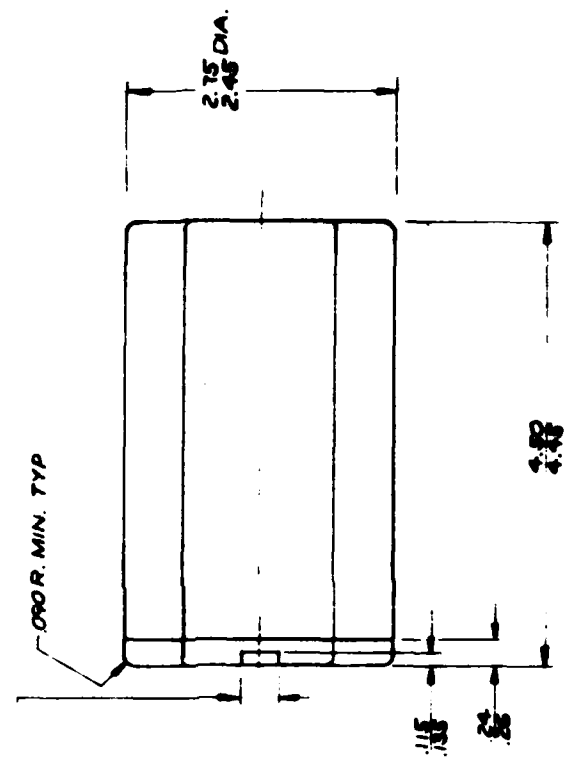
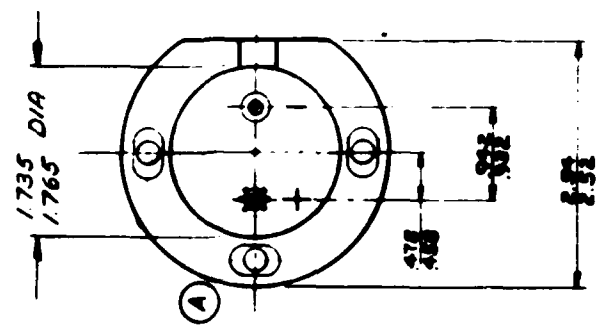


FIG. IV-19

HONEYWELL INC.		Power Systems Center Honeywell Building Phoenix, Arizona, U.S.A.	
BATTERY		— DIMENSIONAL OUTLINE —	
SIZE	CODE IDENT NO	DRAWING NO.	
B	99025	72003066	
SCALE	1/1	SHEET 1 OF 1	
DESIGNER	CHECKER	DATE	BY
MATERIAL			
FINISH SEE NOTE			
NEXT ASBY	USED ON	APPLICATION	

- 1) Maximum open circuit voltage 32 volts
- 2) Maximum load voltage 30 volts
- 3) Test end voltage 20 volts
- 4) Discharge loads 15,000 ohms $\pm$ 1% constant
 57 ohms $\pm$ 1%, 75 ms pulse load
 114 ohms $\pm$ 1%, 15 sec pulse load
- 5) Pulse load cycle, first hour each day - pulses are to be on a one-minute cycle repeated 60 times during the first hour of the discharge test and during the same hour on each succeeding day until test end voltage is attained. Events in the one-minute cycle are as follows:

<u>Seconds</u>	<u>Pulse</u>
0	75 ms
10	75 ms
20	75 ms
30-45	15 sec

- 6) Pulse load cycle, second through 24th hour of each day - 75 ms pulse to be applied every 100 seconds.
- 7) Service: Twenty days minimum under all test conditions of the guidelines. This corresponds to an approximate minimum capacity of 2.1 Ahr (assuming average voltages of 28, 24 and 24 for load conditions of 15,000 ohm continuous, 57 ohms, 75 ms pulses and 114 ohms pulses for 15 sec. respectively.

c. Environmental Temperatures - When discharged under the conditions specified in the previous section, the battery is to deliver the minimum service under each of the following conditions:

- 1) Immediate discharge at $75^{\circ} \pm 7^{\circ}\text{F}$
- 2) Stabilization at $75^{\circ} \pm 7^{\circ}\text{F}$ for a minimum of eight hours and discharge at $75^{\circ} \pm 7^{\circ}\text{F}$ following 30 days of storage at $130^{\circ} \pm 3^{\circ}\text{F}$ ($160^{\circ} \pm 3^{\circ}\text{F}$ desired).
- 3) Stabilization at $-20^{\circ} \pm 3^{\circ}\text{F}$ ($-40^{\circ} \pm 3^{\circ}\text{F}$ desired) for a minimum of eight hours at $-20^{\circ} \pm 3^{\circ}\text{F}$ ($-40^{\circ} \pm 3^{\circ}\text{F}$ desired).
- 4) Stabilization at $-20^{\circ} \pm 3^{\circ}\text{F}$ ($-40^{\circ} \pm 3^{\circ}\text{F}$ desired) for a minimum of eight hours and discharge at $-20^{\circ} \pm 3^{\circ}\text{F}$ ($-40^{\circ} \pm 3^{\circ}\text{F}$ desired) following 30 days of storage at $130^{\circ} \pm 3^{\circ}\text{F}$ ($160^{\circ} \pm 3^{\circ}\text{F}$ desired).
- 5) Stabilization at $125^{\circ} \pm 3^{\circ}\text{F}$ for a minimum of eight hours and discharge at $125^{\circ} \pm 3^{\circ}\text{F}$.

d. Mechanical Environmental Capability - The battery is to meet the minimum service times following exposure to the following:

- 1) **Vibration:** The battery is to be rigidly clamped to the platform of the vibration machine. A simple harmonic motion having an amplitude of 0.03 inch (0.06 inch max. total excursion) will be applied. The frequency is to be varied at the rate of one cycle per second per minute between the limits of 10 and 55 cycles per second. The entire range of frequencies and return is to be traversed in 95 ± 5 minutes for each mounting position (direction of vibration) of the battery. The battery is to be vibrated in three mutually perpendicular directions for approximately equal periods. One of the directions of vibration is to be perpendicular to the terminal face of the battery. Open circuit voltage is to be observed for 30 seconds during the last quarter of each vibration period.

- 2) **Mechanical Shock:** The battery is to be subjected to a total of three shocks of equal magnitude. The shocks are to be applied to each of three mutually perpendicular directions. Each shock is to be applied in a direction normal to a face of the battery. For each shock, the battery is to be accelerated in such a manner that during the first three ms, the minimum average acceleration is 75g.

2. Cell Acceptance Criteria

Based on data developed on the characteristics of the 40 pre-production G2655 cells, the following cell acceptance criteria were established.

Cell voltage	OC > 3.42 volts Load voltage* > 3.10 volts *a 14 ohm load applied for 5 seconds
Cell weight	75-80 grams
Cell thickness	Maximum after 5 days storage at +75°F - 0.520"
Electrolyte weight	10.4 - 12.7 grams
Weight loss	No weight loss shall occur after 5 days storage at room temperature
Discharge	The attached curves, Figures IV-20, 21 and 22, show typical performance of G2655 cells under 200 mA constant current load at +125, +75 and -20°F. Performance should not deviate more than 10%.

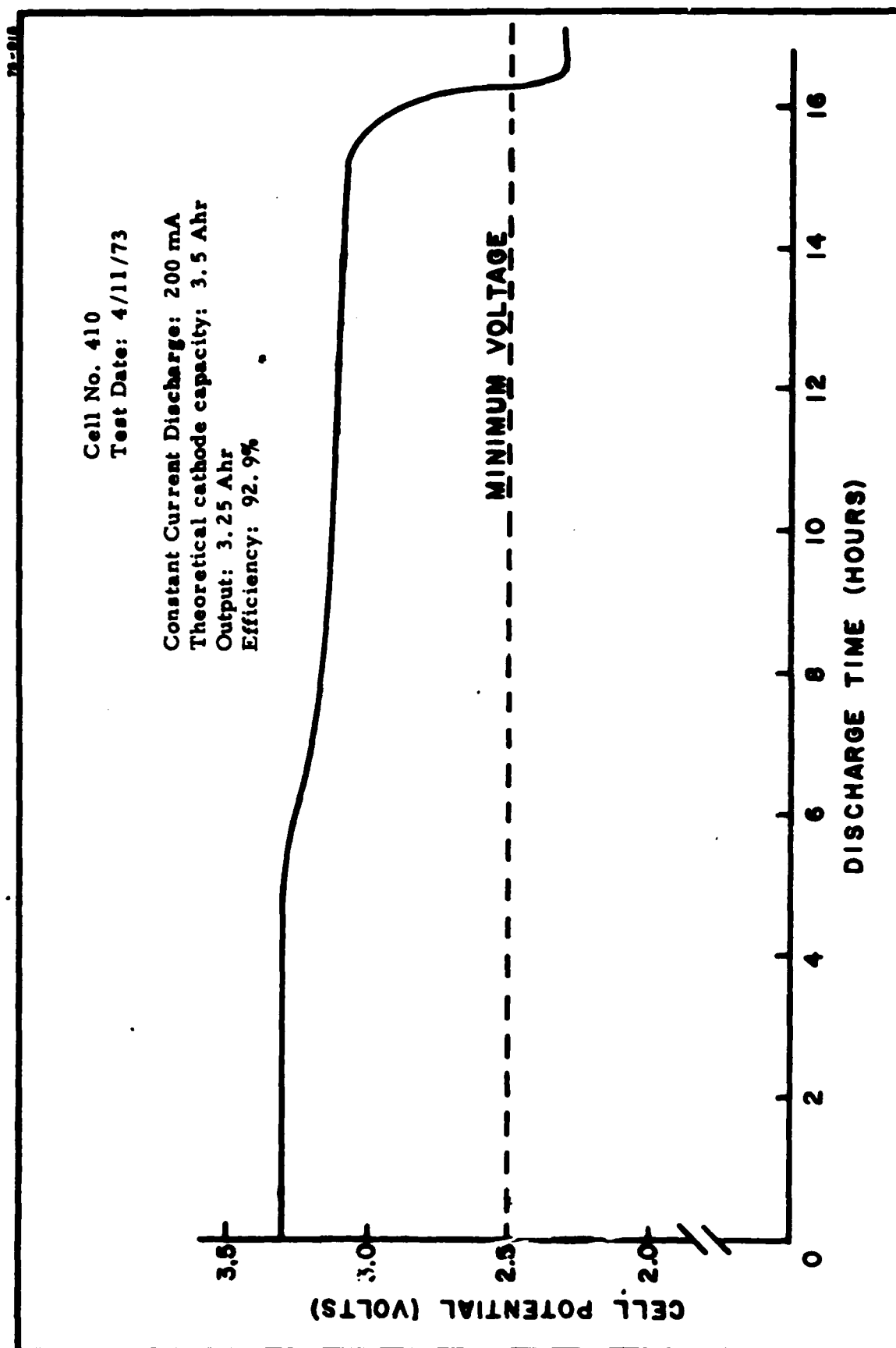
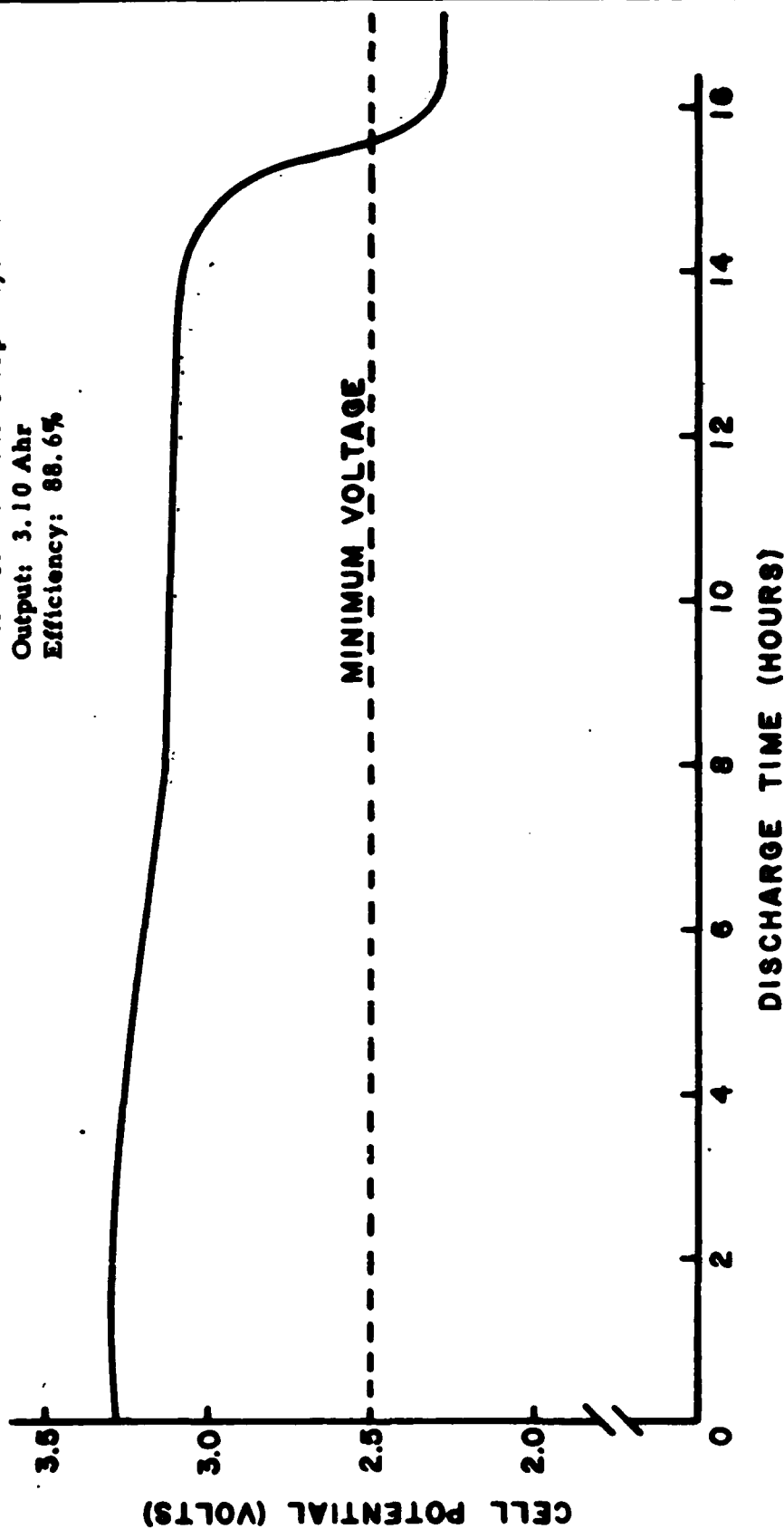


Figure IV-20. Constant Current Discharge Test of G2655 at +125°F

17-914

Cell No. 412
Test Date: 4/9/73

Constant Current Discharge: 200 mA
Theoretical cathode capacity: 3.5 Ahr
Output: 3.10 Ahr
Efficiency: 88.6%



FORM PM-101

Figure IV-21. Constant Current Discharge Test of G2655 at +75°F

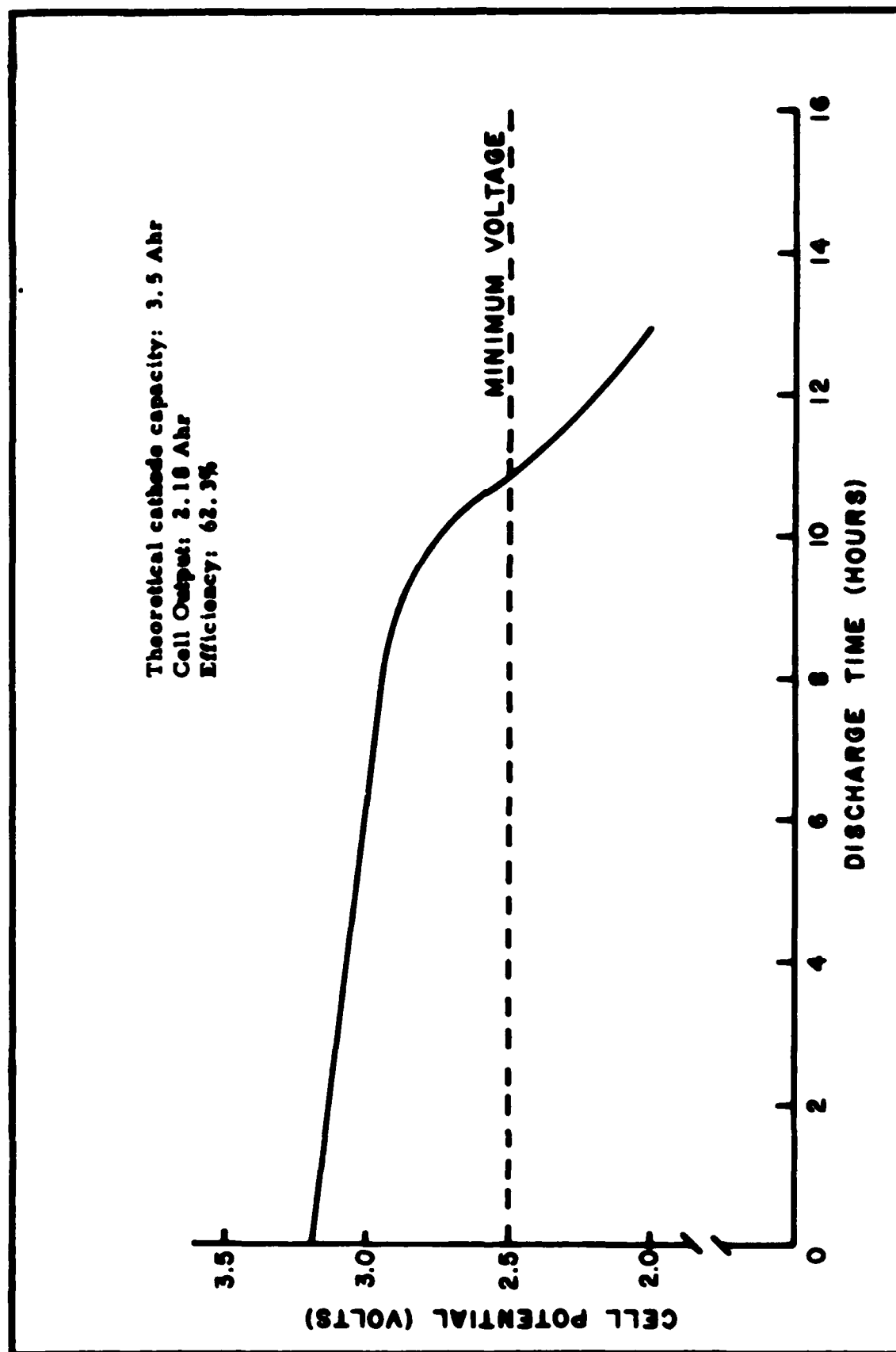


Figure IV-22. Constant Current Discharge Test of G2655 at -20°F

3. Battery Design Details

The battery design was shown in Figure IV-12. It consists of eight Model G2655 Li/V₂O₅ cells of the design described previously. The nominal voltage is 28 volts with a maximum allowable of 32 volts. Each cell is protected against reverse charging by a #1N645 diode. Incorporated in the battery plastic cap is a 10 amp slow blow fuse, as a safety feature against continuous shorting of the battery. It meets the electrical requirements of the technical guidelines of the contract. The maximum weight of the battery is to be 1.75 pounds. The battery is potted with epoxy to insure that the battery will withstand rough handling conditions.

G. BATTERY TESTS

Due to the corrosion problems which occurred during the build of cells for delivery, the only battery fabricated and tested was that assembled from the cells of the 40 cell build just before the 1200 cell build. This battery was stored and discharged according to the loads and cycles required by the contract technical guidelines. The open circuit voltage and 57 ohm random pulse voltage (4 during storage as shown) during +130°F storage are shown in Figure IV-23. The performance of the battery under worst case discharge conditions (-20°F) is shown as Figure IV-24. As can be seen, the performance requirements were easily met. Figure IV-25 shows the initial pulse voltages. Only the very first pulse was below the minimum voltage level.

The total battery weight was 1.89 pounds (1.75 maximum allowable). This problem is deemed correctable. The above battery was subjected to vibration as specified in the contract technical guidelines after discharge was complete. At that time, voltage measurements were made at various loads. After vibration, the loads were again applied. The data are shown below in Table IV-3.

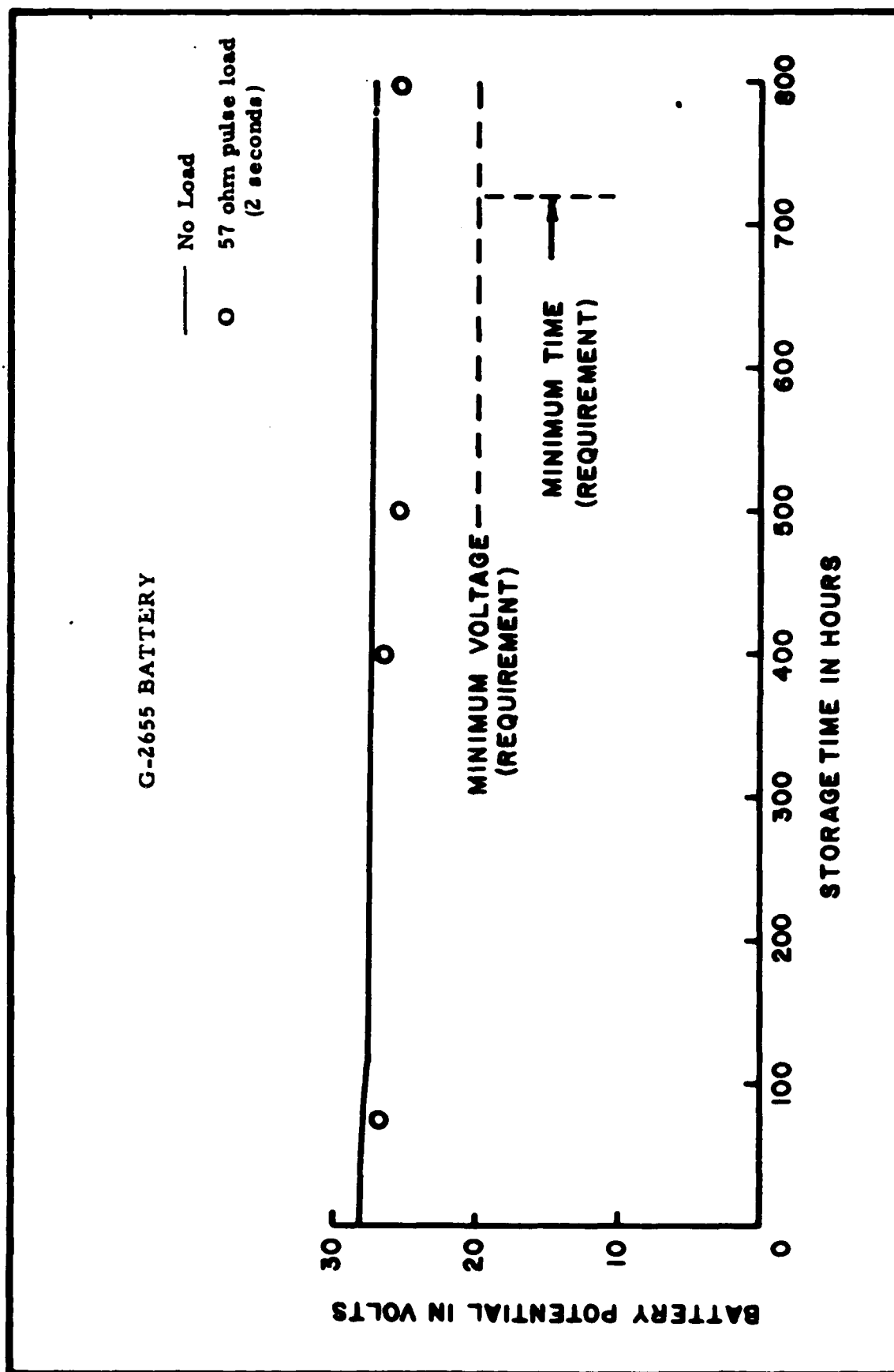
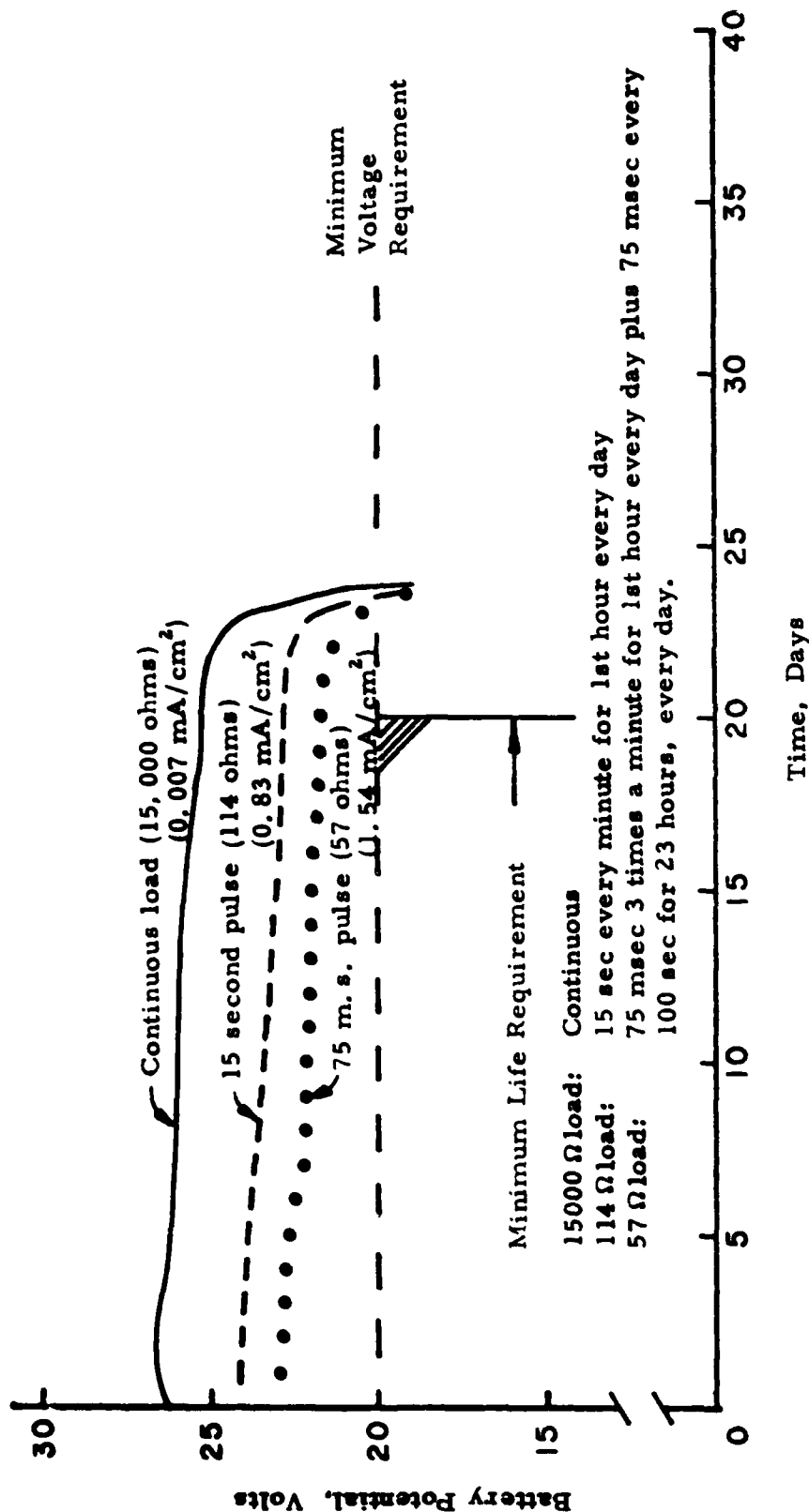


Figure IV-23. Minimum Pulse Voltage for Battery During Storage at +130°F

Discharge Temp: -20°F
 Storage Temp: 130°F
 Storage Time: 1 Month



75-013

DISCHARGE OF G2655 Li/V₂O₅ CELLS ASSEMBLED AS A BATTERY
 (8 CELLS IN SERIES)

FIGURE 7

Battery Model G-2655 No. - 001
 Test Temperature: -20°F
 Previous Storage : 30 days at
 130°F
 Test Start Date : 3/6/73

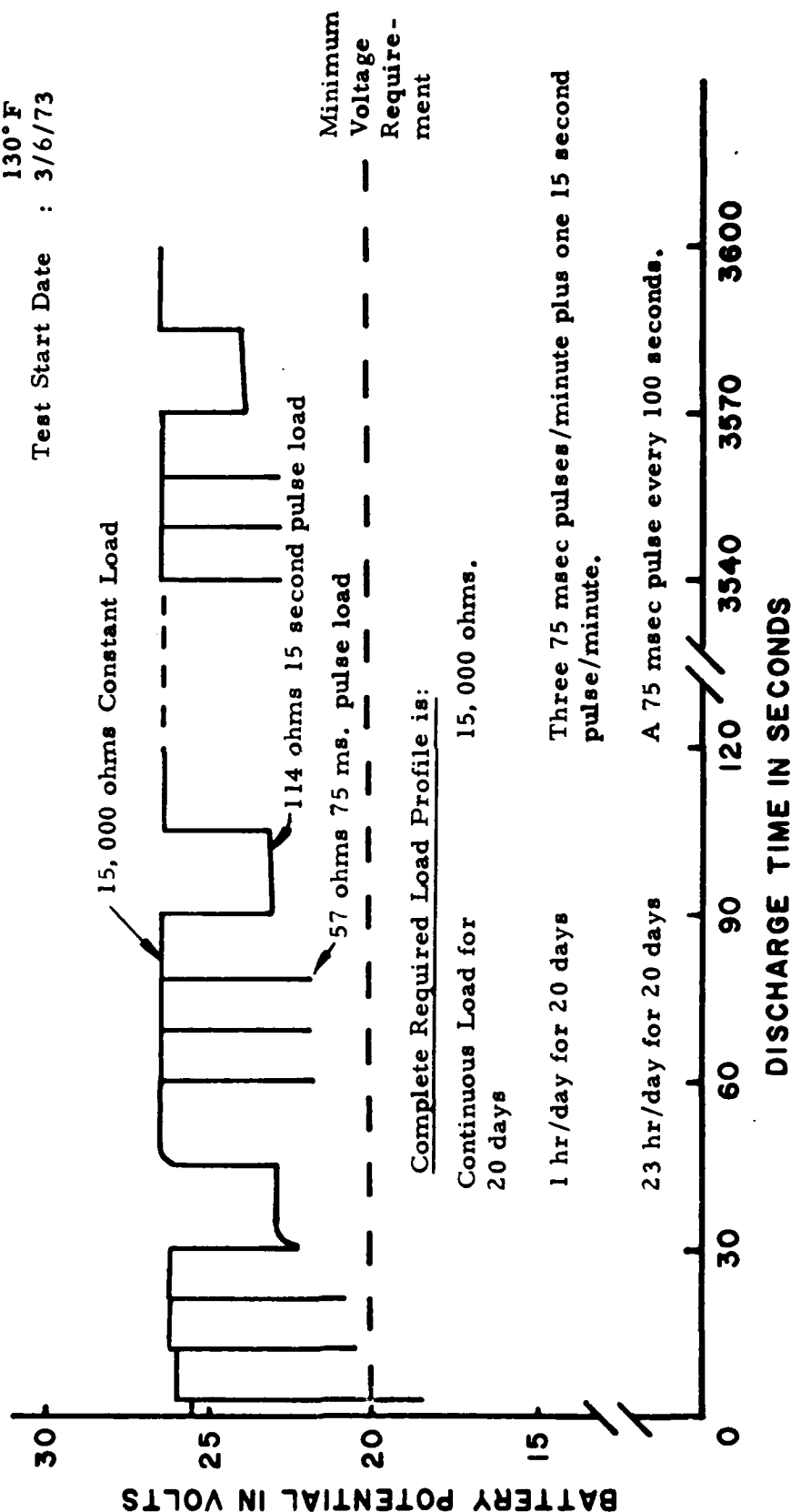


Figure IV-25. G2655 Battery Discharge Performance - First Hour at -20°F
 After 30 Days Storage at $+130^{\circ}\text{F}$

Table IV-3. Battery Voltage Before and After Vibration
Test Temp: 75°F

<u>Resistance</u>	<u>Voltage</u>	
	<u>Before Vibration</u>	<u>After Vibration</u>
Open Circuit	24.8	24.8
1000 Ohms	24.6	24.7
500 Ohms	24.5	24.6
114 Ohms	23.7	23.9
57 Ohms	22.9	23.1

No significant electrical changes were found as a result of vibration testing.

In conclusion, the electrochemical system chosen for this battery is capable of meeting the electrical requirements of the contract.

V. DEVELOPMENT OF A Li/SO_2 ORGANIC ELECTROLYTE BATTERY

The Li/SO_2 system has been undergoing development in standard configuration hardware at Honeywell for approximately three years. Due to its projected low cost in high volume production, it is a likely candidate for batteries used by the DOD in applications requiring large volumes of expendable batteries such as remote sensors and manpack communications.

At the time the original contract was modified, Honeywell was developing a cell configuration that was compatible with the BA-5386 configuration and requirements. It was agreed that it would be beneficial to the government for Honeywell to demonstrate the capabilities of the Li/SO_2 system in the BA-5386 configuration as this battery is destined for relatively high volume procurement.

The only activity required to make the cell completely suitable was to incorporate a safety feature. Beyond that, the development activity included considerable cell testing for discharge characteristics and safety, and a battery design, build, and qualification program. The contract revision regarding this activity called for the build of 66 batteries, the test of 16 and the delivery of 50.

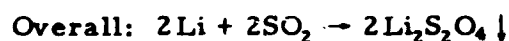
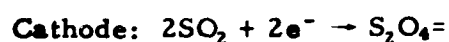
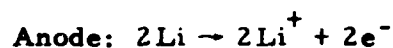
This section summarizes the characteristics of the Li/SO_2 electrochemical system, cell design, safety feature, testing and battery related development activities.

A. ELECTROCHEMICAL SYSTEM

The Li/SO_2 electrochemical system consists of a lithium anode, a carbon cathode and an electrolyte consisting of lithium bromide and sulfur dioxide dissolved in acetonitrile.

1. Reactions

The overall reactions involved in the Li/SO₂ electrochemical system are assumed to be as follows:



The SO₂ reduction occurs on an active carbon substrate with Li₂S₂O₄ reaction product being precipitated in the active carbon mass. The SO₂ reagent is dissolved in the cell electrolyte. A conductive grid (aluminum) is embedded in the active carbon substrate to provide a conductive path for electrons required to reduce the SO₂. The active carbon does not enter the reaction; however, its capacity is limited by the Li₂S₂O₄ precipitate within its structure. The active carbon structure on its grid is considered the cell cathode since this is the reduction site.

2. Theoretical Capacity

Theoretical capacity of the two active materials are:

Li: 3.86 Ahrs/gm

SO₂: 0.419 Ahrs/gm

3. Electrolyte

The electrolyte (1.0M LiBr/AN/SO₂) consists of lithium bromide and sulfur dioxide (64.4 wt percent) dissolved in acetonitrile. The formulation was optimized for specific conductivity over the expected temperature range and by making tradeoffs against solute concentration, density, vapor pressure, viscosity and other required parameters. Compatibility of the optimized electrolyte with other materials was determined by storing cells at +165°F. Electrochemical techniques such as cyclic voltammetry, polarography, and reference electrode measurements as well as visual observations were used to determine the nature and extent of any undesirable reactions.

The conductivity of the electrolyte is shown in Figure V-1 over a temperature range of -60°C to +100°C. Figure V-2 shows the density variation of the electrolyte from -40°C to +100°C. The vapor pressure of the electrolyte, which is a critical factor in the design of the pressure relief safety mechanism, is shown in Figure V-3.

4. Cathode

A low cost cathode substrate consisting of 77 percent acetylene black, 5 percent paper pulp, and 18 percent teflon binder was found to be superior to other carbons such as graphite, activated carbon, carbon fabrics, etc. for efficient reduction of liquid sulfur dioxide. The combination of high surface area, high conductivity carbon, and a large apparent electrode surface area was found to be necessary for the moderate and high rate discharges contemplated for the cell system.

The cathode is a long thin rectangular shape with an aluminum grid (collector) mounted in the center of the carbon substrate. Aluminum is used for its resistance to corrosion as a positive collector.

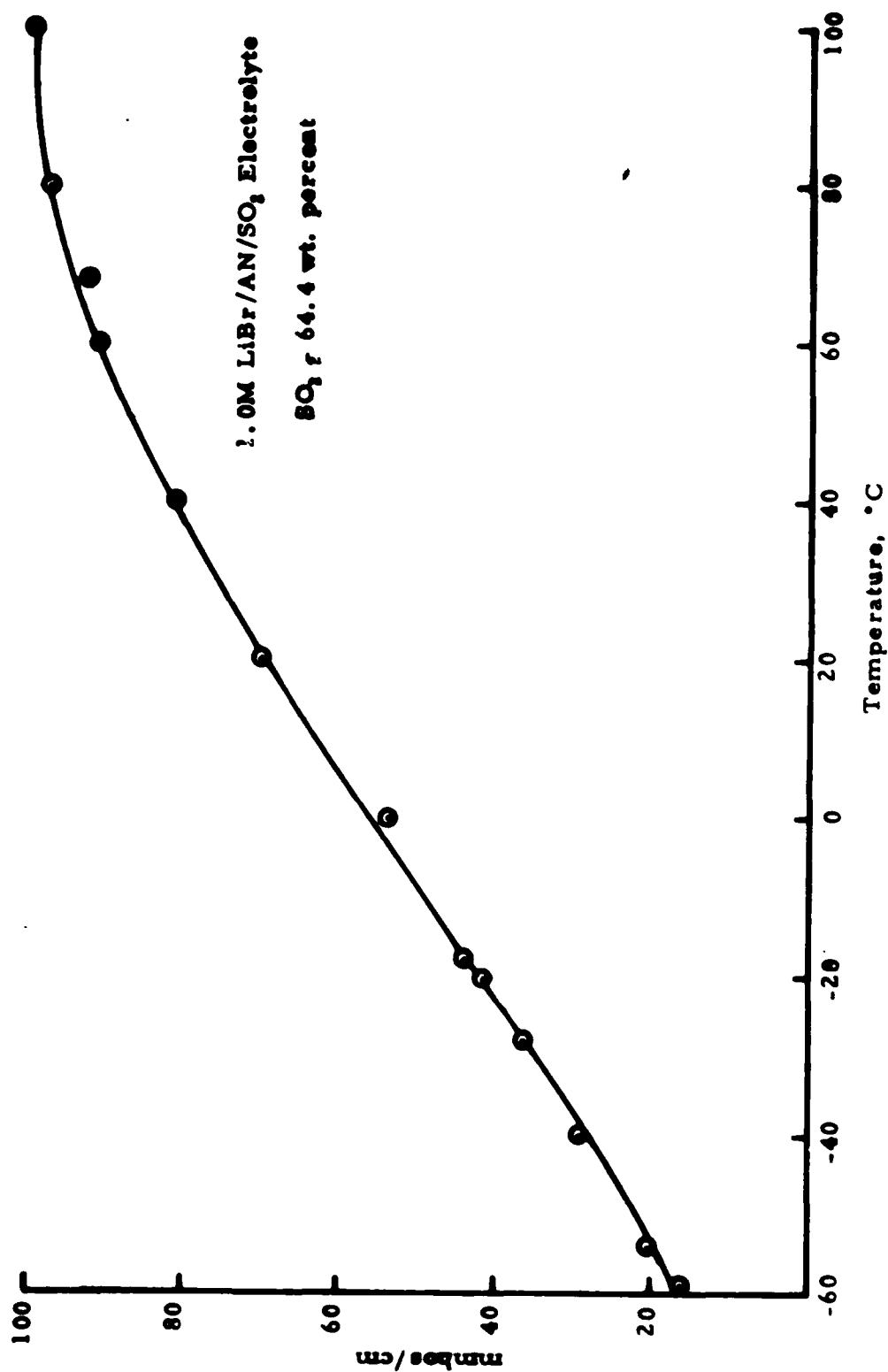
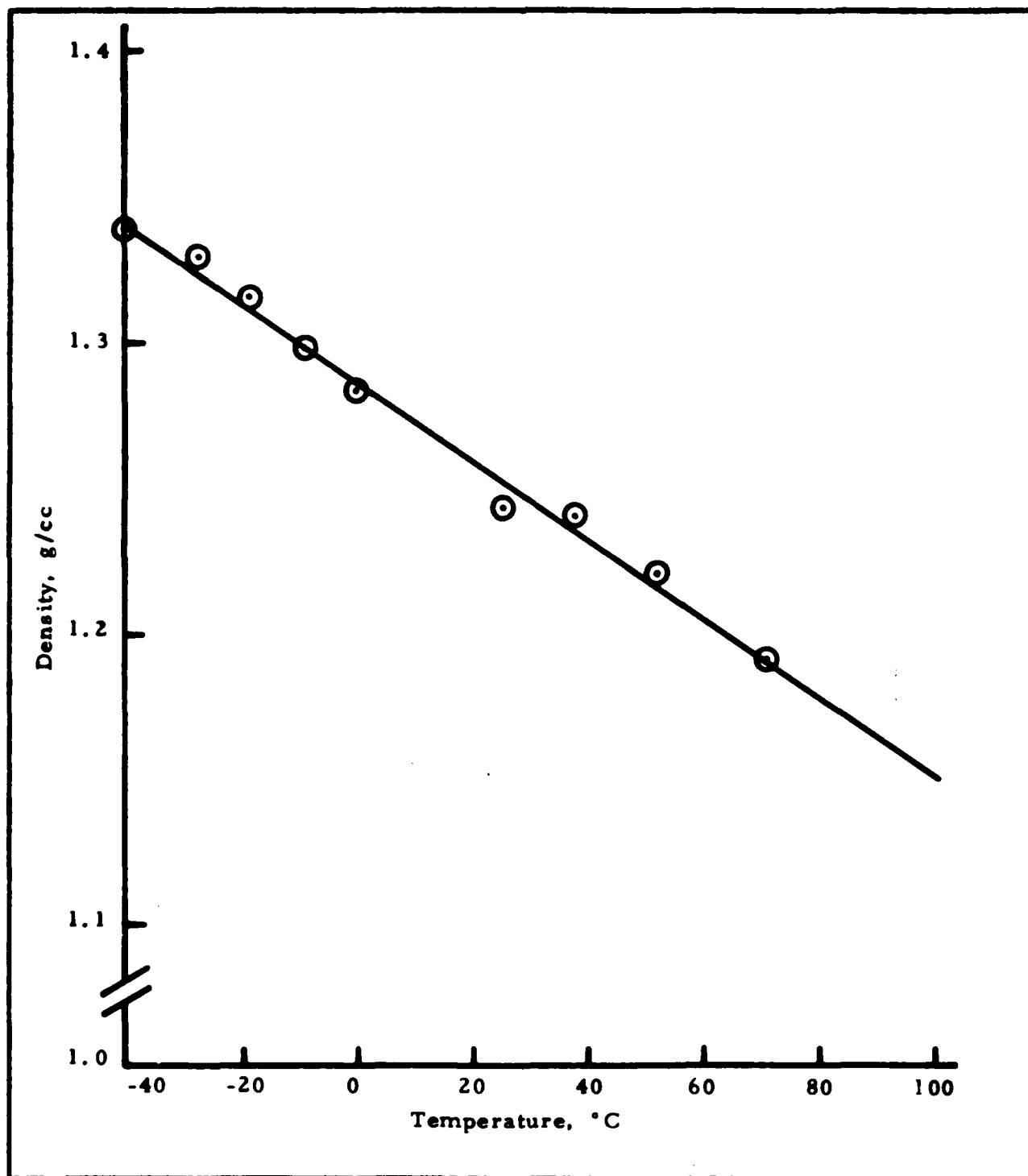


Figure V-1. Conductivity Vs. Temperature for LiBr/AN/SO₂ Electrolyte



FORM FM-100

Figure V-2. Density Vs. Temperature for LiBr/AN/SO₂ Electrolyte

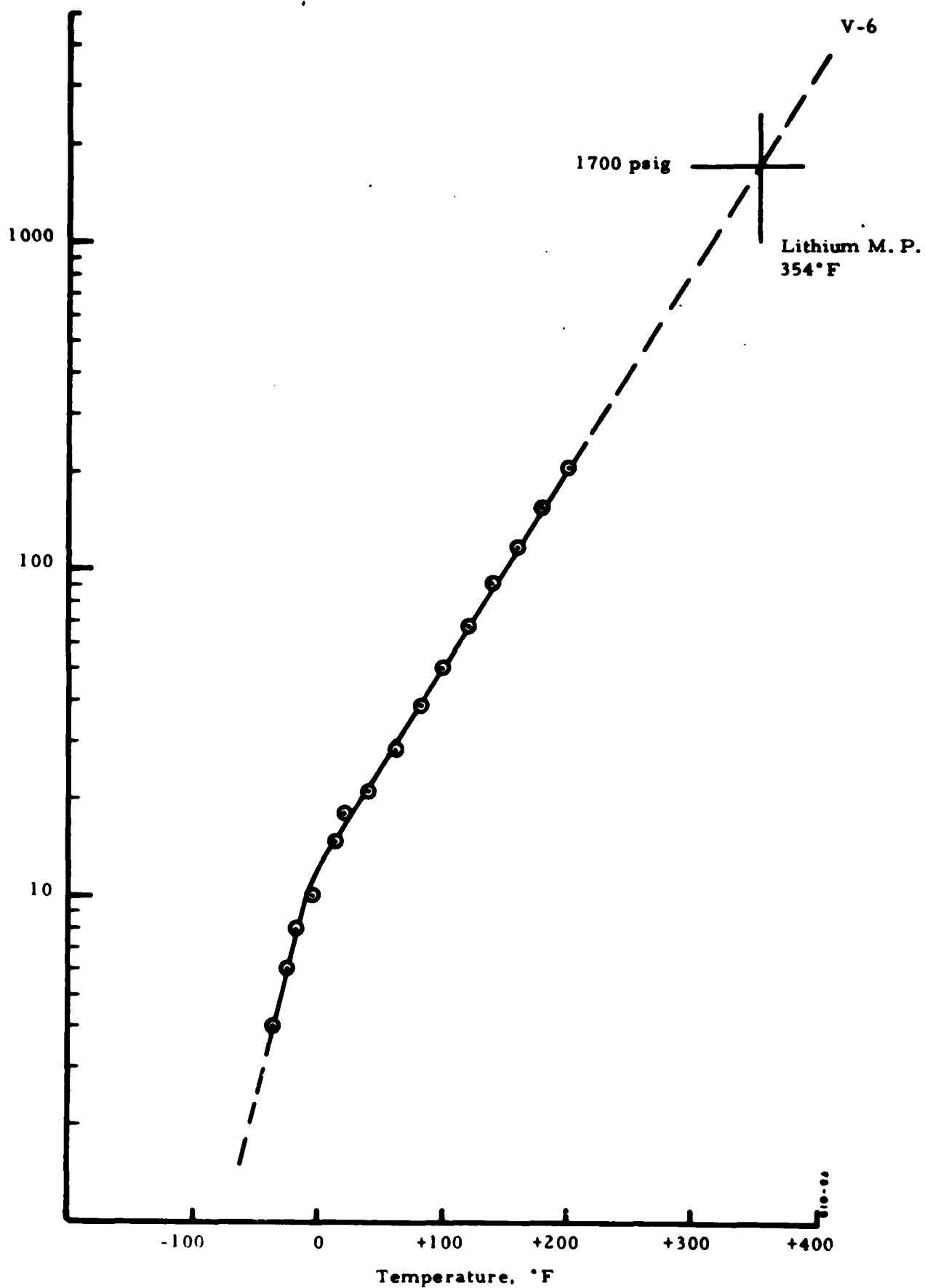


Figure V-3. Vapor Pressure Vs. Temp - LiBr/AN/SO₂ Electrolyte

B. CELL DESIGN

The Honeywell Model G2686 was developed in 1972 and 1973 under internal investment funding. It formed the baseline for the G2686-C which was ultimately used in the fabrication of the Honeywell version of the BA-5386 batteries.

1. Baseline Cell Design

The design of the baseline G2686 is shown in Figure V-4. In order to meet the objective of a low cost cell, a roll crimp elastomer seal was designed. This seal was composed of a talc-filled polypropylene molded ring which has shown a solvent leak rate of less than 1 percent under actual cell storage conditions of 6 months at +130°F. Incorporated in the terminal plate of the cell was a unique valve pin that permitted the pressurized electrolyte to enter the cell from a filling apparatus and also served as a final seal when pressed into place. Figure V-5 is a cross-sectional view of the elastomer crimp seal and pin.

Typical discharge performance of the G2686 as functions of rate and temperature are shown in Figures V-6 and V-7, respectively. From the discharge curves, the lithium/sulfur dioxide has a flat discharge profile and high energy output over a broad temperature range. Although the current density capability and single cell voltage are not as high as for the lithium/vanadium pentoxide system, this early cell design showed that they were more than adequate for many military devices.

2. G2686-C Design

The principal cell design problems related to adapting the G2686 to the BA-5386 application involved the geometry of the battery container and the development of

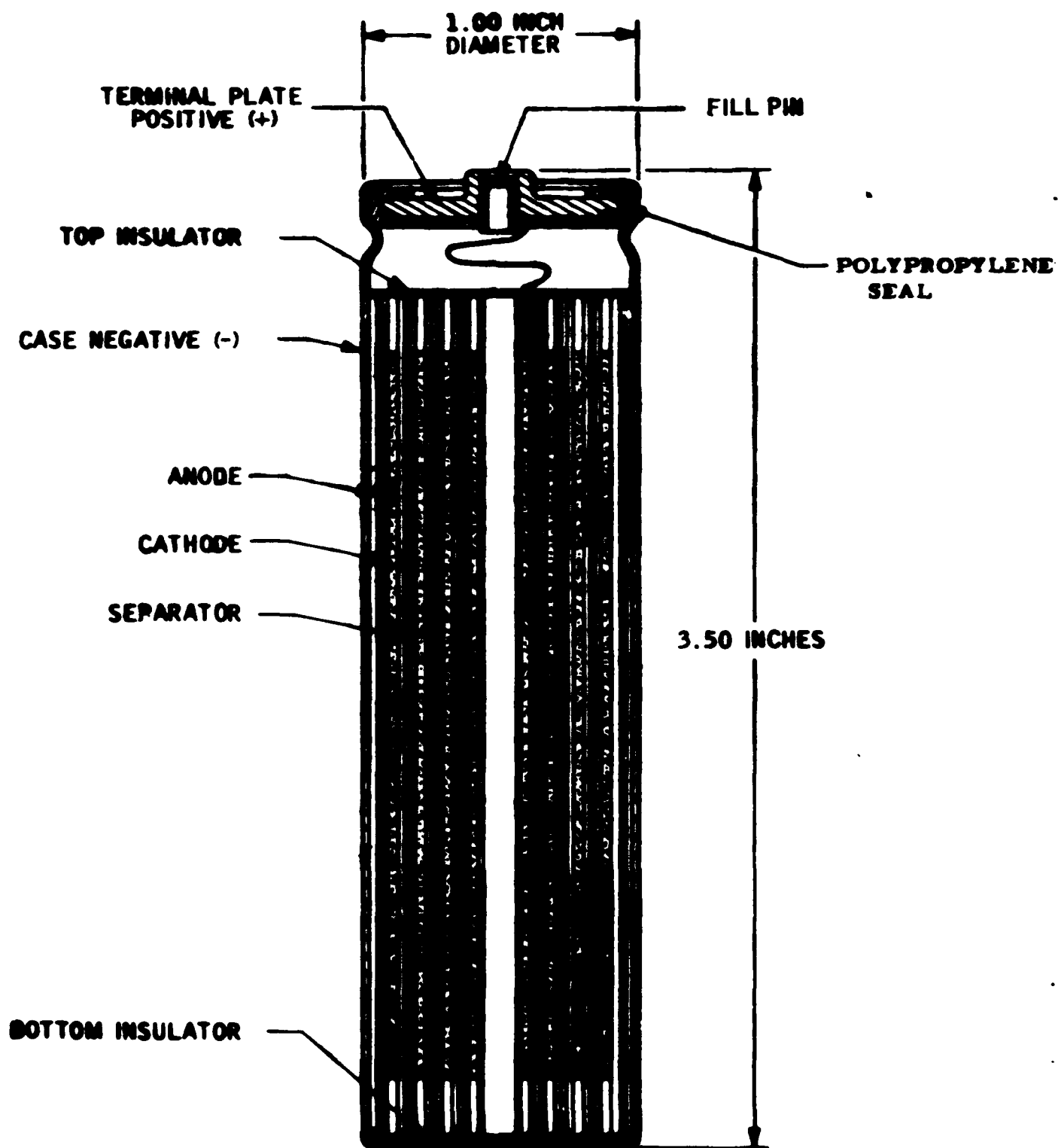


Figure V-4. Baseline Design - G2686

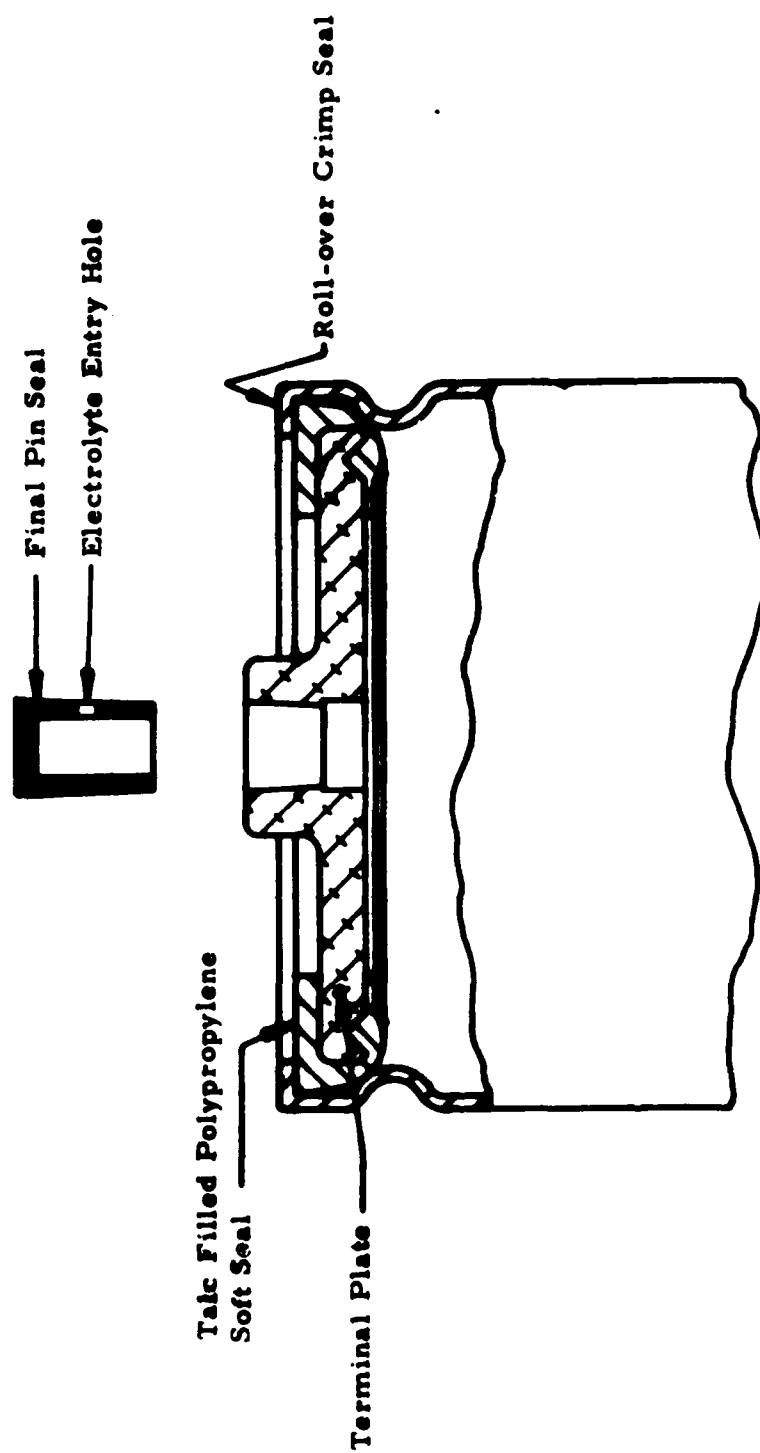


Figure V-5. Cross-Sectional View of Elastomer Crimp Seal and Pin

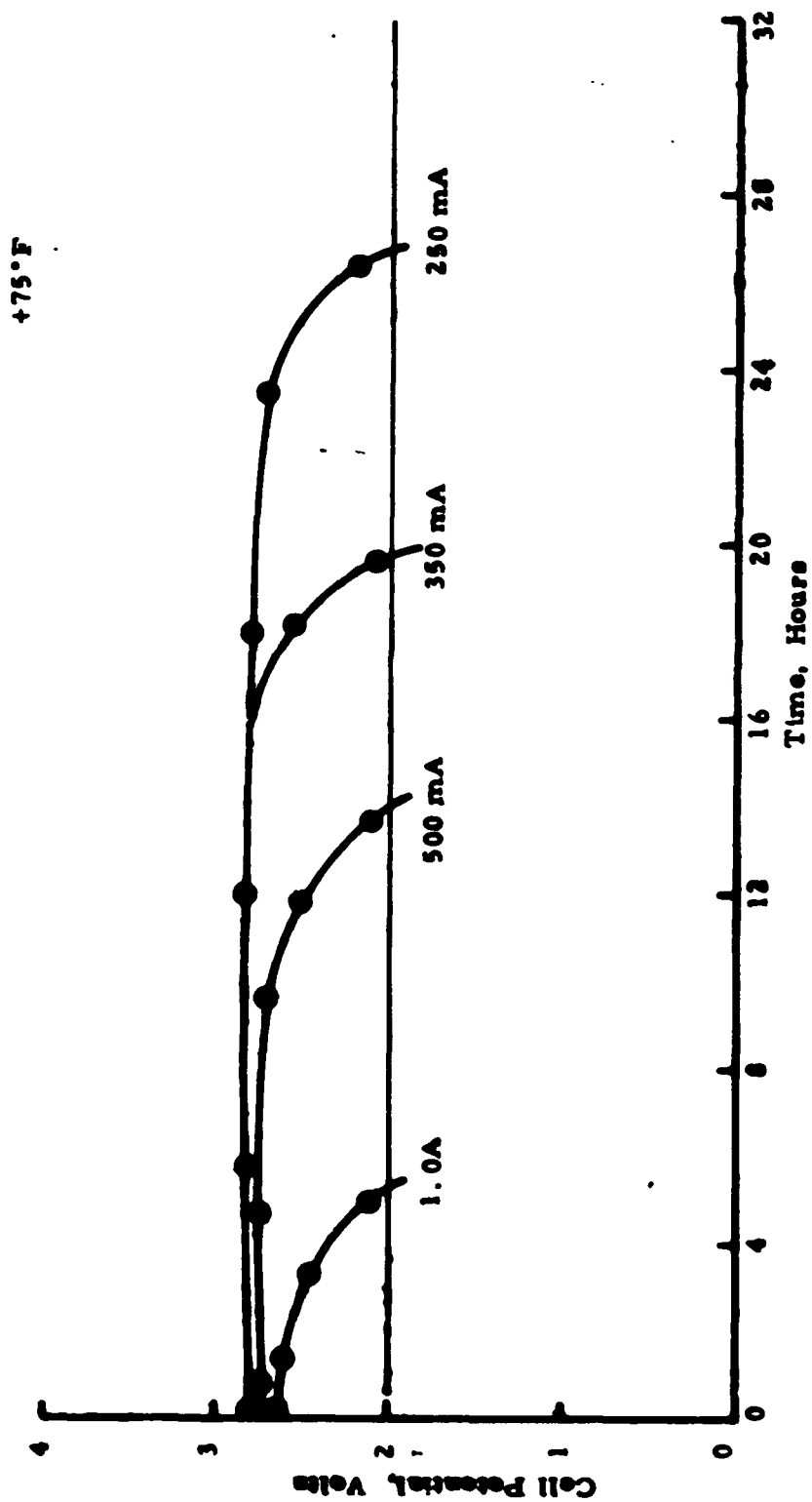


Figure V-6. Discharge Performance as a Function of Rate - G2686

Discharge Temp.	Load ohms	Theoretical Capacity	Capacity Delivered, Ahr	Eff., % ⁽¹⁾	Ave. E	Whr/lb	Whr/in. ³
-20°F	4.62	7 Ahr	4.4 Ahr	63%	2.33	58	3.6
0°F	4.62	7 Ahr	5.1 Ahr	73%	2.35	71	4.4
+75°F	5.50	7 Ahr	6.9 Ahr	99%	2.53	104	6.4
+130°F	5.50	7 Ahr	7.2 Ahr	103%	2.63	113	6.9

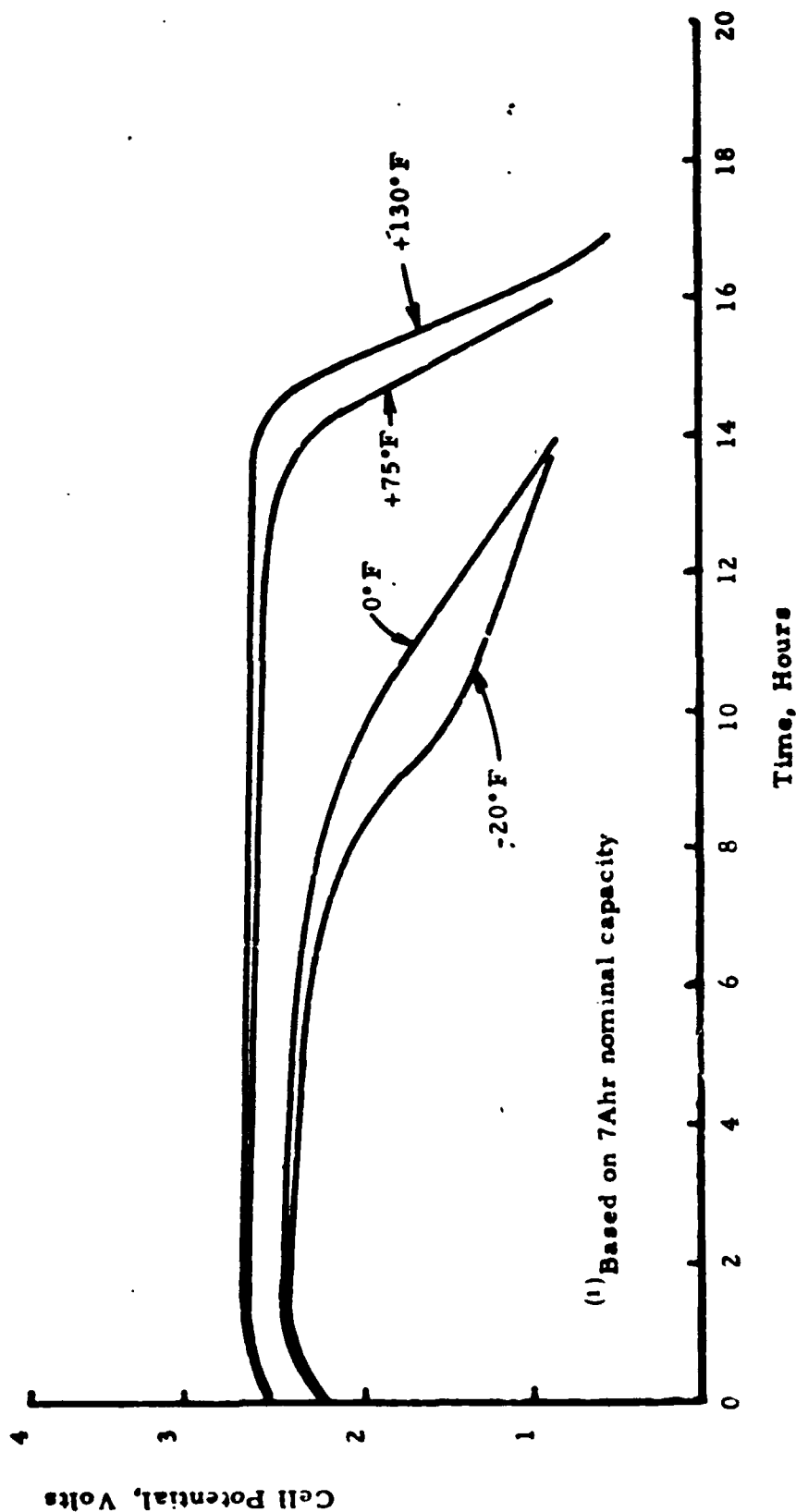


Figure V-7. Discharge Performance as a Function of Temperature for G2686 at a Rate of Approximately 0.5 Ampere

a safety device to prevent a hazardous condition in the event of cell overpressure. From the known rate and capacity data on the 2"C" length cell (approximately 7 Ahr at 500 mA), it was apparent that five series-wired stacks of three parallel cells each would be required to provide sufficient capacity to meet the BA-5386 requirement (16.4 Ahr at room temperature - pulse current approximately 2.5 amps). The required 15 cells could be accommodated within the battery configuration by placing the axis of the cell parallel to the 3.625" edge of the battery.

The maximum cell length was determined to be 3.5 inches after allowing for battery case tolerance and case material thicknesses. Although this length was identical with baseline G2686 cell, it was necessary to modify the internal configuration due to the volume change caused by the addition of the safety seal.

The cell configuration (Honeywell Model G2686-C) selected for this demonstration is detailed below. The basic construction difference between this cell and the baseline G2686 is in the seal/vent area which is shown in Figure V-8.

Cell Dimensions:

Diameter:	1.02" max.
Length:	3.5" max.
Weight (nominal):	72.5 gms

Seal: Roll crimp with Tefzel*G70-25 rupture diaphragm.

*Registered Tradename, E. I. DuPont Corp.

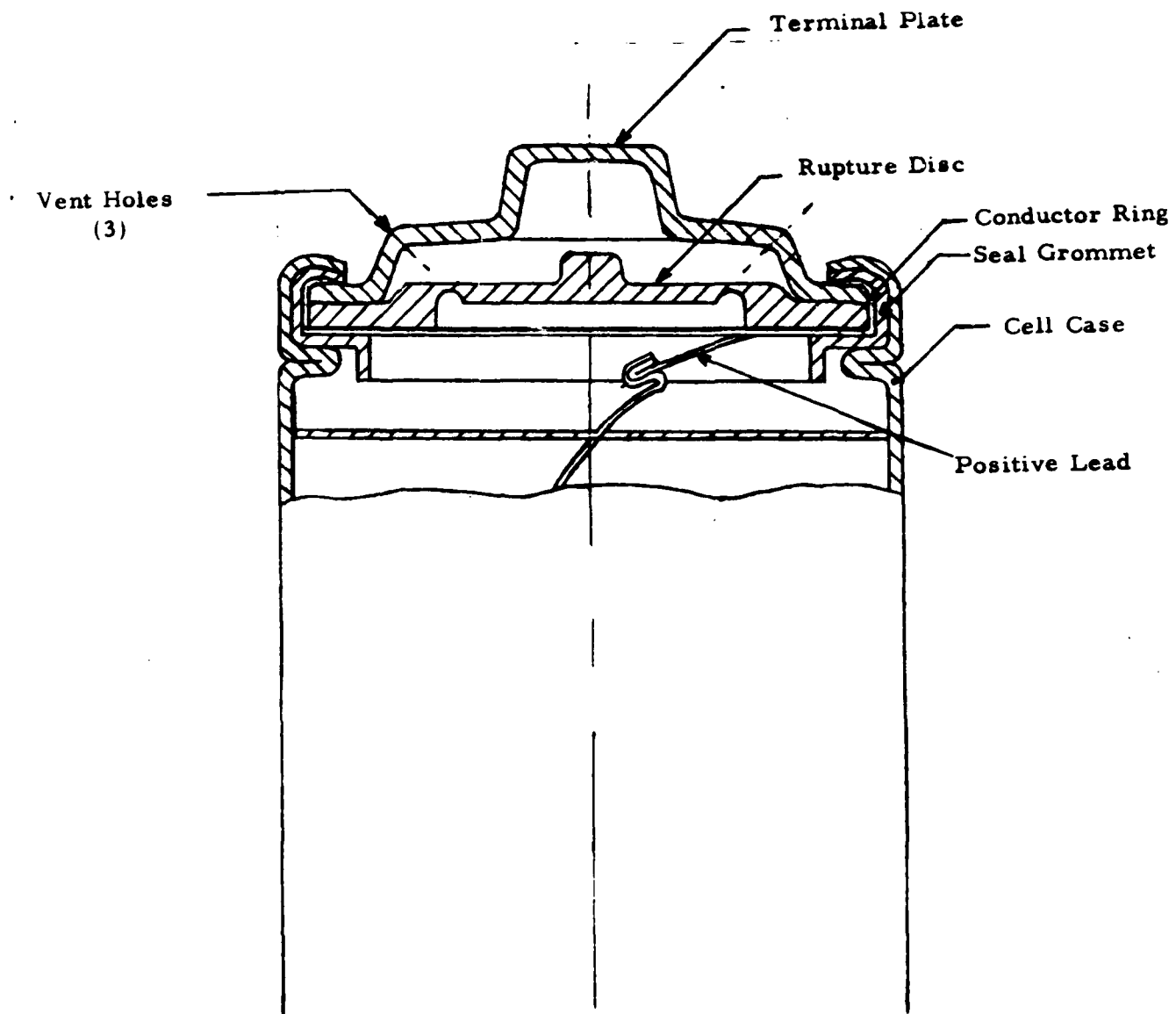


Figure V-8. Cross-Sectional View of the G2686C Closure and Vent

Anode:

Construction: Sandwich-grid between two strips of lithium
Li Thickness: Each piece $0.010 \pm .001''$
Li Length: $L_1 = 6.50 - 0.10''$
 $L_2 = 8.50 - 0.10''$
Width: $2.42 - 0.04''$
Grid: Expanded copper - 5Cu8-284
Li Volume (Nominal): 5.94 cc
Li Weight (Nominal): $5.94 \times .534 = 3.17 \text{ gms}$
Theoretical Capacity: $3.17 \text{ gms} \times 3.86 \text{ Ahr/gm} = 12.24 \text{ Ahr}$

Cathode:

Construction: Slurry molded over grid
Thickness: $0.045'' \pm 0.005''$
Length: $2.45 \pm .05''$
Grid: Expanded aluminum - 5AL8-284
Weight (total): $5.65 \pm 0.35 \text{ gms}$
Area (nominal): 114 cm^2
Opposed Area (anode-cathode, nominal): 228 cm^2

Electrolyte:

Materials: Lithium Bromide 8.0 wt %, Acetonitrile 27.6 wt %, Sulfur Dioxide 64.4 wt %
Total Weight: $28.25 \pm 1.25 \text{ gms}$
Active Weight (SO₂): 18.3 gms
Theo. Capacity: $18.3 \times 0.419 \text{ Ahr/gm} = 7.67 \text{ Ahr}$

Separator:

Type: Webril^{*} E-1488 Type M - Battery grade
Construction: Double thickness between electrodes
Width: 2.80 - 0.05"
Thickness: 0.0027

Cell Case:

Diameter: 1.0" nominal
Material: Cold rolled steel
Thickness: 0.020" nominal

3. Discussion

With three cells in parallel, the required capacity for each cell is 5.5 Ahr. Based on active SO_2 weight, an efficiency of 72% was required. Currents required at the three battery loads (pulse, transmit, receive), on the basis of three cells in parallel, are approximately 0.83 amps per cell pulse, 0.305 amps per cell transmit and 0.017 amps per cell receive. The respective current densities are:

$$830 \div 228 = 3.65 \text{ mA/cm}^2$$

$$305 \div 228 = 1.34 \text{ mA/cm}^2$$

$$17 \div 228 = 0.07 \text{ mA/cm}^2$$

The G2686-C cell used in the build of the BA-5386 batteries is approximately 0.3 inch shorter than the standard Honeywell G2686B cell which is a full "Double C" length. The shorter cell was necessary to stay within the dimensional requirements of the BA-5286 battery. The G2686-B cell provided a point of comparison for predicting the performance of the G2686-C cell and for establishing the suitability of the G2686-C for the BA-5386 application.

Standard acceptance tests on the G2686-B are run at 8 ohms (340 mA). Under these conditions, nominal capacity is 7.0 Ahr.

This cell has a theoretical electrolyte capacity of 7.96 ampere-hours. Opposed electrode area is 264 cm^2 resulting in a nominal current density of 1.29 mA/cm^2 which approximates the transmit load current density. At this current density, efficiency of cathode active material utilization is approximately 88% - well above the required 72% for the battery requirement.

C. SAFETY FEATURE DESIGN

1. Requirements

The design requirements for cell safety are as follows:

- 1) Reliable venting at over-pressure conditions with adequate safety factor to protect cell structure.
- 2) Reliable seal at under-pressure with adequate safety factor to prevent failure at any conditions within the cell design envelope of operating conditions.
- 3) Can withstand thermal cycle, thermal shock, mechanical shock and vibration.
- 4) Relatively inexpensive and can be mass produced.
- 5) Does not create a hazard when it functions.

2. Approach

The approach to this problem was to design a rupture disc to be incorporated into the cell seal (see Figure V-8). Due to the small area available, it was felt that a plastic material having relatively brittle properties would be most suitable. Poly-sulfone was selected initially, but it was found to be subject to stress cracking under electrolyte conditions. A search for a more suitable material resulted in the selection of a glass filled teflon type material (Tefzel G70-25) manufactured by DuPont. The glass filling allows the rupture disc to break cleanly at room temperature conditions and still retain most (approximately 70%) of its strength at +160°F.

The maximum area for the break-out disc in the center of the seal is approximately 0.5 inch in diameter. The required material thickness for a room temperature breaking strength of approximately 500 psi was found by making several experimental moldings. The proper thickness was found to be 0.031 inch for a break-out pressure of 550 psi. The bulk of the disc is approximately 0.050 inch thick.

To conduct current around the disc, a thin aluminum ring was used (conductor ring). This part is a shallow cup with a tab at the bottom for positive lead attachment. A cold rolled steel (plated) top cap 0.030" thick is nested in the conductor ring above the rupture disc. Contact is made between the conductor ring and the top cap when the cell case is crimped to seal the cell. Initial testing of this seal design indicated excessive electrolyte loss at high temperature (+160°F). The loss was believed to be partially due to diffusion of SO₂ through the Tefzel disc and partially due to leakage around the disc and through the fit between the Tefzel disc and the top cap. The seal was modified by cementing a thin (0.005") disc of aluminum foil to the bottom (inside of the cell) of the rupture disc and cementing the top cap to the top of the Tefzel disc. This made the parts a single assembly to be fitted inside the conductor ring. Additional sealant was applied to the seal area outside of the cell.

3. Leakage

Cell leakage with this modified design is approximately 1 mg/day at room temperature and 30 mg/day at +160°F. The seal withstands thermal shock well;

however, the high leakage rate, and the fact that the Tefzel disc is at best difficult to mold, has led to an effort to provide an improved seal. A recent design, presently under test, replaces the Tefzel disc with a thin aluminum diaphragm. Preliminary tests (30 days) indicate a leakage rate under 2 mg/day at +160°F.

D. FABRICATION METHODS

1. Cells

The Model G2686C cells used for this study were produced using pilot assembly facilities located at the Honeywell Power Sources Center, Horsham, Pa. The G2686C cell is a reduced length modification of the standard "CC" size design. The process described represents the standard size. The only modification of the process used for this build was the trimming of can length, anode, cathode, and separator width.

a. Cathode -

1) Cathode Grid - Cathode grids are die cut from expanded aluminum grid stock manufactured with an interspersed solid (unexpanded area). The die cut trims the edges and forms a tab (lead) that is formed by double folding the prepared part of the unexpanded metal with a jig. This eliminates the usual weld required to place a lead on the cathode grid.

2) Cathode Slurry - Cathode slurry is prepared with deionized water in a 30 gallon mix tank. Water is added by volume and the remaining ingredients by weight. When the slurry mix is complete, it is drawn off in jars to provide premeasured quantities for casting.

3) **Casting** - Cathodes are formed using a partitioned Deckel box. Each repetition of the operation provides four cathodes. Premeasured portions of slurry are charged to the box and the water removed by vacuum. A grid is placed in each compartment of the box and a second portion of slurry is added followed by water removal.

4) **Cathode Finishing** - Following cathode casting, the green cathodes are gang pressed between blotters to remove free water, sintered in large batches in a Hotpack furnace and calendared to thickness.

b. Anode -

1) **Anode grid** - Anode grid is die cut from expanded copper stock having an interspersed solid. A doubled stainless steel lead is jig welded to the unexpanded portion of the anode grid.

2) **Anode** - Lithium stock is jig cut to length.

3) **Anode assembly** - The anode assembly is built in a pressing jig that locates the grid lead and the two pieces of lithium. The assembly is cold pressed in a Carver press and removed from the jig. All operations involving lithium are carried out in a dry atmosphere (dew point -10°F or lower).

c. Separator - The separator is assembled in one operation with an assembly fixture. Four pieces of E-1488 webriil are cut from a roll and collated for alignment at edges and one end. After alignment, the aligned end is fused together with heat sealing apparatus.

d. Element - The jelly roll element is made using a wrapping jig with a split pin. The sealed end of the separator is located and held in the split pin with alignment

maintained by the fixture. Cathode and anode are manually collated into the separator assembly to provide two layers of separator material between anode and cathode. The collated assembly is manually wrapped under controlled tension. After wrapping, the outer layer of separator is heat sealed to the layer below it and the wrap assembly is removed from the split pin.

e. Open Cell Assembly - Open cell assembly starts with a degreased cold rolled steel cell case. A polypropylene disc is inserted into the bottom of the cell as a bottom insulator. The wrapped element is then inserted into the case and the negative lead welded to the side of the case. A polypropylene top insulator (disc with central slot) is inserted above the element with the positive lead projecting through the insulator slot.

f. Forming Cell Case - A support flange is formed in the top of the cell case in two steps. The first step involves spinning an indent in the wall of the cell case with a specially tooled lathe. The flange is then formed by collapsing the indent using special tooling involving a nest to support the cell case and a punch to press the top of the cell case down. The punch is designed to maintain a close tolerance between the top of the formed flange and the top edge of the cell case.

g. Seal Grommet and Conductor Ring - A seal grommet is placed in the top of the cell bottoming on the flange formed in Section f above. It serves to insulate the positive terminal of the cell from the negative cell case as well as a compression member to maintain the cell closure. An aluminum conductor ring is nested inside of the seal grommet. The function of this part is to carry cell current from the positive wrap lead (to which it is welded) around the plastic rupture disc to make contact with the plated cold rolled steel top cap that serves as the positive terminal.

h. Seal and Terminal Assembly - The seal and terminal assembly consists of three parts bonded together with a urethane resin. The most critical part of this assembly is the rupture disc. It is an injection molded part made of "Tefzel" G70-25 glass filled fluorocarbon manufactured by DuPont. The rupture disc serves as the safety vent for the cell. A thin (0.0005" thick) aluminum foil vapor barrier is cemented to the bottom of the disc and the top cap (cold rolled steel positive terminal with vent holes) is cemented to the top of the rupture disc. Cementing is done with a urethane resin.

i. Cell Filling and Sealing - The seal design required a method of filling an open cell with the high vapor pressure electrolyte followed by insertion of the seal assembly and crimping the cell case over the top terminal. A method was developed to accomplish this task involving a specially designed filling machine using electrolyte chilled below the boiling point and chilled cell assemblies. After the cell is filled and crimped, it is weigh checked and checked for open circuit voltage to assure the cell is not shorted. After warming to room temperature, an external sealant was applied to the terminal end as additional sealant for the roll crimp closure.

j. Finishing Operations - After filling the cells were allowed to stand for one week at open circuit. Cells are then screened for weight, leakage (visual), open circuit and closed circuit voltage. The screened cells are lot sampled and tested for capacity at 8 ohms load and room temperature.

k. Electrolyte Manufacture - Electrolyte is produced in batches using a stainless steel pressure vessel. The vessel and lithium bromide (LiBr) are vacuum oven dried individually. The dry LiBr is added (by weight) to the vessel and the LiBr again dried in the mixing vessel under heat and vacuum. At this point, the vessel is

sealed and the two liquid ingredients (acetonitrile and sulfur dioxide) are added using sealed piping systems. All ingredients are added by weight. The batch is then mixed and sampled for density and water content.

2. Batteries

Battery assembly was accomplished as one batch (a total of 66 batteries) using completely manual methods. Cells were first soldered in parallel (3 cells) with a diode across each stack. The parallel stack assemblies were then put in an inner paperboard box with paperboard insulating partitions between each group. The parallel stacks were then wired in series with a tap for the 3-volt section. Fuses (each positive lead) and a connector were located at one end of the inner box.

The above steps completed the basic battery assembly. The cells were next potted with 40-45 grams of 12 lb/cu ft urethane foam and the cell terminals protected with a sheet of Scottfoam. The potted assembly was finally placed inside the outer water-resistant paperboard box and sealed.

3. Cell and Battery Inspection Methods

Quality Control inspection of batteries and cells is maintained for the monitoring of process yield/capability versus design intent. The Quality Control System to accomplish this is governed by MIL-Q-9858 and includes the following.

- Piece part, subassembly, and final assembly characteristics classified as critical, major and minor.
- Piece part, subassemblies, and final assembly inspected on a lotting basis and/or process control criteria. Total of 30 inspection stations.

- Sample plans utilized are from MIL-STD-105 and take into consideration the classification of characteristics, the process technique and the process capability.
- Where non-conformance and/or deviation from established standards/specification are detected, the need for corrective action is determined.
- Prints and specifications define processes, components and materials.
- Inspection and process instructions are written and revised per experience and customer requirements.
- Inspection equipment, process equipment, and test equipment maintained under calibration.
- Non-conforming material/product does not continue through processing until Material Review Board disposition is determined. Material review Board consists of Production and Quality Engineering; Design Engineering included as required.
- Completed assemblies/subassemblies are identified by lot numbers and traceable to inspection results.
- Vendors selected on the basis of capability. Purchase orders define make criteria for acceptance.
- Final inspection for corrosion, evidence of overfill, weight check, CCV, OCV, and visual security of seal after a minimum of five (5) days stand.
- Raw materials purchased with certified test data and periodic analysis.

E. CELL CAPACITY TESTS

A small lot of cells (Model G2686-C, BA-5386 cell) was built prior to the seal improvement work and placed on +160°F stand. Two groups of three cells each were tested at -40°F and at -20°F at intervals of one week, two weeks, three weeks and at 30 days. Cells were tested under loads equivalent to BA-5386 condition B. Curves showing the average of three cells under each test condition follow (Figures V-9 through V-18).

Leakage of these cells became a problem after the second week and the principal cause of the severe capacity and voltage reduction noted in the third week tests. The cells were tested on their sides and electrolyte leakage caused shorting at the cell closure. Leakage was significantly greater at -20°F than at -40°F. To reduce the effects of cell leakage, the test at 30 days was run with the cells vertical.

To check the efficiency and performance of the modified seal design, a group of six cells (Model G2686-B2) was removed from the +160°F seal test group at 20 days and tested under BA-5386 condition B load at -20°F and -40°F. Curves of the average of each group of three are shown in Figures V-19 and 20. One of the three cells tested at -20°F exhibited unusually low load voltage. The low voltage cell was stable and was maintained on test. Its values are included in the average. These cells gave approximately 150% of the required BA-5386 capacity. The G2686-B2 cell has a nominal capacity approximately seven percent greater than the Model G2686-C used for the BA-5386 (due to its greater length, 3.75 inches vs. 3.5 inches).

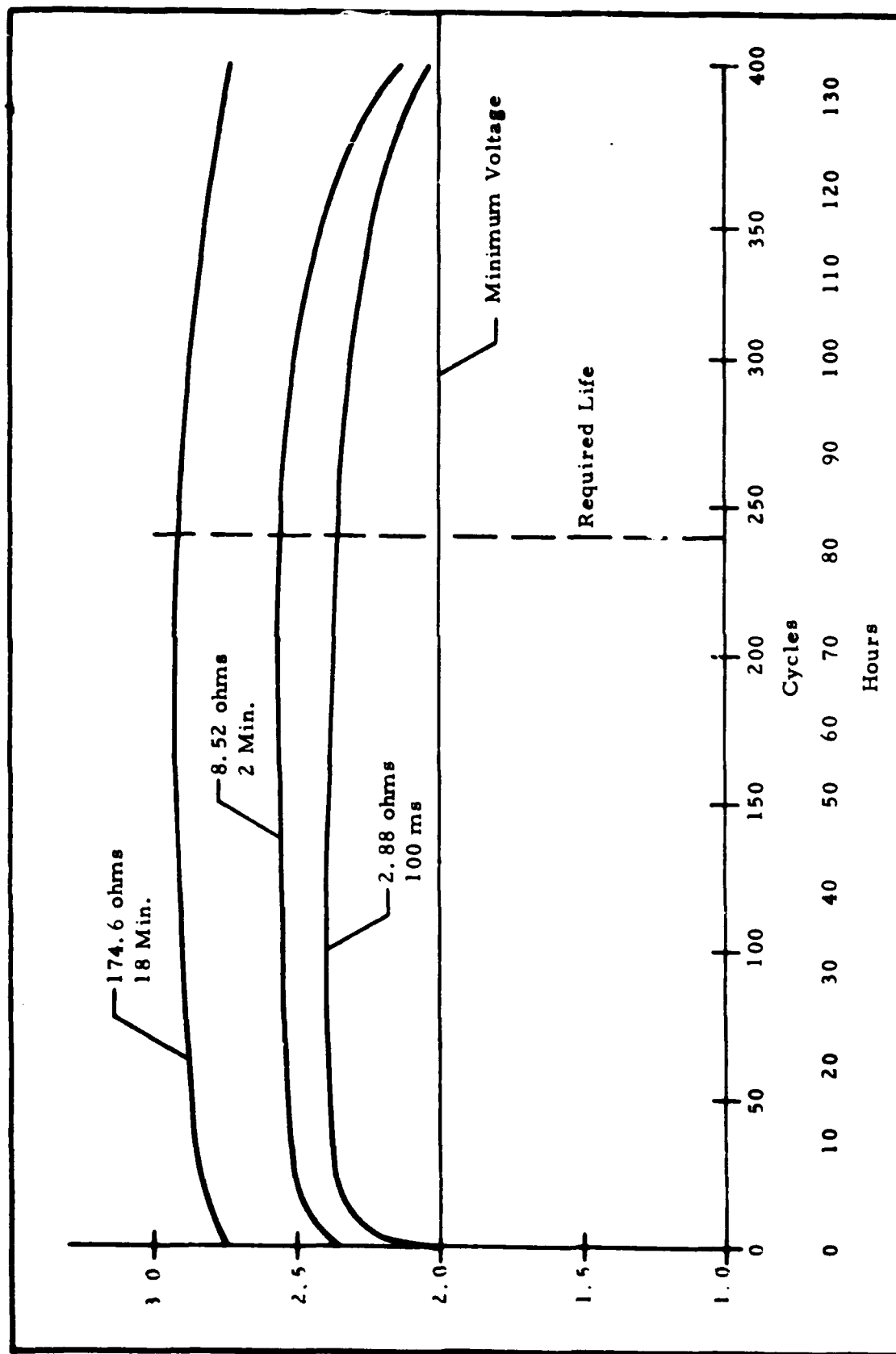


Figure V-9. Discharge of G2686C Cells, BA-5386 Loads, -20°F, No Storage

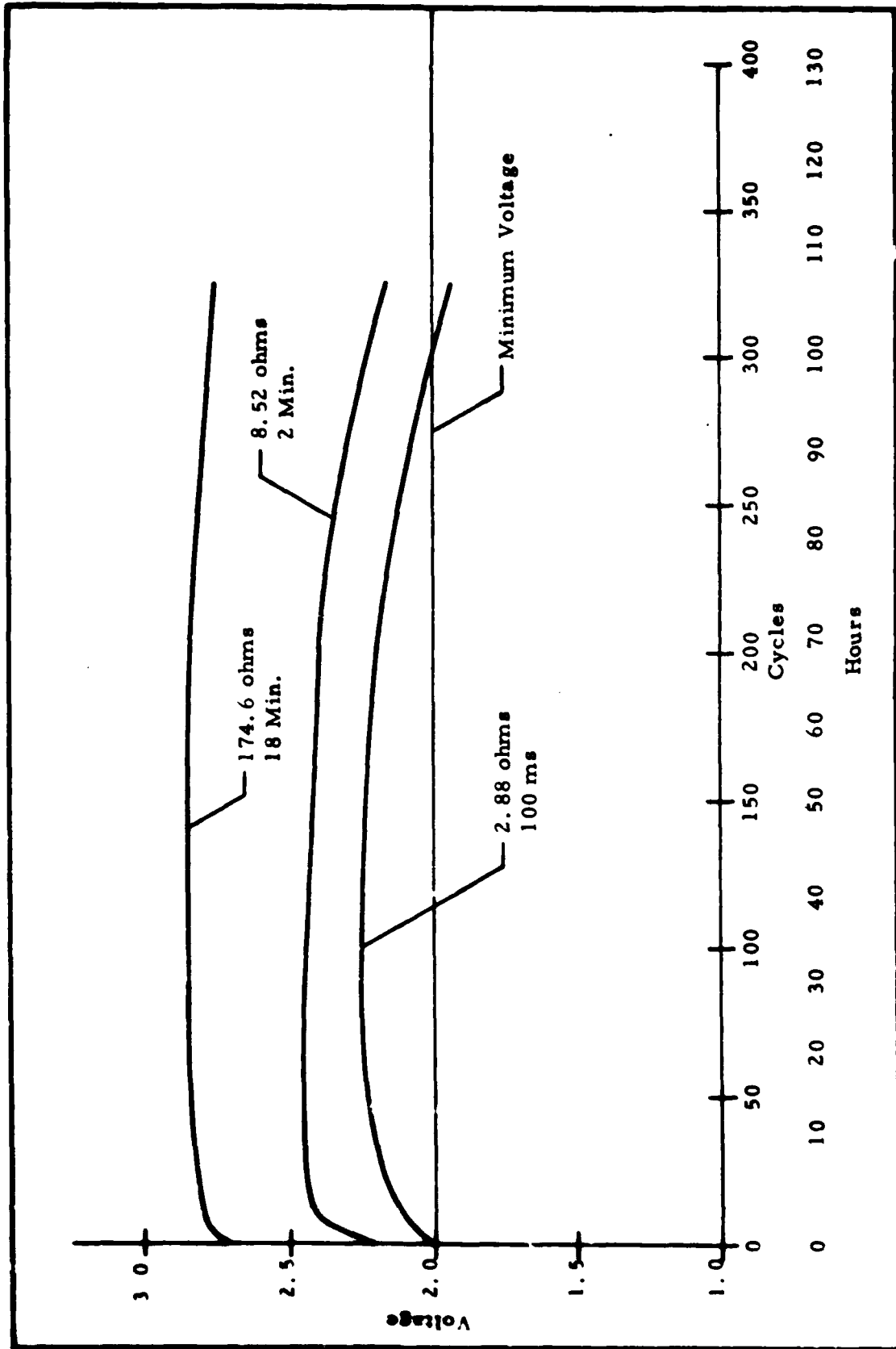
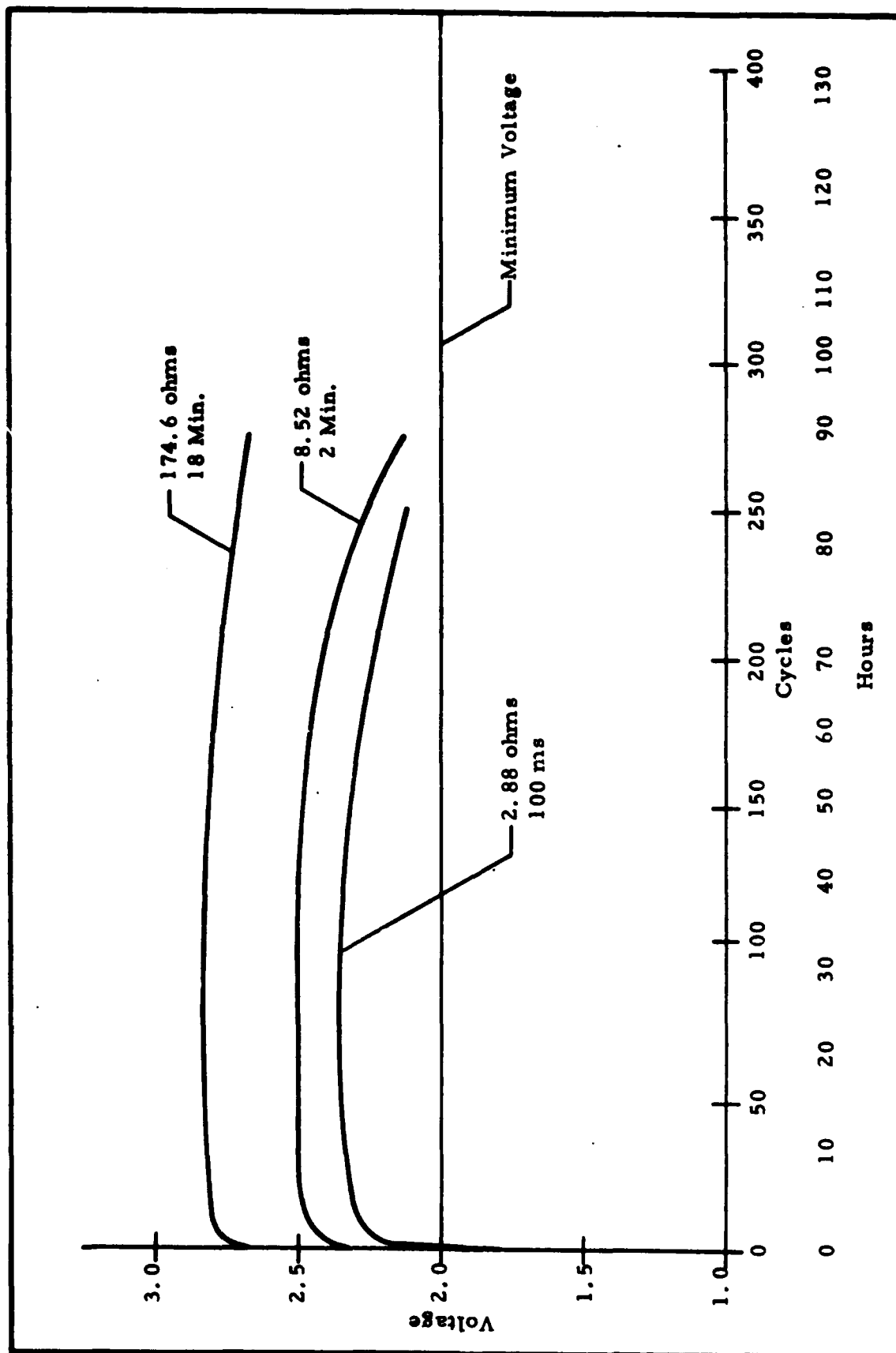


Figure V-10. Discharge of G2686C Cells, BA-5386 Loads, -20°F, After 7 Days Storage at +165°F



78-010

Figure V-11. Discharge of G2686C Cells, BA-5386 Loads, -20°F.
After 14 Days Storage at +165°F

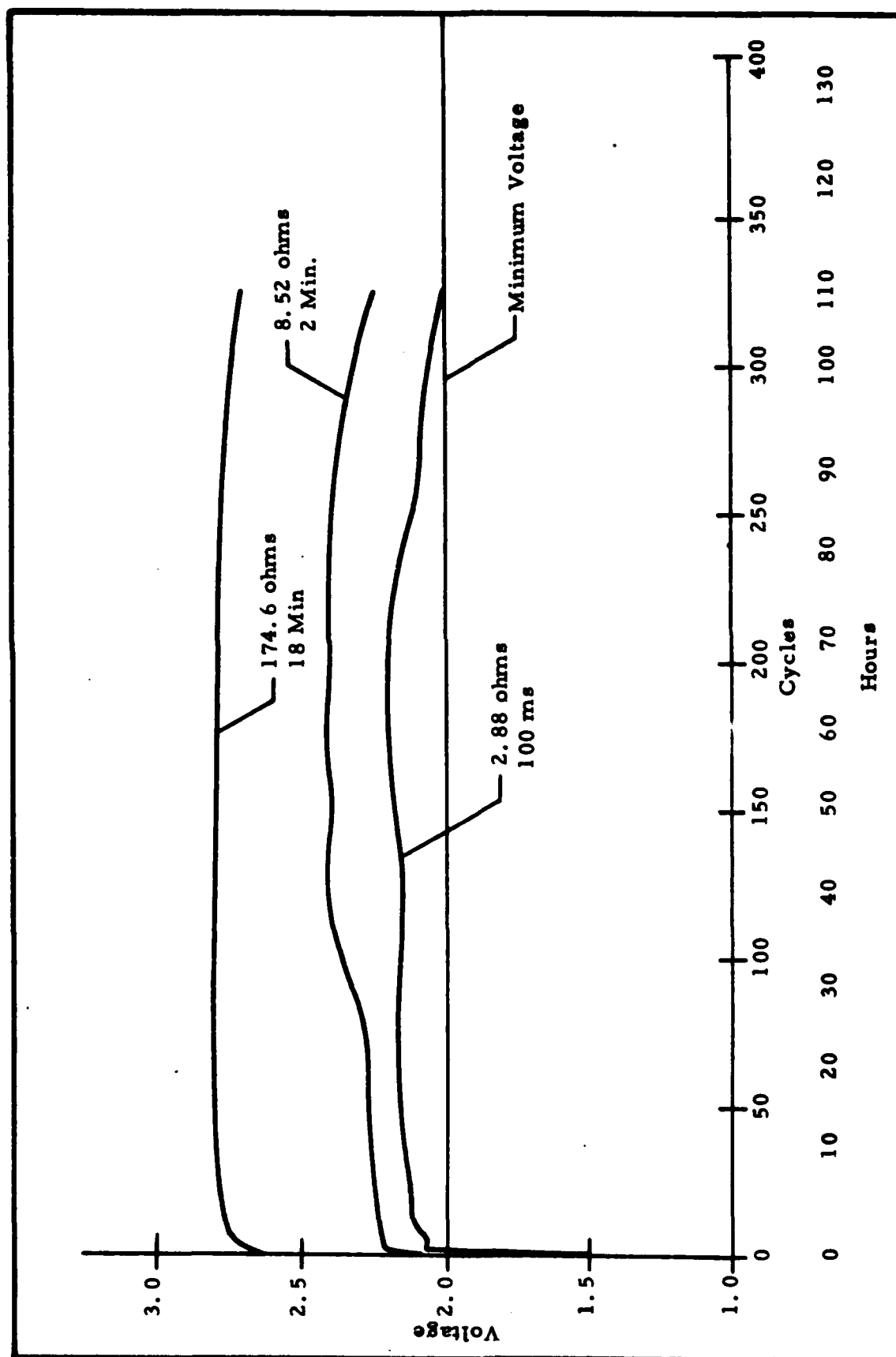


Figure V-12. Discharge of G2686C Cells, BA-5386 Loads, -20°F.
After 21 Days Storage at +165°F

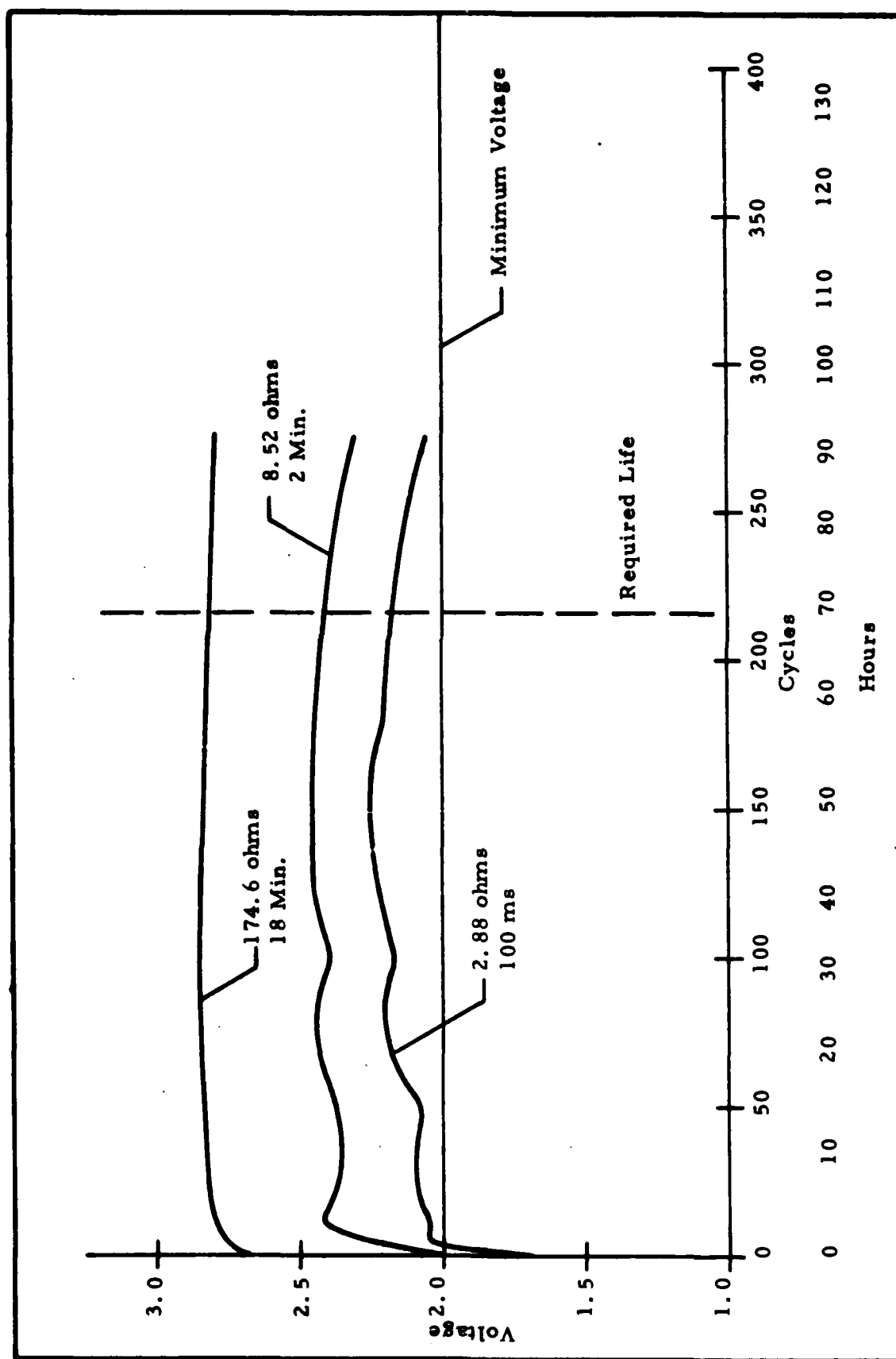


Figure V-13. Discharge of G2686C Cells, BA-5386 Loads, -20°F, After 30 Days Storage at +165°F

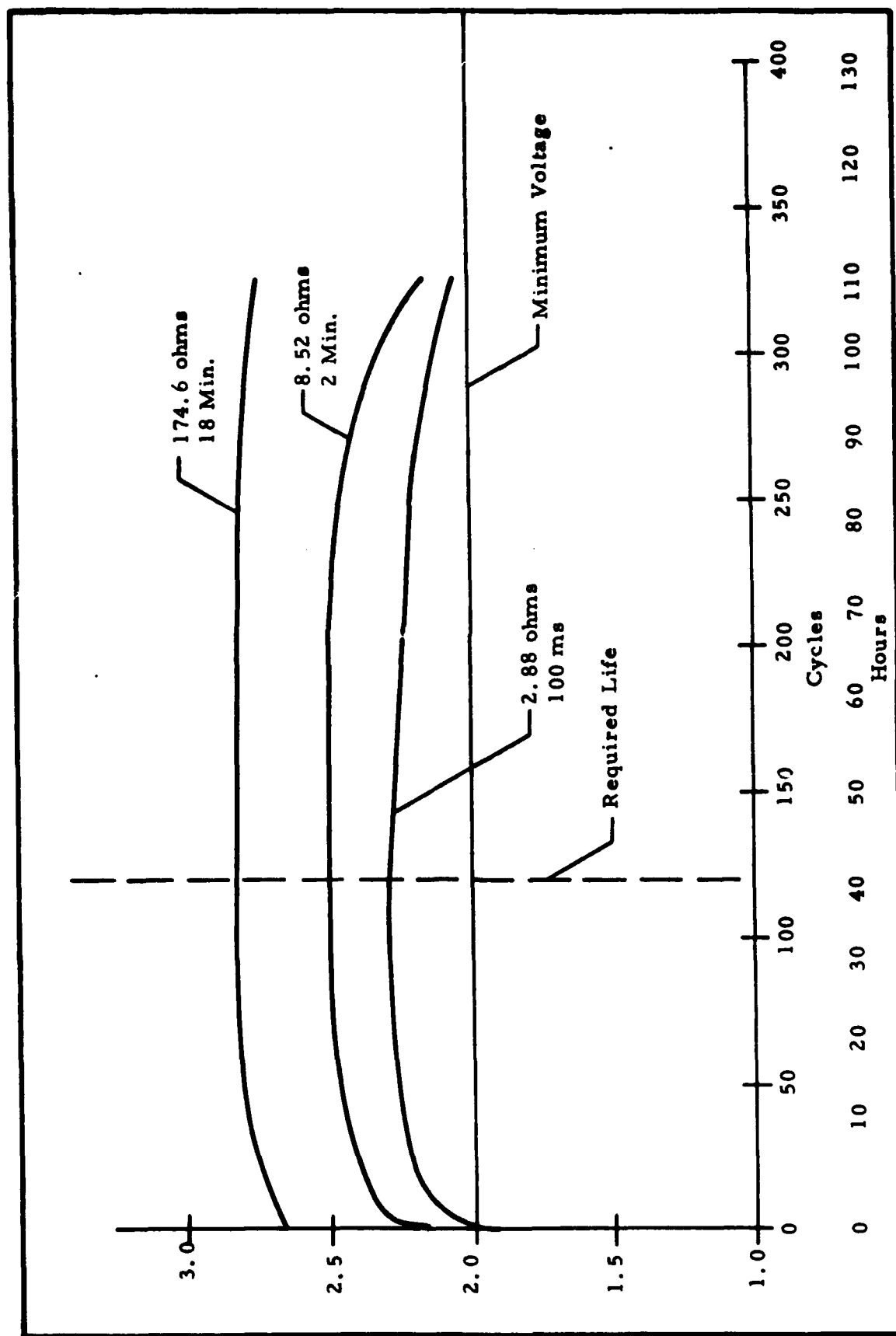


Figure V-14. Discharge of G2686C Cells, BA-5386 Loads, -40°F, No Storage

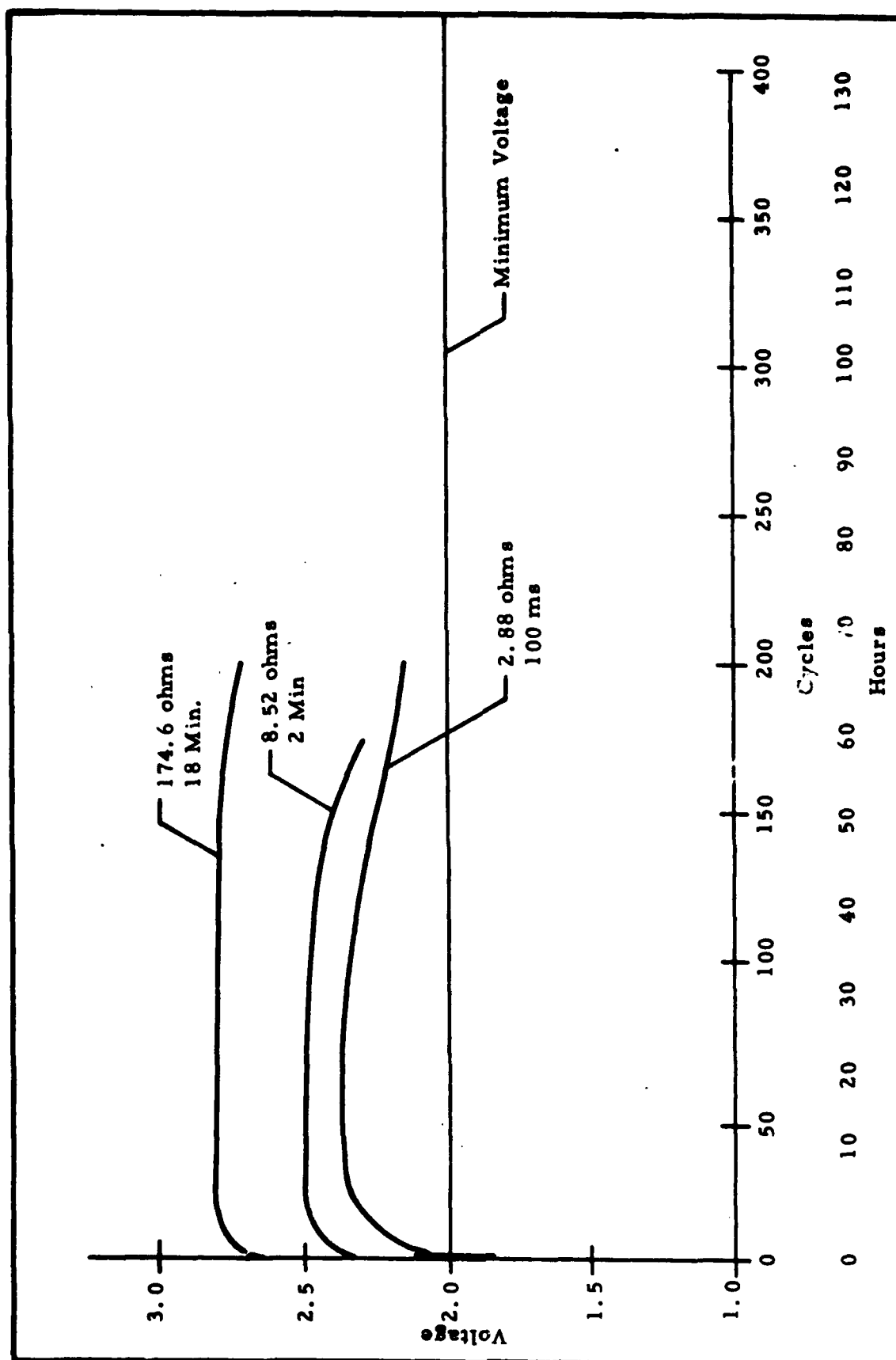
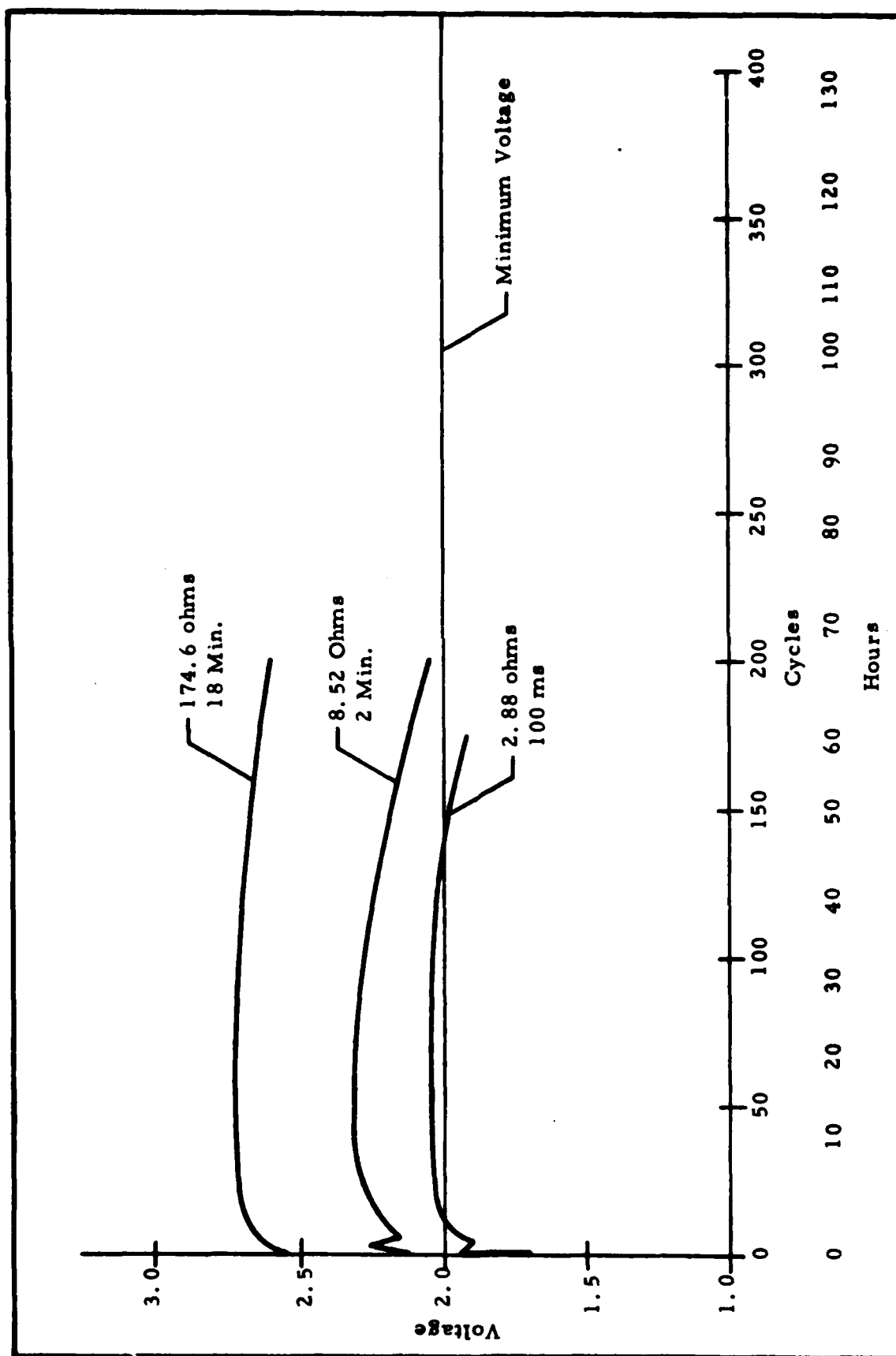


Figure V-15. Discharge of G2686C Cells, BA-5386 Loads, -40°F, After 7 Days Storage at +165°F



74-000

Figure V-16. Discharge of G2686C Cells, BA-5386 Loads, -40°F
After 14 Days Storage at +165°F

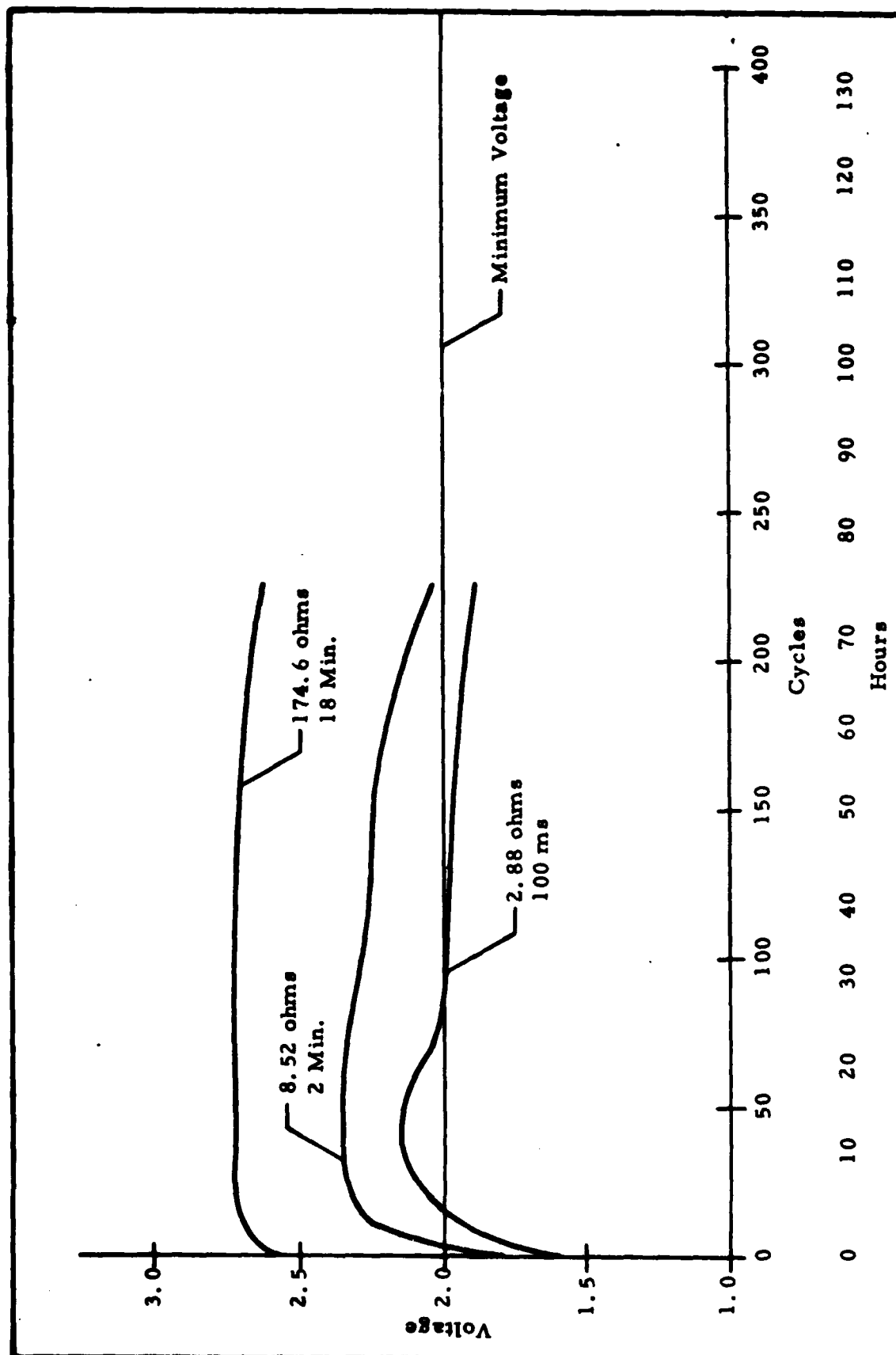


Figure V-17. Discharge of G2686C Cells, BA-5386 Loads, -40°F, After 21 Days Storage at +165°F

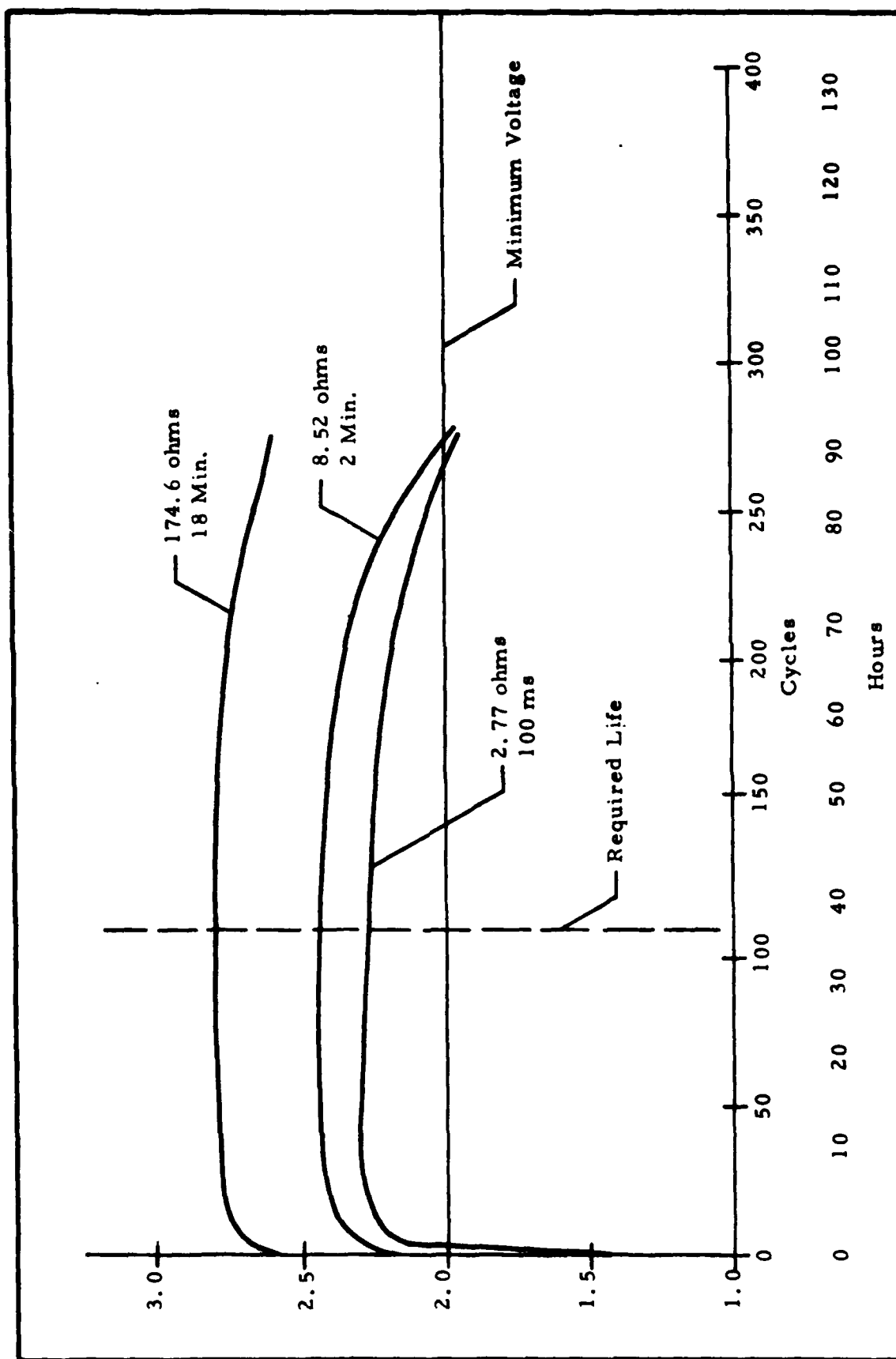


Figure V-18. Discharge of G2686 Cells, BA-5386 Loads, -40°F
After 30 Days Storage at +165°F

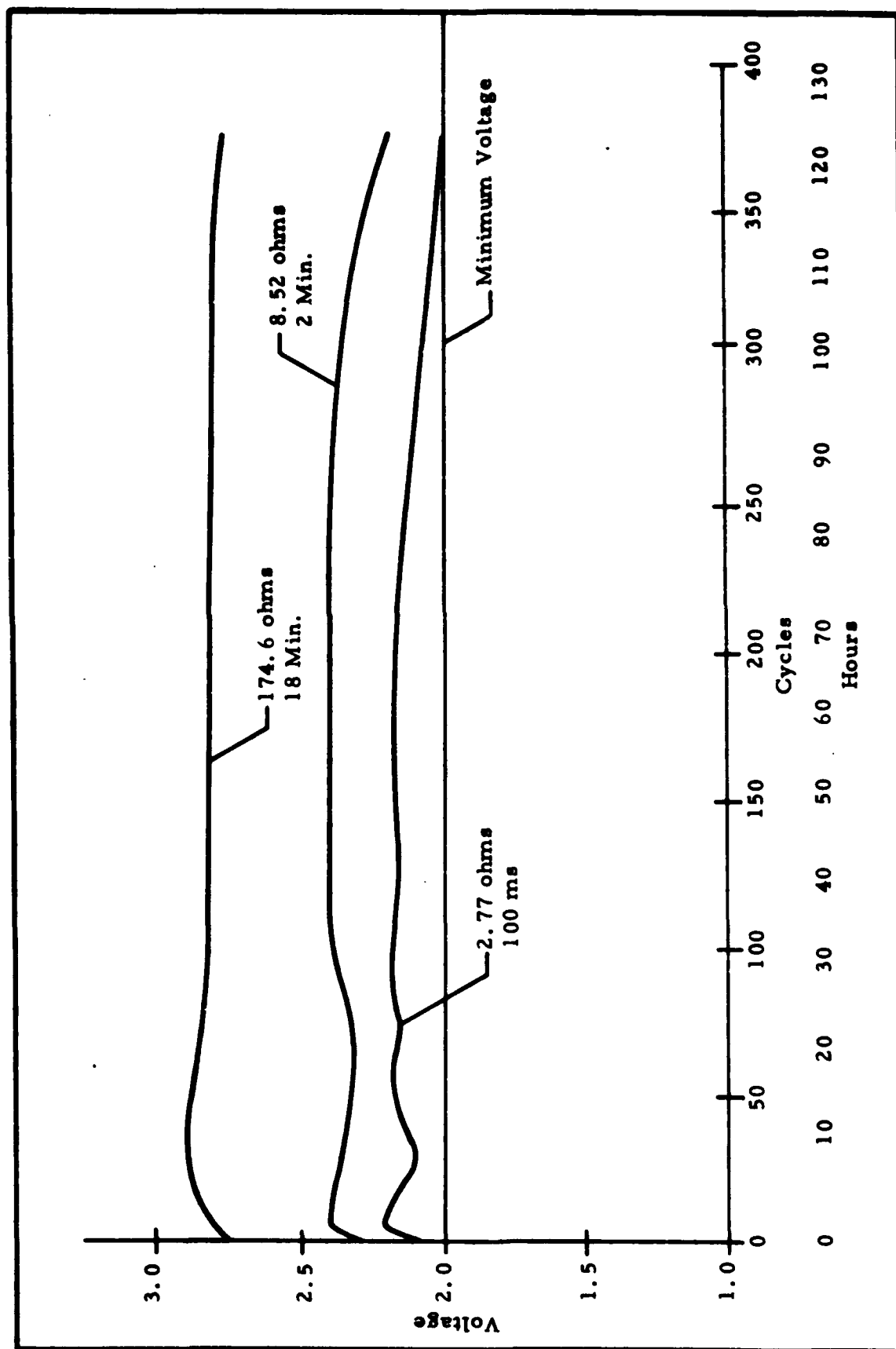
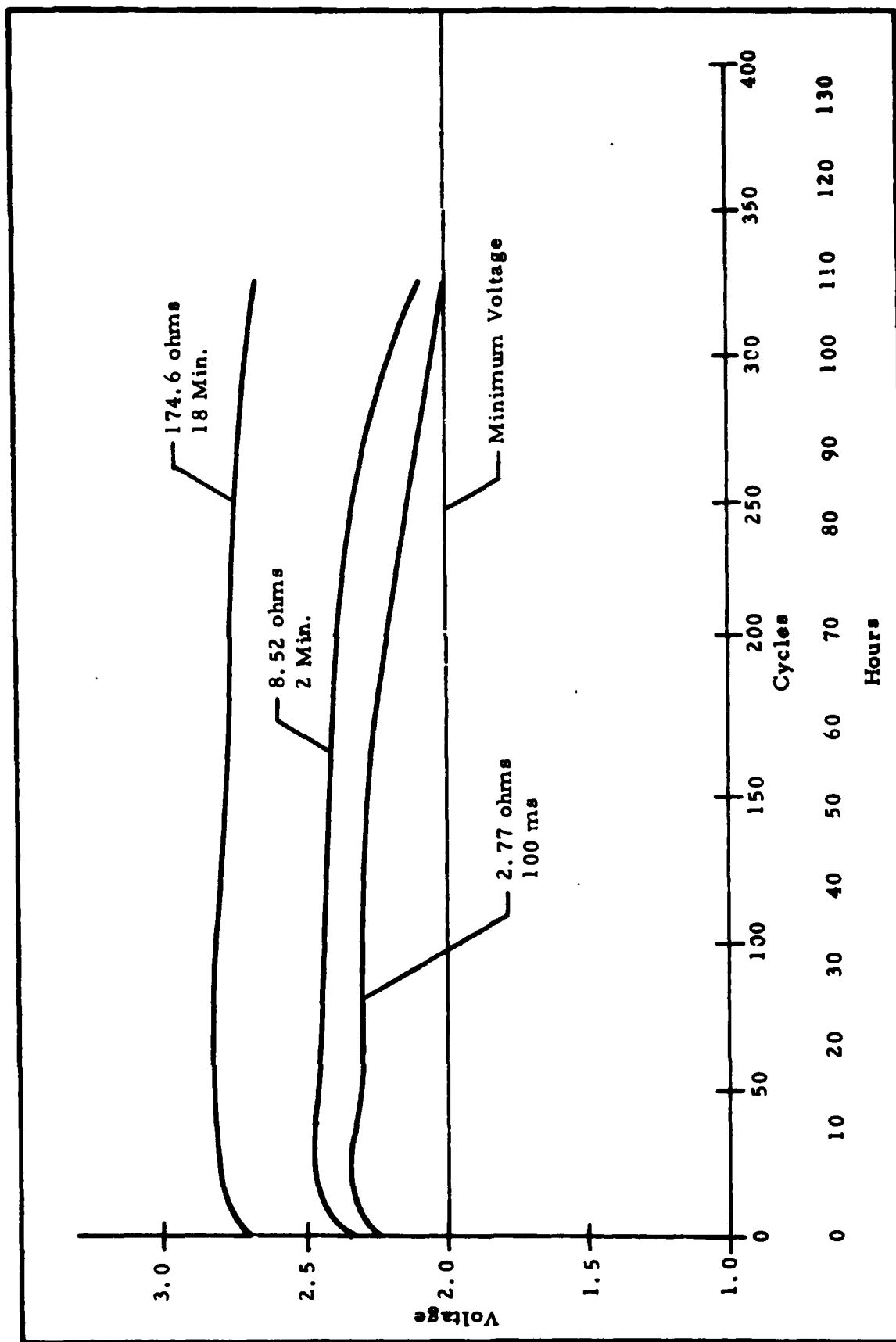


Figure V-19. Discharge of G2686B2 Cells, BA-5386 Loads, -20°F , After 20 Days Storage at $+160^{\circ}\text{F}$



70-001

Figure V-20. Discharge Performance of G2686B2 Cells, BA-5386 Loads, -40°F, After 30 Days Storage at +160°F

F. SAFETY TESTS

Cells were put through a series of safety tests according to ECOM Technical Guidelines dated 30 January 1973. Test data and a thorough discussion of the results are contained in Safety Study Report, dated April 1975.

In general, these results indicate that the safety feature design is effective for normal electrical stresses (high rate and short circuit). The safety mechanism will protect the cell in the event of certain failure conditions (those that might normally be encountered), but prolonged localized heating at high rates can cause weakening of the cell case at the point of flame impingement causing the cell wall to rupture even after the safety disc has allowed the cell to vent.

In addition to the data and photographs presented in the test report, the safety tests were documented with slow motion moving pictures.

G. BATTERY DESIGN

1. Electrical Requirements

The BA-5386 battery requirements (15 April 1974) specify two load conditions (A and B). The rate and capacity requirement for each condition are as outlined below.

a. Electrical, Condition A - The battery has two voltage outputs, A_1 and A_2 with the following electrical requirements:

1) Voltages under Load

A_1 Section 3.0 volts maximum, 2.12 test end voltage

A_2 Section 14.4 volts nominal, 16.6 volts maximum, 10.0 test end voltage

2) Voltage Limitation - The voltage of the A_1 section under a load of 6.76 ohms cannot exceed 3.0 volts.

3) Discharge Loads - The A_1 and A_2 sections are discharged concurrently through load 1 resistances for 2 minutes, then through load 2 resistances for 18 minutes, with the cycle repeated continuously to the test end voltage. Immediately prior to each application of the $14.2 \pm 1\%$ ohm load, a $4.8 \pm 1\%$ ohm load of 100 millisecond duration is applied.

	<u>Load 1 (ohms)</u>	<u>Load 2 (ohms)</u>
A_1 Section	$6.76 \pm 1\%$	OC
A_2 Section	$14.2 \pm 1\%$	$291 \pm 1\%$

4) Service - The battery is required to deliver the following service to end voltage under each of the following conditions:

- a) 90 hours under immediate discharge at $75^{\circ}\text{F} \pm 7^{\circ}\text{F}$.
- b) 80 hours under immediate discharge at $125^{\circ}\text{F} \pm 3^{\circ}\text{F}$ following stabilization of the battery for a minimum of 8 hours at $125^{\circ}\text{F} \pm 3^{\circ}\text{F}$.
- c) 60 hours under immediate discharge at $-20^{\circ}\text{F} \pm 3^{\circ}\text{F}$ following stabilization of the battery for a minimum of 8 hours at $-20^{\circ}\text{F} \pm 3^{\circ}\text{F}$.
- d) 30 hours (goal) under immediate discharge at $-40^{\circ}\text{F} \pm 3^{\circ}\text{F}$ following stabilization of the battery for a minimum of 8 hours at $-40^{\circ}\text{F} \pm 3^{\circ}\text{F}$.

Current requirements under these conditions are (approximately):

$$A_1 \text{ Section} \quad \text{Load 1} \quad \frac{2.70\text{V}}{6.76\Omega} = 0.40 \text{ amps}^*$$

$$A_2 \text{ Section} \quad \text{Load 1} \quad \frac{2.60 \times 5\text{V}}{14.2 \Omega} = 0.92 \text{ amps}^*$$

$$\text{Load 2} \quad \frac{2.85 \times 5\text{V}}{291 \Omega} = 0.05 \text{ amps}$$

$$100 \text{ ms pulse} \quad \frac{2.4 \times 5\text{V}}{4.8 \Omega} = 2.5 \text{ amps}$$

* The A_1 load is superimposed on the A_2 load giving total A_1 current of 1.32 amps.

Capacity requirements (per cycle) on the most loaded section (A_1 - tapped):

$$\text{Load 1 - Cell (2 min)} = .40 \times \frac{2}{60} = 0.0133 \text{ Ahrs}$$

$$\text{Load 1 - Battery (2 min)} = 0.92 \times \frac{2}{60} = 0.031 \text{ Ahrs}$$

$$\text{Load 2 - Battery (18 min)} = 0.05 \times \frac{18}{60} = 0.015 \text{ Ahrs}$$

$$\text{Pulse} = 2.5 \times \frac{0.1}{3600} = \text{negligible amp hrs removed}$$

Total capacity requirement per cycle (20 min) for A₁ Section of $0.0133 + 0.031 + 0.015 = 0.0593$ Ahrs, or $0.0593 \times 3 = 0.178$ Ahrs/hr.

The total capacity requirements for various temperatures specified are:

<u>T, °F</u>	<u>Hours</u>	<u>Ahrs</u>
+75	90	16.01
+125	80	14.23
-20	60	10.67
-40	30 (goal)	5.34

b. Electrical, Condition B - The battery is also to be capable of meeting the following electrical requirements:

- 1) Voltage under load - A₂ Section only - 14.4 volts nominal, 16.6 volts maximum, 10.0 end voltage.
- 2) Discharge loads - The A₂ Section is discharged through load 1 resistance for 2 minutes, then through load 2 resistance for 18 minutes, with the cycle repeated continuously.

	<u>Load 1 (ohms)</u>	<u>Load 2 (ohms)</u>
A ₂ Section	14.2 ± 1%	291 ± 1%

Immediately prior to each application of the 14.2 ± 1% ohm load, a 4.8 ± 1% ohm load of 100 ms shall be applied to the battery.

3) Service - The battery is required to deliver the following service to end voltage under each of the following conditions:

- a) 120 hours under immediate discharge at 75°F ± 7°F.
- b) 100 hours under immediate discharge at 125°F ± 3°F following stabilization of the battery for a minimum of 8 hours at 125°F ± 3°F.
- c) 80 hours under immediate discharge at -20°F ± 3°F following stabilization of the battery for a minimum of 8 hours at -20°F ± 3°F.
- d) 40 hours (goal) under immediate discharge at -40°F ± 3°F following stabilization of the battery for a minimum of 8 hours at -40°F ± 3°F.

Current requirements under these conditions are (approximately):

$$\text{Load 1} = \frac{2.60 \times 5V}{14.2 \Omega} = 0.92 \text{ amps}$$

$$\text{Load 2} = \frac{2.85 \times 5V}{291 \Omega} = 0.05 \text{ amps}$$

$$100 \text{ ms pulse} = \frac{2.4 \times 5V}{4.8 \Omega} = 2.5 \text{ amps}$$

Capacity requirements (per cycle) are:

$$\text{Load 1} = 0.92 \times \frac{2}{60} = 0.031 \text{ Ahrs}$$

$$\text{Load 2} = 0.05 \times \frac{18}{60} = 0.015 \text{ Ahrs}$$

$$100 \text{ ms pulse} = 2.5 \times \frac{0.1}{3600} = \text{negligible amp hrs removed}$$

$$\text{Total capacity per cycle (20 min)} = 0.031 + 0.015 = 0.046 \text{ Ahrs}$$

$$\text{or, } 0.046 \times 3 = 0.138 \text{ Ahrs/hr}$$

The total capacity requirements for various temperatures specified are:

<u>T, °F</u>	<u>Hrs</u>	<u>Ahrs</u>
+75	120	16.56
+125	100	13.80
-20	80	11.04
-40	40 (goal)	5.52

It will be noted that the capacity requirement is slightly greater under load condition B and this condition was specified for battery tests done under this program.

2. Other Considerations

The BA-5386 battery and the G2686C cell are shown in Figure V-21. The battery design is in compliance with specification furnished by ECOM (see Figure V-22) with respect to external dimensions, connector, and weight. A reverse biased diode was provided around each parallel section to prevent cell reversal and a 4-amp slow blow fuse was provided in each positive leg of the battery to prevent cell damage due to accidental external short circuits. A circuit diagram is given in Figure V-23.

Cell stacks were separated by a paperboard (egg crate) assembly and blocking was provided to support the connector, fuses, and the cell stack for shock and vibration.

After assembly, the battery was potted with 12 lb/cu ft urethane foam. The external box was made of water resistance paperboard.

H. BATTERY TESTS

1. General

Sixteen batteries built under this program were tested in accordance with the technical guidelines dated 15 April 1974. The tests included storage at +160°F for 30 days* followed by shock (3 axis), vibration (3 axis), temperature and humidity (2 days), followed by an insulation resistance test and discharge under load condition B. A test report (PTL-1242-1) is attached as Appendix A. The results of these tests are summarized in Table V-1 thru V-4.

*Note: One oven containing 8 (half) of the test batteries went out of control 22 days into the test and reached a temperature of +190°F for approximately 2 hours.

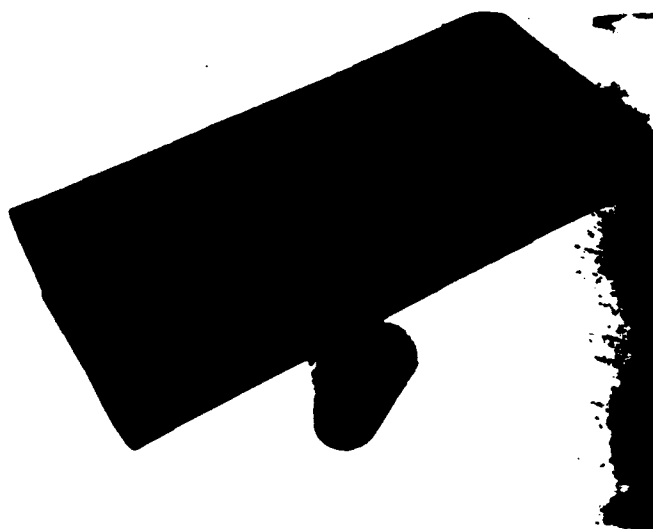
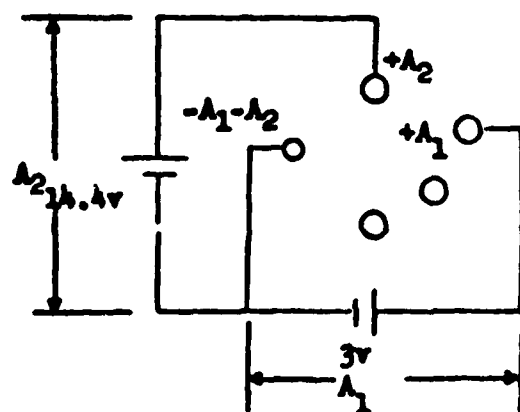
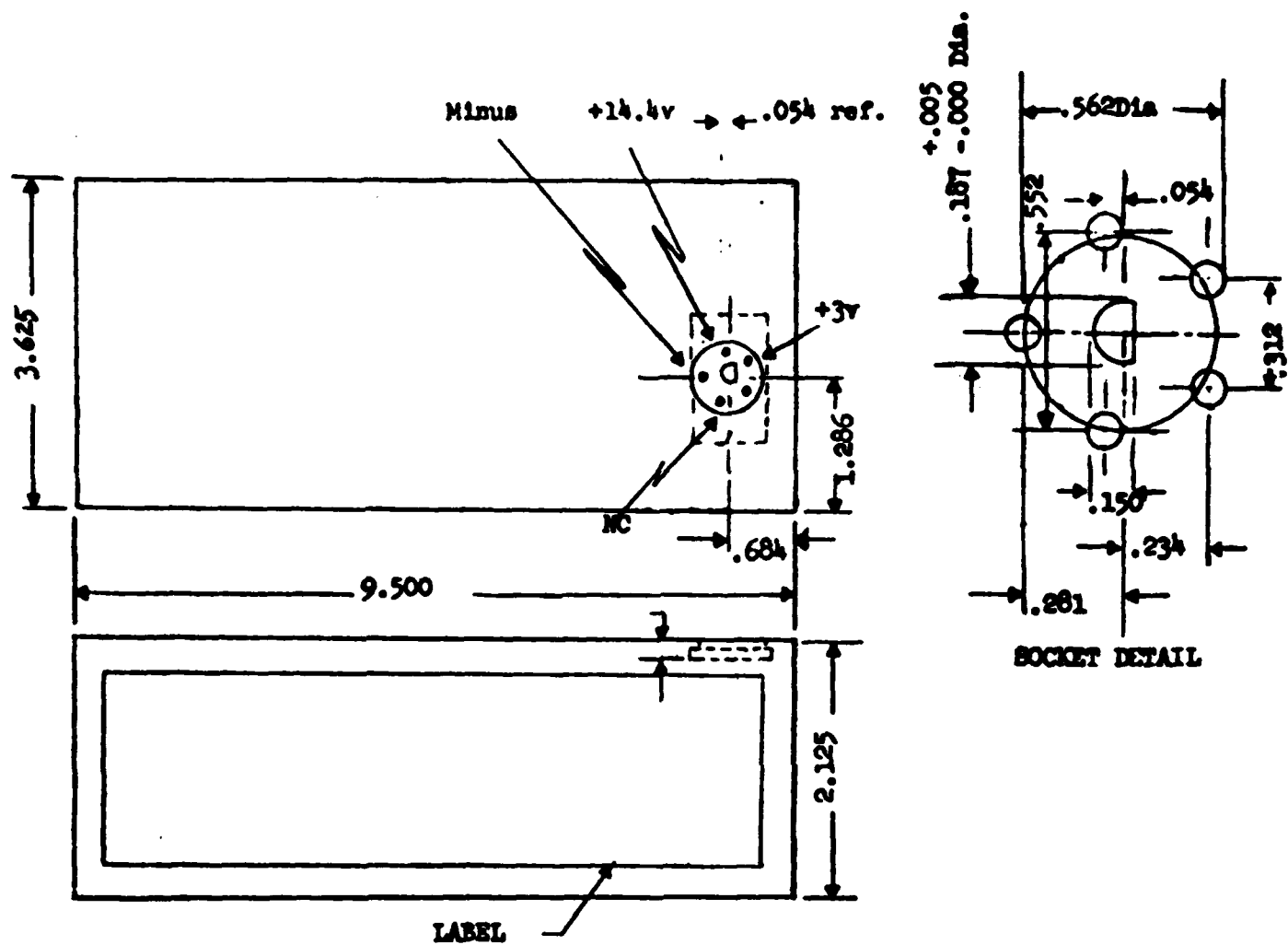
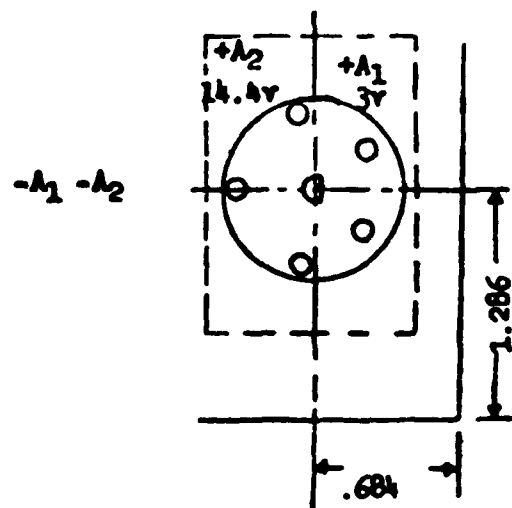


Figure V-21. BA5386 Battery and G2686C Cell



UNIT WIRING DIAGRAM



SOCKET PLACEMENT AND VOLTAGE MARKINGS

Figure V-22.- Battery, Primary, BA-5386()/U

12
 Contract No. DAAB07-71- C-0191 Honeywell, Inc. Modification #P00005 to

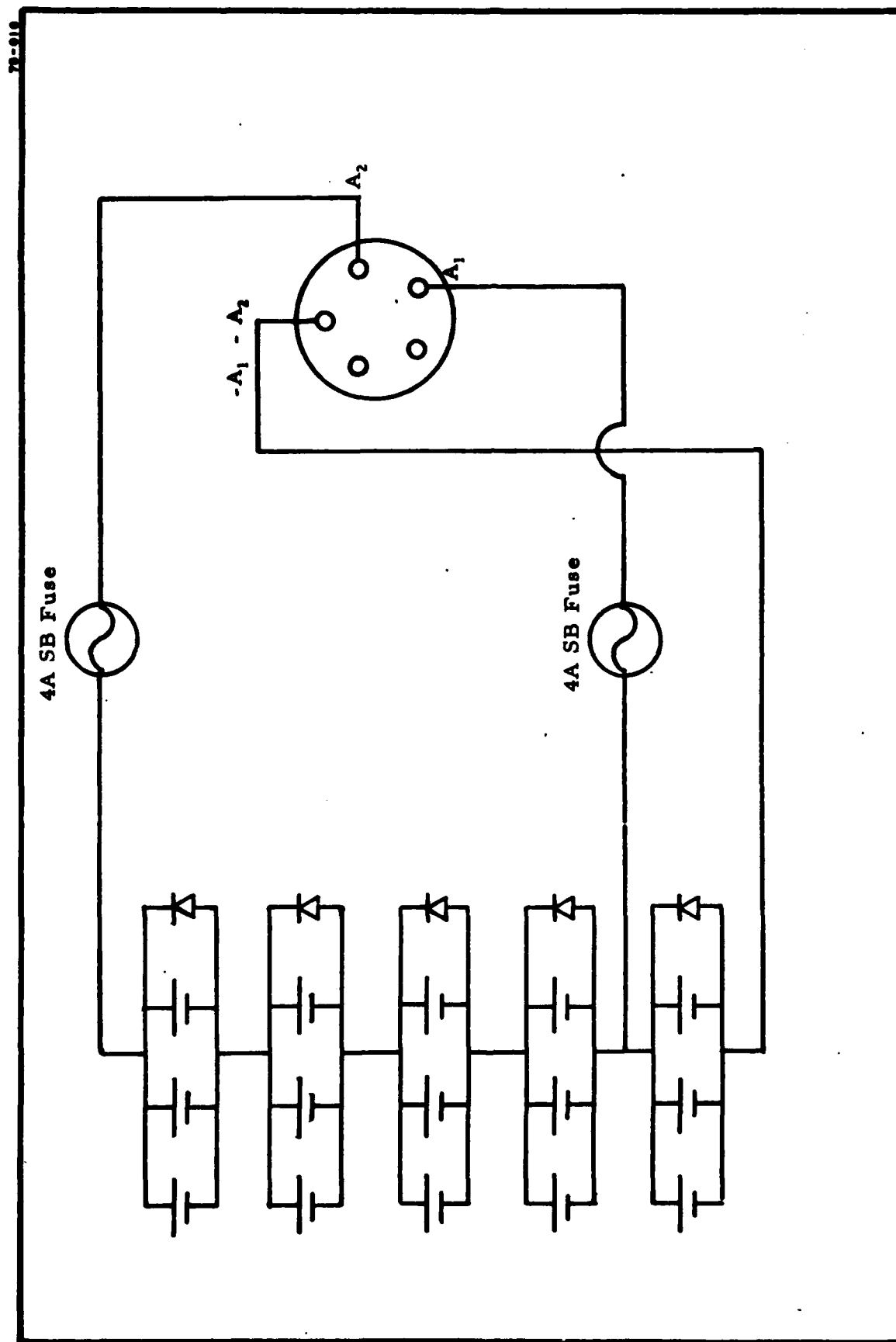


Figure V-23. BA-5386 Circuit Diagram

Battery weights after 30 days stand at +160°F are given in Table V-1. This tabulation clearly shows the greater weight loss of the batteries stored in the oven that went out of control on the 22nd day. (Average 12 grams per battery less weight than those stored under conditions not exceeding $160 \pm 3^\circ\text{F}$.)

The results of shock test on the batteries are given in Table V-2. All batteries successfully completed the shock test as shown by the open circuit voltages of each section after each shock.

Two batteries (#15 and #16) failed during vibration testing. Both had been subject to overtemperature. As shown in Table V-3, battery #16 suffered a substantial drop in OCV after the first axis vibration. Battery #15 showed a drop after 2nd axis with some recovery after 3rd axis. Battery #16 subsequently recovered OCV as shown in Table V-4 after temperature and humidity test. Excessive leakage was detected in battery #8 after vibration testing and the unit (along with #15) was not exposed to the temperature and humidity test. Insulation resistance, as shown in Table V-4, was satisfactory after temperature and humidity testing.

Battery test results under cyclic load are summarized in Table V-5. The tests were continued well beyond the point where the pulse load dropped below the 10 volt cutoff. The table indicates little or no correlation between those batteries subject to overtemperature (and high leakage) and those run under normal conditions. The performance of these batteries was subject to further analysis (below) and it was shown that a substantial number of cells (over 20%) could not discharge due to the formulation of a high resistance in the positive terminal of the cell under the conditions of battery storage.

Table V-1. Weight After 30 Days Storage at +160°F

<u>Missimer*</u>	<u>Batt. #</u>	<u>Weight</u>	<u>OCV₁</u>	<u>OCV₂</u>	
	41	1216	14.79	2.97	
	51	1237	14.82	2.98	Mean = 1228.4
	28	1225	14.52	2.85	
	15	1232	14.81	2.98	Range = 23
	44	1218	14.28	2.86	
	16	1239	14.84	2.94	Mean (Volts) = 14.72
	36	1221	14.91	2.96	
	37	1239	14.85	2.98	Range = 0.63
<u>Hotpack</u>	49	1245	14.99	2.99	
	40	1235	14.92	2.98	Mean = 1240
	08	1242	14.91	2.99	
	06	1249	14.97	2.99	Range = 22
	61	1236	15.10	2.99	
	32	1228	14.80	2.99	Mean (Volts) 14.94
	50	1250	14.94	2.99	
	11	1235	14.92	2.97	Range = 0.30

*The Missimer is the oven which experienced over-temperature to 190°F.

Table V-2. Voltage After Drop

<u>Batt. #</u>	<u>AXIS 1</u>		<u>AXIS 2</u>		<u>AXIS 3</u>	
	<u>OCV₁</u>	<u>OCV₂</u>	<u>OCV₁</u>	<u>OCV₂</u>	<u>OCV₁</u>	<u>OCV₂</u>
50	14.89	2.98	14.89	2.97	14.88	2.98
6	14.82	2.87	14.86	2.98	14.86	2.98
+ 28	14.58	2.90	14.56	2.89	14.55	2.89
+ 37	14.72	2.98	14.74	2.98	14.74	2.98
40	14.88	2.98	14.89	2.98	14.89	2.98
08	14.84	2.97	14.87	2.98	14.87	2.98
+ 15	14.59	2.97	14.56	2.97	14.56	2.97
+ 44	14.38	2.90	14.33	2.90	14.33	2.90
11	14.82	2.96	14.83	2.96	14.83	2.96
61	15.06	2.97	15.07	2.98	15.07	2.98
+ 41	14.51	2.97	14.47	2.97	14.51	2.97
+ 36	14.86	2.95	14.86	2.96	14.86	2.95
49	14.84	2.97	14.87	2.97	14.87	2.97
32	14.73	2.98	14.74	2.98	14.74	2.98
+ 51	14.54	2.97	14.51	2.97	14.50	2.97
+ 16	14.80	2.95	14.81	2.94	14.81	2.94

All drops were completed on 12-23-74.

+ Batteries subjected to overtemperature.

Table V-3. Voltage After Vibration

<u>Batt.#</u>	<u>AXIS 1</u>		<u>AXIS 2</u>		<u>AXIS 3</u>	
	<u>OCV₁</u>	<u>OCV₂</u>	<u>OCV₁</u>	<u>OCV₂</u>	<u>OCV₁</u>	<u>OCV₂</u>
50	14.81	2.97	14.81	2.97	----	----
6	14.76	2.96	14.75	2.97	14.26	2.96
+ 28	14.70	2.94	14.64	2.93	14.69	2.93
40	14.72	2.97	14.73	2.97	14.67	2.96
8	14.62	2.95	13.66	2.96	14.62	2.96
+ 15	14.49	2.96	10.67	2.96	12.58	2.96
+ 44	14.42	2.92	14.51	2.94	14.49	2.94
+ 37	14.62	2.93	14.63	2.94	14.62	2.93
11	14.65	2.92	14.65	2.92	14.63	2.92
61	14.92	2.96	14.95	2.96	14.97	2.96
+ 36	14.74	2.89	14.71	2.88	14.70	2.89
+ 41	14.69	2.95	14.69	2.94	14.69	2.94
32	14.64	2.97	14.64	2.97	14.65	2.96
49	14.77	2.92	14.77	2.92	14.75	2.91
+ 16	10.90	2.90	10.86	2.91	11.00	2.91
+ 51	14.62	2.87	14.68	2.93	14.69	2.94

+ Batteries subjected to overtemperature.

Table V-4. Voltage, Weight, and Insulation Resistance After T&H

<u>Test Temp.</u>	<u>Batt. #</u>	<u>Weight (g)</u>	<u>OCV₁</u>	<u>OCV₂</u>	<u>Insulation Resistance</u>
-20	40	1223	2.96	14.70	∞
	+44	1178	2.93	14.65	∞
	08	1225	2.96	12.25	-- *
	+15	1202	2.96	10.56	-- *
+75	+28	1209	2.91	14.75	∞
	06	1251	2.96	14.75	∞
	+37	1228	2.89	14.55	∞
	50	1252	2.97	14.68	∞
+125	61	1240	2.97	14.80	∞
	+36	1218	2.88	14.51	∞
	+41	1192	2.92	14.73	∞
	11	1219	2.91	14.45	∞
-40	+16	1205	2.97	14.60	3×10^8
	32	1207	2.97	14.61	5×10^8
	49	1228	2.86	14.71	2×10^8
	+51	1231	2.95	14.68	10^9

+ Batteries subjected to overtemperature

*Did not see T&H

Table V-5. BA-5386 Cyclic Load Test

<u>Battery No.</u>	<u>Test Temperature</u>	<u>Running Hours to 10.0 Volts</u>		
		<u>Pulse</u> <u>4.8Ω, 100 ms</u>	<u>Transmit</u> <u>14.2Ω, 2 min</u>	<u>Receive</u> <u>291Ω, 18 min</u>
+36	+125°F	--	--	102
11	+125°F	--	38	86
61	+125°F	37	45	104
+41	+125°F	--	3	92
6	+75°F	--	--	84
+28	+75°F	--	--	84
+37	+75°F	30	45	132
50	+75°F	--	--	84
40	-20°F	--	30	128
+44	-20°F	--	--	89
49	-40°F	--	--	78
+51	-40°F	--	--	29
32	-40°F	--	17	83

+ Batteries subjected to overtemperature.

2. Post Mortem Analysis

Following the test, some of the failed batteries and cells were subjected to post mortem analysis. The details of this analysis are given in Appendix B. In general, these results indicated that leakage of some cells was excessive (particularly the batteries subject to over-temperature). A more significant result of the analysis was the determination that several of the cells had not discharged at all. The reasons for these problems were the subject of a further series of tests described below.

3. Additional Tests

Following the battery test and post mortem analysis, a number of tests were conducted to determine, and try to reproduce, the causes of failure.

a. Soldering vs. Leakage - In one series of tests, a group of soldered and control cells were placed in a +160°F oven for 26 days. It was determined that soldered cells either leaked catastrophically (3 of 15) or had leakage rates equivalent to control (12 of 15 - approx. 30 mg/day). Cells lying on their sides (as they were in the batteries) had slightly lower average leakage than cells stored vertically. It was concluded that soldering increased the probability of excessive cell leakage at high temperature and recommended that in the future, cell leads be welded. It was also determined that all of the 22 cells remaining after 26 days storage had normal closed circuit voltage.

b. High Terminal Resistance - The reason for cells failing to discharge was traced to a high resistance that developed between the conductor ring and the top cap (this is a pressure contact). The cause has been determined to be corrosion (from the outside), but at the writing of this report the failure had not been reproduced under controlled conditions. Thousands of cells have been built and stored under dry room conditions without a single incidence of this type of failure and hundreds of cells have

been stored at +160°F without this failure mode. A group of G2686-C cell rejects, built with the battery cells, has been stored under ambient conditions and show no failures. However, the incidence of this type of failure is high in the battery build.

c. Environmental Conditions - As a check to determine whether or not the environmental testing (+160°F stand, shock and vibration) was the principal cause of battery failure, a group of four batteries, stored at room temperature, was selected at random and tested, 2 each, at -20°F and room temperature. Performance of these batteries was slightly better than those subjected to the environmental tests. However, performance was still unsatisfactory. Post mortem analysis indicated substantially no leakage and a high (15 of 45 cells checked) incidence of undischarged cells. Cell analysis confirmed the cause to be high resistance between the conductor ring and top cap. Test results for this group are given in PTL-1338-1 (Appendix C).

d. Confirmation of High Terminal Resistance as Failure Mode - As a final check, a group of 6 batteries showing high loaded voltage was selected from the remaining batteries stored at room temperature. After the batteries were selected, but before they were tested, the cells were individually checked for load voltage. It was determined that 12 cells were "defective" (unable to support voltage under load). Details of these batteries are provided in Table V-6 and the test report (PTL 1225-1) reproduced in Appendix D.

The only battery having no "defective" cells was #46. This battery came within 1 cycle (20 min) of meeting the full capacity requirement. The percentage of required capacity is roughly equal to the maximum percentage of defective cells in a stack and it is relatively unimportant how many bad stacks are in the battery as shown in Table V-7.

Table V-6. Summary of Test Results of Six BA-5386 Batteries

Battery S/N	Voltage 5A Load			Defective Cells in Parallel Sections					Test Temp, °F	Hrs to 10 Volts
	A ₁ Sect	A ₂ -A ₁ Sect	Battery	1*	2	3	4	5		
07	1.98	7.50	9.48	0	1	0	1	0	75	87.7
20	2.08	7.49	9.57	0	2	0	0	1	75	49.0
34	1.96	7.28	9.24	0	0	0	0	1	-20	54.0
46	1.98	7.58	9.56	0	0	0	0	0	-20	79.7
60	1.82	7.63	9.45	1	0	1	0	0	-20	64.3
64	1.82	7.52	9.34	1	1	1	0	1	75	91.0

*Sect 1 is the A₁ Section

Table V-7. Analysis of Defective Cells and Stacks Vs. Delivered Capacity

<u>Battery #</u>	<u>Max "def" Cells/Stack</u>	<u># Bad Stacks</u>	<u>% of req'd Capacity</u>	<u>Fract. Good Cells in Limiting Stack</u>
07	1	2	73	2/3
20	2	2	41	1/3
34	1	1	68	2/3
46	0	0	100	1
60	1	2	80	2/3
64	1	4	76	2/3

1) **Statistical Analysis** - The distribution of "defective" cells through the stacks in these 6 batteries follows closely the predicted number from a mathematical model based on randomly distributed defectives.

The percent defectives found was $\frac{12}{90} \times 100 = 13.3\%$

The probability calculations are:

All good	=	$(0.867)^3$	=	0.652
1 defective	=	$3(0.867)^2(0.133)$	=	0.300
2 defective	=	$3(0.867)(0.133)^2$	=	0.046
3 defective	=	$(0.133)^3$	=	<u>0.002</u>
TOTAL				1.000

for the total number of stacks (5/battery x 6 batteries) = 30 (multiply each probability by 30):

<u>Condition</u>	<u>Expected</u>	<u>Found</u>
All good	19.67	19
1 defective	9.00	10
2 defective	1.38	1
3 defective	0.06	0

e. Conclusions - The major cause of battery failure is the incidence of cells that cannot discharge due to high resistance between the positive lead (inside the cell) and the top cap (positive terminal outside the cell). This is due to corrosion of the aluminum conductor contacting the nickel plated top cap caused by access of atmospheric humidity and aggravated (or precipitated) by soldering leads to the top cap. Excessive leakage was found (particularly those batteries subject to +190°F) and this contributed to capacity reduction. Excessive leakage (catastrophic) was found to be induced by soldering leads to the top cap.

COPY LIST:

J. O. Crabb
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J. B. Jenkins
N. A. Remer
C. R. Walk
Central Files



APPENDIX A
GOVERNMENT AND AERONAUTICAL
PRODUCTS DIVISION

REPORT NO. PTL-1242-1
DEV. NO. BA-5386/8403

ENGINEERING TEST REPORT

DATE 1-31-75

PAGE 1 OF 23

ISSUED BY:

Product Test Lab

Units Tested

Sixteen (16) BA5386 batteries, identification numbers, 06, 08, 11, 15, 16, 28, 32, 36, 37, 40, 41, 44, 49, 50, 51, and 61. PTL test numbers 743844 through 743859.

Purpose

Acceptance test samples submitted by Quality Department.

KEYWORDS:

Procedure and Results

The units were tested in accordance with the attached inspection procedures. The batteries were put into the 30 day storage on 11-22-74. They were split between 2 chambers (8 in ea). On 12-14-74 one of the ovens went to 190°F for 1 hour and 54 minutes before the condition was discovered and corrected. The 30 day storage was ended on 12-22-74 and the units were allowed to return to ambient conditions overnight. They were then weighed and the open circuit voltages were taken. These results are shown in Table I. The units were then subjected to shock testing. The shock conditions were 75 g's minimum average for 3 milliseconds with a peak of 175 g's. They were shocked in 3 mutually perpendicular axis and after each shock the open circuit voltages were taken. These results are shown in Table II. Between 12-28-74 and 12-31-74, all the units experienced vibration testing. They were vibrated in 3 mutually perpendicular axis to a maximum amplitude of 0.06 inches and a frequency of 10 to 55 CPS and return in 95 ± 5 minutes. The actual time excursion was 102 minutes. Again after this testing was completed the open circuit voltages were recorded and they are shown in Table III.

ATTACHMENTS:

After vibration they were put into temperature and humidity storage for 48 hours. The conditions were 75 ± 5°F and 50 ± 15% relative humidity. After T&H, weights, open circuit voltages and insulation, resistance from terminal to case were recorded. These results are shown in Table IV.

DATA BOOK NO.	PAGE
REQUESTED BY A. R. Beebe	DATE
DEPARTMENT Quality	WRITTEN BY B. F. Erwin
	APPROVED W. F. Kawalec

The units were then put in discharge testing. The load cycle was $4.8 \pm 1\%$ ohms for 100 msec, $14.2 \pm 1\%$ ohms for 2 minutes and $291 \pm 1\%$ ohms for 18 minutes. Four batteries were tested at each of 4 different temperatures, -40, -20, +75 and +125°F. None of the units met discharge specifications which were 10 volts minimum and:

108 Hrs at 75°F
90 Hrs at 125°F
72 Hrs at -20°F
36 Hrs at -40°F

Attached are the graphs of the batteries which were tested. Note: Batteries number 8, 15, and 16 were not tested due to large loss of open circuit voltages. All charts are in storage in the Test area.

TABLE I

WEIGHT AFTER 30 DAYS

<u>Missimer*</u>	<u>Batt. #</u>	<u>Weight</u>	<u>OCV₁</u>	<u>OCV₂</u>	
	41	1216	14.79	2.97	
	51	1237	14.82	2.98	Mean = 1228.4
	28	1225	14.52	2.85	
	15	1232	14.81	2.98	Range = 23
	44	1218	14.28	2.86	
	16	1239	14.84	2.94	Mean (Volts) = 14.72
	36	1221	14.91	2.96	
	37	1239	14.85	2.98	Range = 0.63
<u>Hotpack</u>	49	1245	14.99	2.99	
	40	1235	14.92	2.98	Mean = 1240
	08	1242	14.91	2.99	
	06	1249	14.97	2.99	Range = 22
	61	1236	15.10	2.99	
	32	1228	14.80	2.99	Mean (Volts) = 14.94
	50	1250	14.94	2.99	
	11	1235	14.92	2.97	Range = 0.30

* The Missimer is the oven which experienced the over temperature.

-3423

TABLE II

VOLTAGE AFTER DROP

<u>Batt. #</u>	<u>AXIS 1</u>		<u>AXIS 2</u>		<u>AXIS 3</u>	
	<u>OCV₁</u>	<u>OCV₂</u>	<u>OCV₁</u>	<u>OCV₂</u>	<u>OCV₁</u>	<u>OCV₂</u>
50	14.89	2.98	14.89	2.97	14.88	2.98
6	14.82	2.87	14.86	2.98	14.86	2.98
28	14.58	2.90	14.56	2.89	14.55	2.89
37	14.72	2.98	14.74	2.98	14.74	2.98
40	14.88	2.98	14.89	2.98	14.89	2.98
08	14.84	2.97	14.87	2.98	14.87	2.98
15	14.59	2.97	14.56	2.97	14.56	2.97
44	14.38	2.90	14.33	2.90	14.33	2.90
11	14.82	2.96	14.83	2.96	14.83	2.96
61	15.06	2.97	15.07	2.98	15.07	2.98
41	14.51	2.97	14.47	2.97	14.51	2.97
36	14.86	2.95	14.86	2.96	14.86	2.95
49	14.84	2.97	14.87	2.97	14.87	2.97
32	14.73	2.98	14.74	2.98	14.74	2.98
51	14.54	2.97	14.51	2.97	14.50	2.97
16	14.80	2.95	14.81	2.94	14.81	2.94

All drops were completed on 12-23-74.

TABLE III

VOLTAGE AFTER VIBRATION

<u>Batt. #</u>	<u>AXIS 1</u>		<u>AXIS 2</u>		<u>AXIS 3</u>	
	<u>OCV₁</u>	<u>OCV₂</u>	<u>OCV₁</u>	<u>OCV₂</u>	<u>OCV₁</u>	<u>OCV₂</u>
50	14.81	2.97	14.81	2.97	----	----
6	14.76	2.96	14.75	2.97	14.26	2.96
28	14.70	2.94	14.64	2.93	14.69	2.93
40	14.72	2.97	14.73	2.97	14.67	2.96
8	14.62	2.95	13.66	2.96	14.62	2.96
15	14.49	2.96	10.67	2.96	12.58	2.96
44	14.42	2.92	14.51	2.94	14.49	2.94
37	14.62	2.93	14.63	2.94	14.62	2.93
11	14.65	2.92	14.65	2.92	14.63	2.92
61	14.92	2.96	14.95	2.96	14.97	2.96
36	14.74	2.89	14.71	2.88	14.70	2.89
41	14.69	2.95	14.69	2.94	14.69	2.94
32	14.64	2.97	14.64	2.97	14.65	2.96
49	14.77	2.92	14.77	2.92	14.75	2.91
16	10.90	2.90	10.86	2.91	11.00	2.91
51	14.62	2.87	14.68	2.93	14.69	2.94

-4923

TABLE IV
VOLTAGE, WEIGHT, AND INSULATION RESISTANCE AFTER T&H

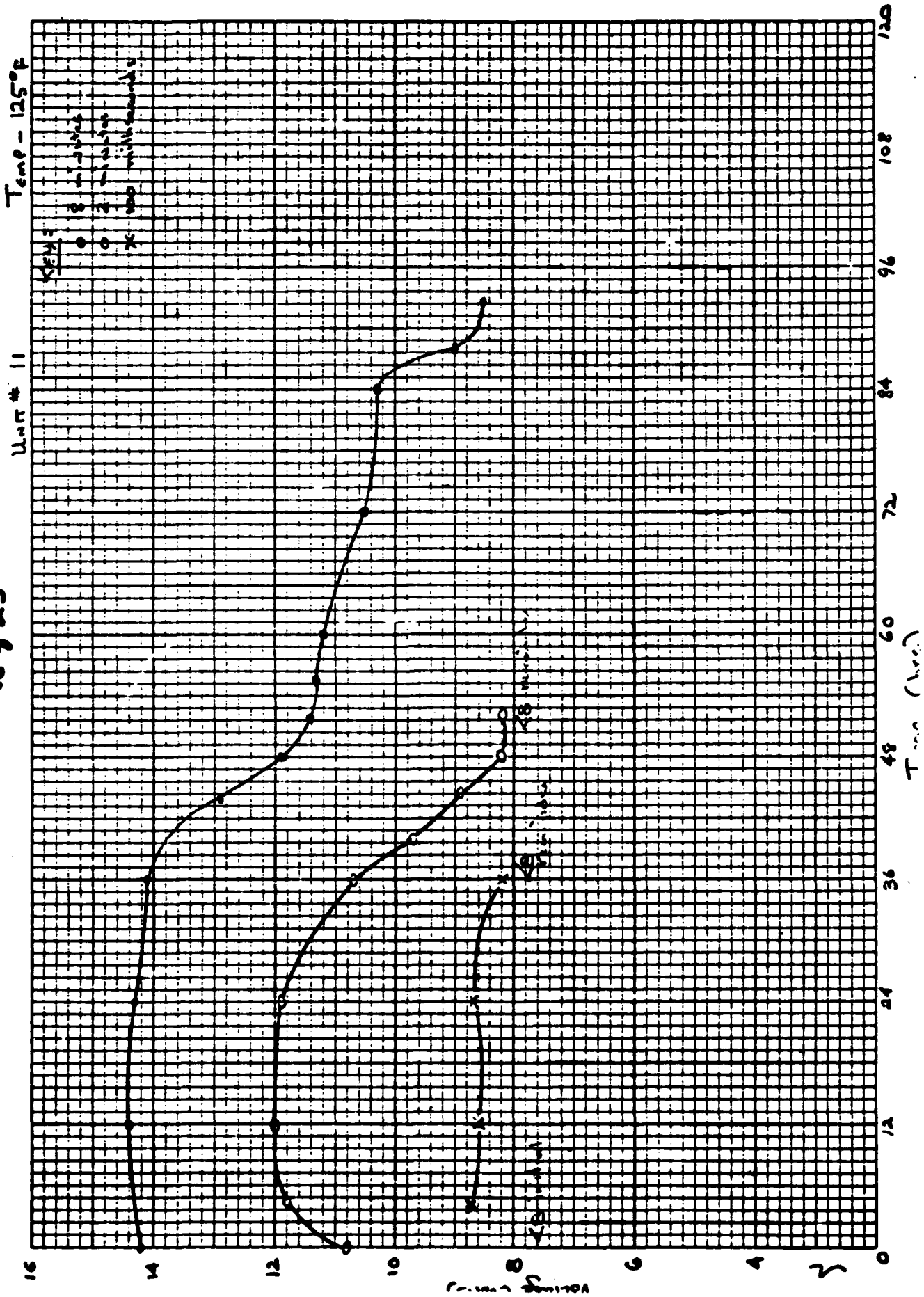
<u>Test Temp.</u>	<u>Batt. #</u>	<u>Weight (g)</u>	<u>OCV₁</u>	<u>OCV₂</u>	<u>Insulation Resistance</u>
-20	40	1223	2.96	14.70	∞
	44	1178	2.93	14.65	∞
	08	1225	2.96	12.25	-- *
	15	1202	2.96	10.56	-- *
+75	28	1209	2.91	14.75	∞
	06	1251	2.96	14.75	∞
	37	1228	2.89	14.55	∞
	50	1252	2.97	14.68	∞
+125	61	1240	2.97	14.80	∞
	36	1218	2.88	14.51	∞
	41	1192	2.92	14.73	∞
	11	1219	2.91	14.45	∞
-40	16	1205	2.97	14.60	3×10^8
	32	1207	2.97	14.61	5×10^8
	49	1228	2.86	14.71	2×10^8
	51	1231	2.95	14.68	10^9

* Did not see T&H

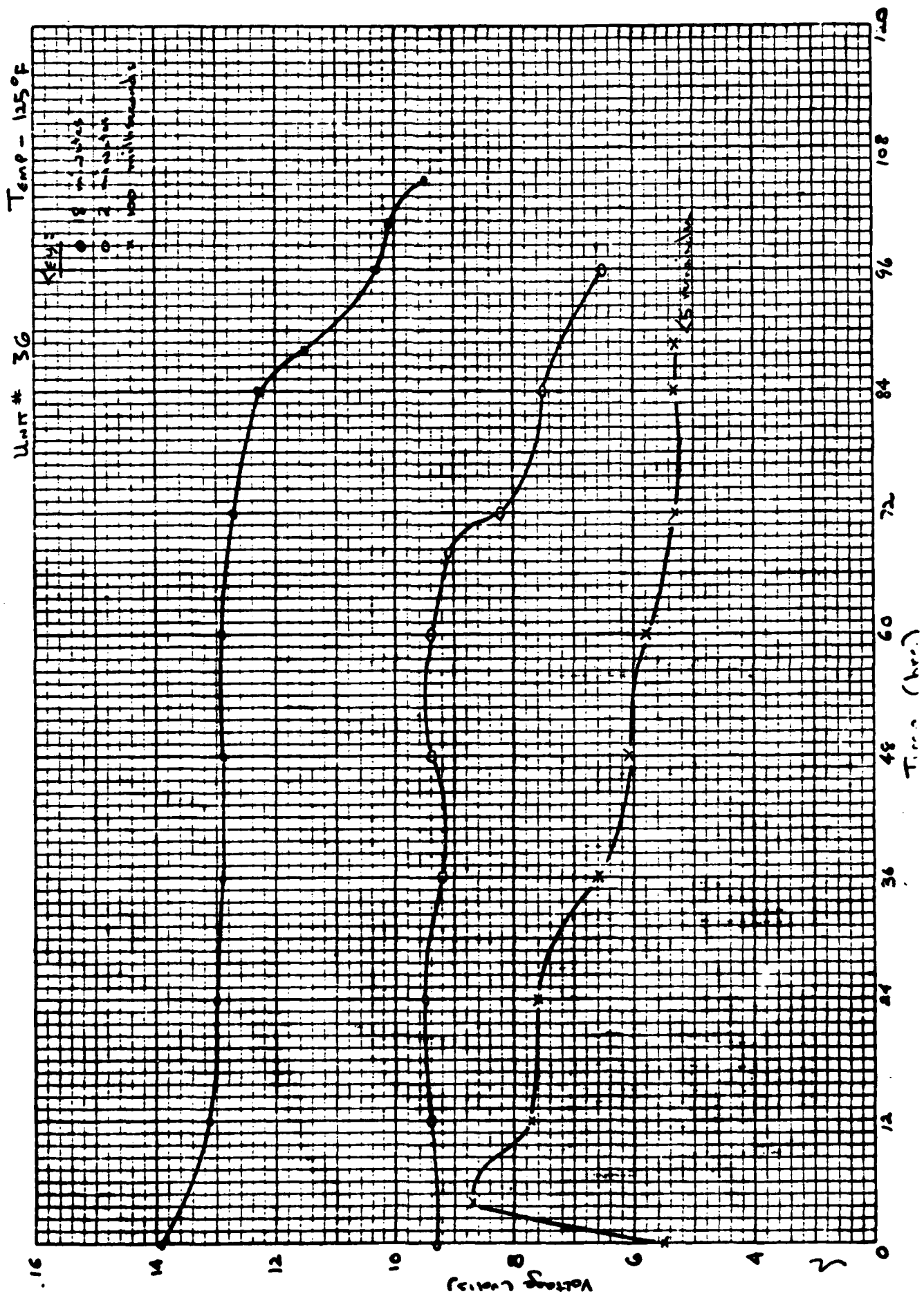
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10 X 10 PER INCH

EUGENE DIETZEN CO.
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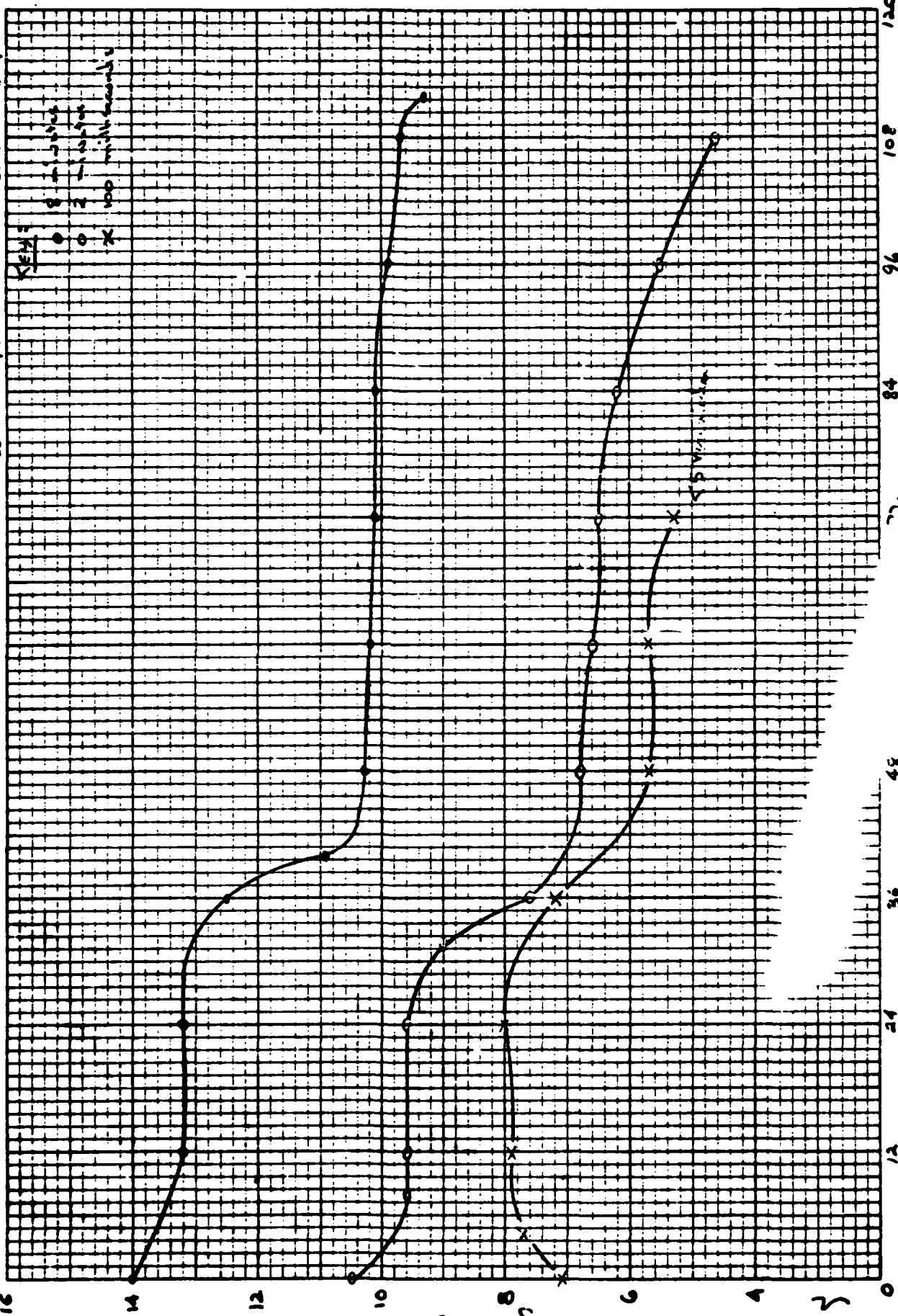
EUGENE DIETZEN CO.
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NO. 340R-10 DIETZEN GRAPH PAPER
10 X 10 PER INCH

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Temp - 125°F

Unit # 41

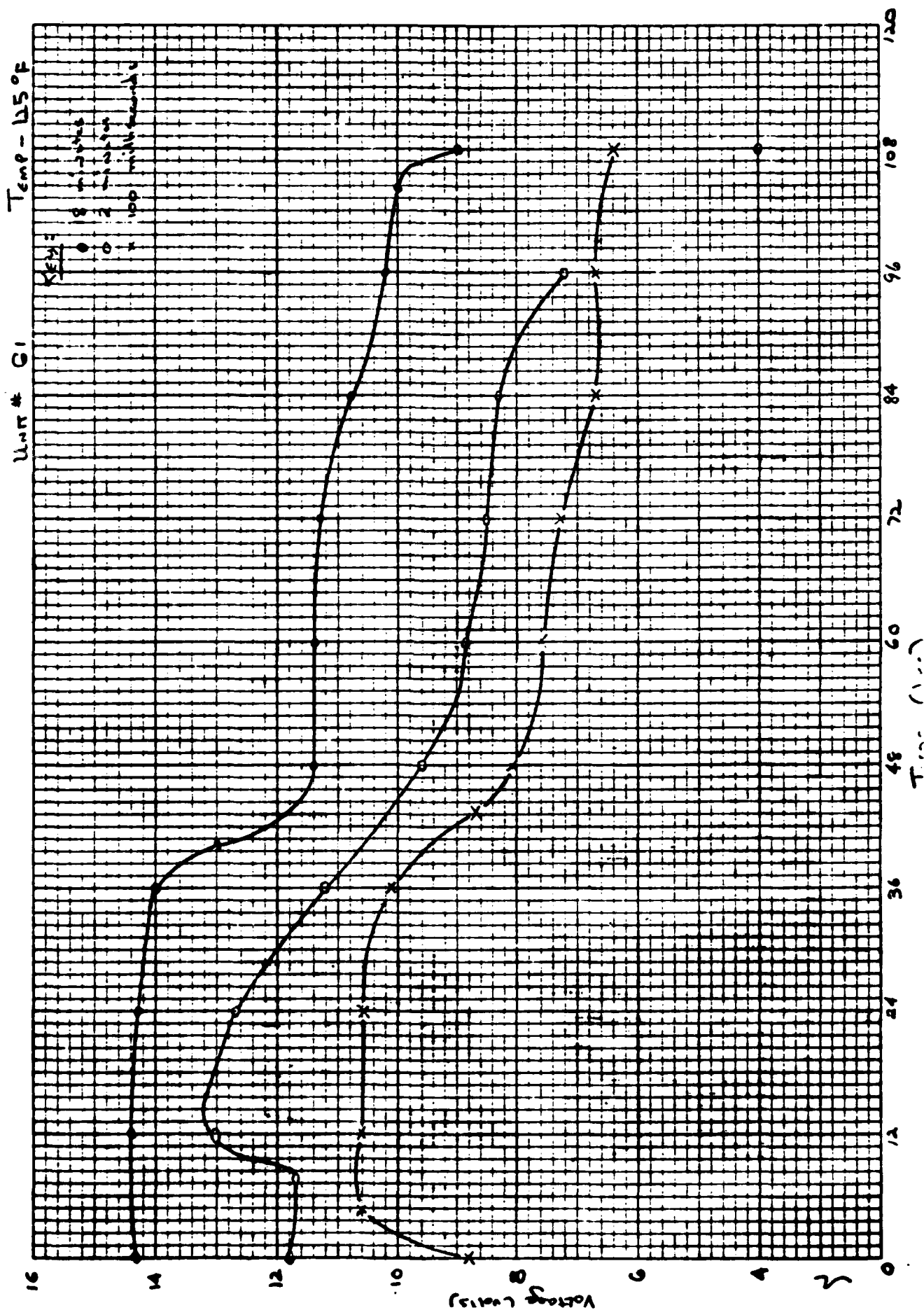


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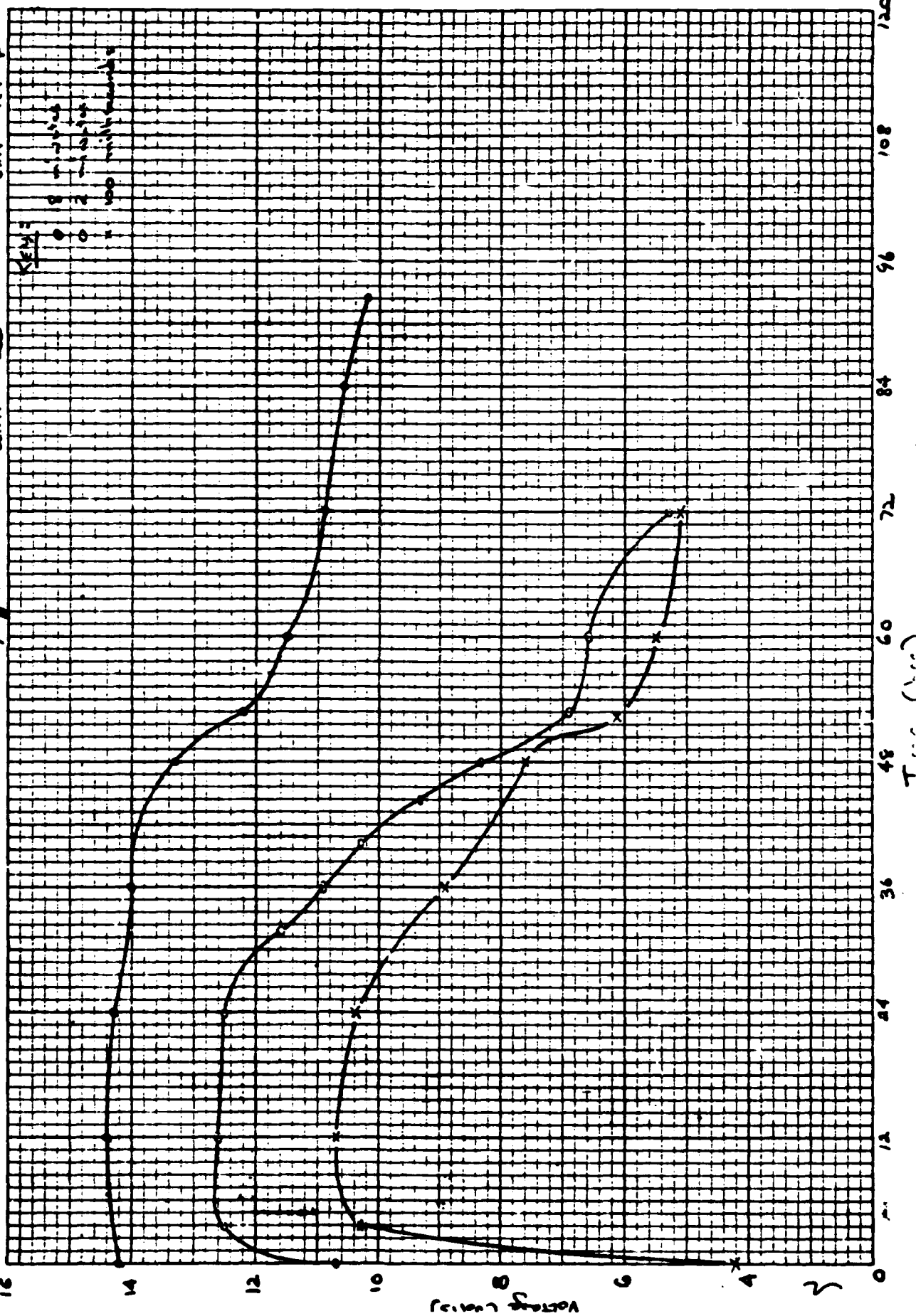
-8423



9423

Unit # 28

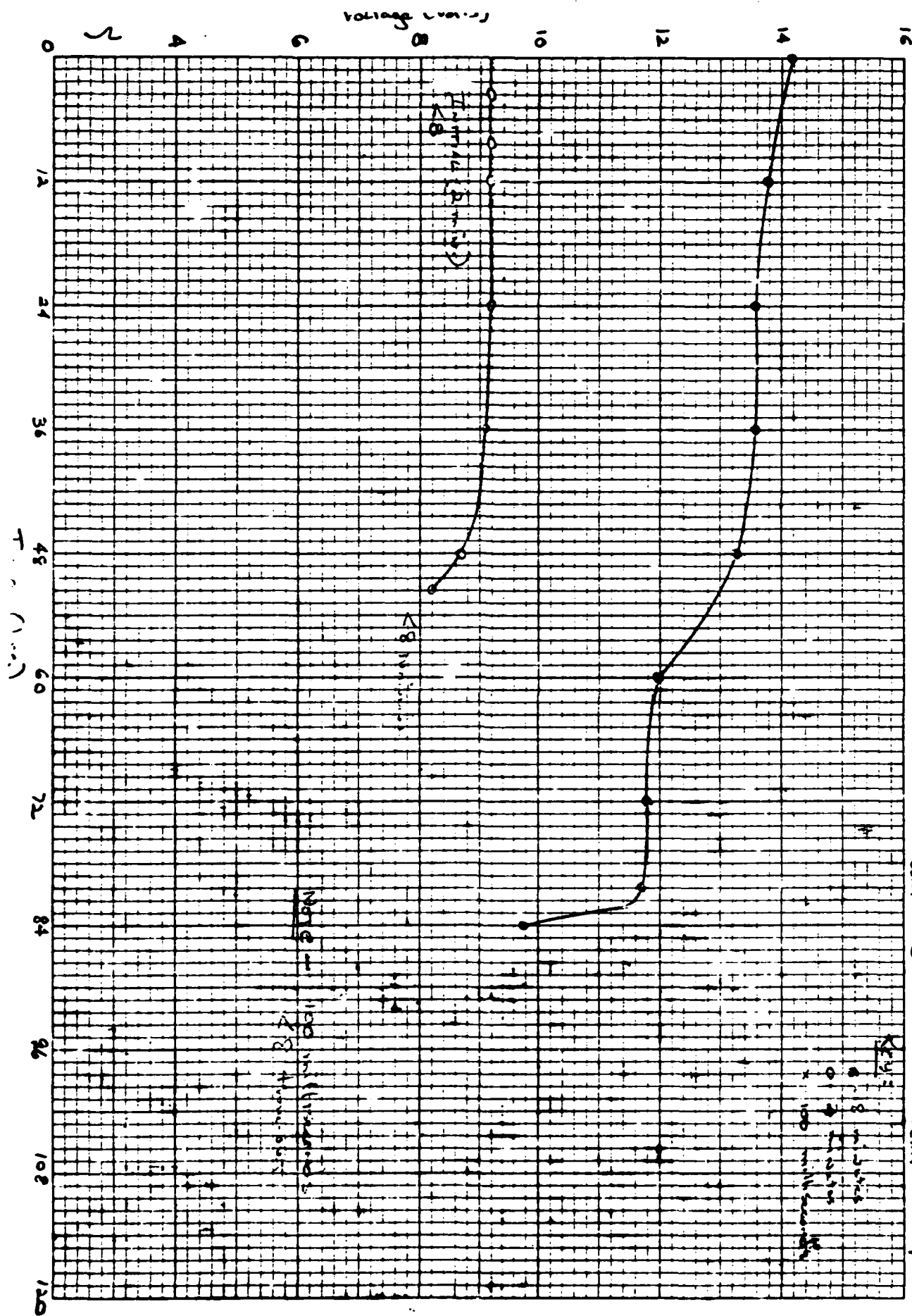
Temp - RT OF



10823

Unit # 6

Temp - R to F



-11923

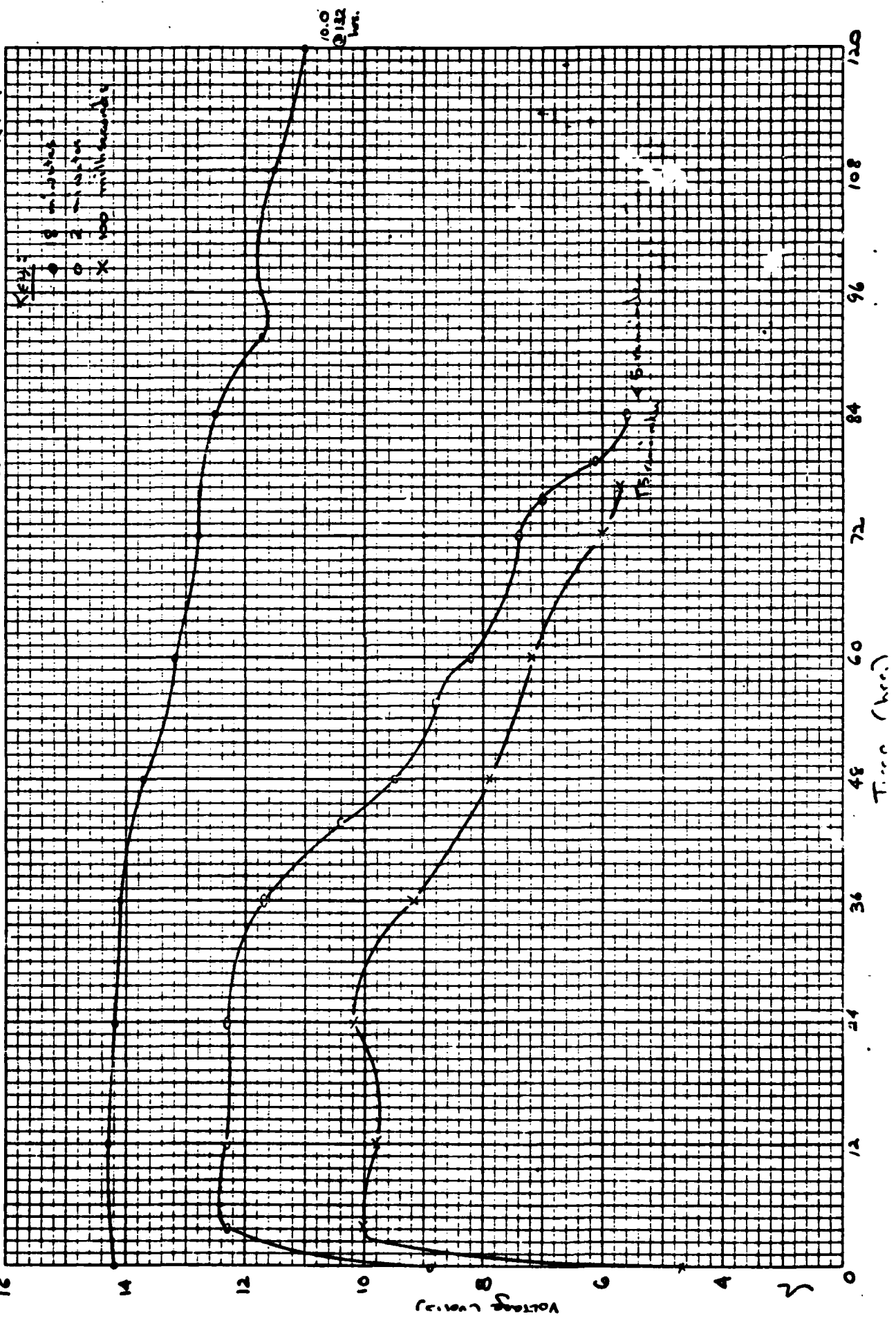


-12823

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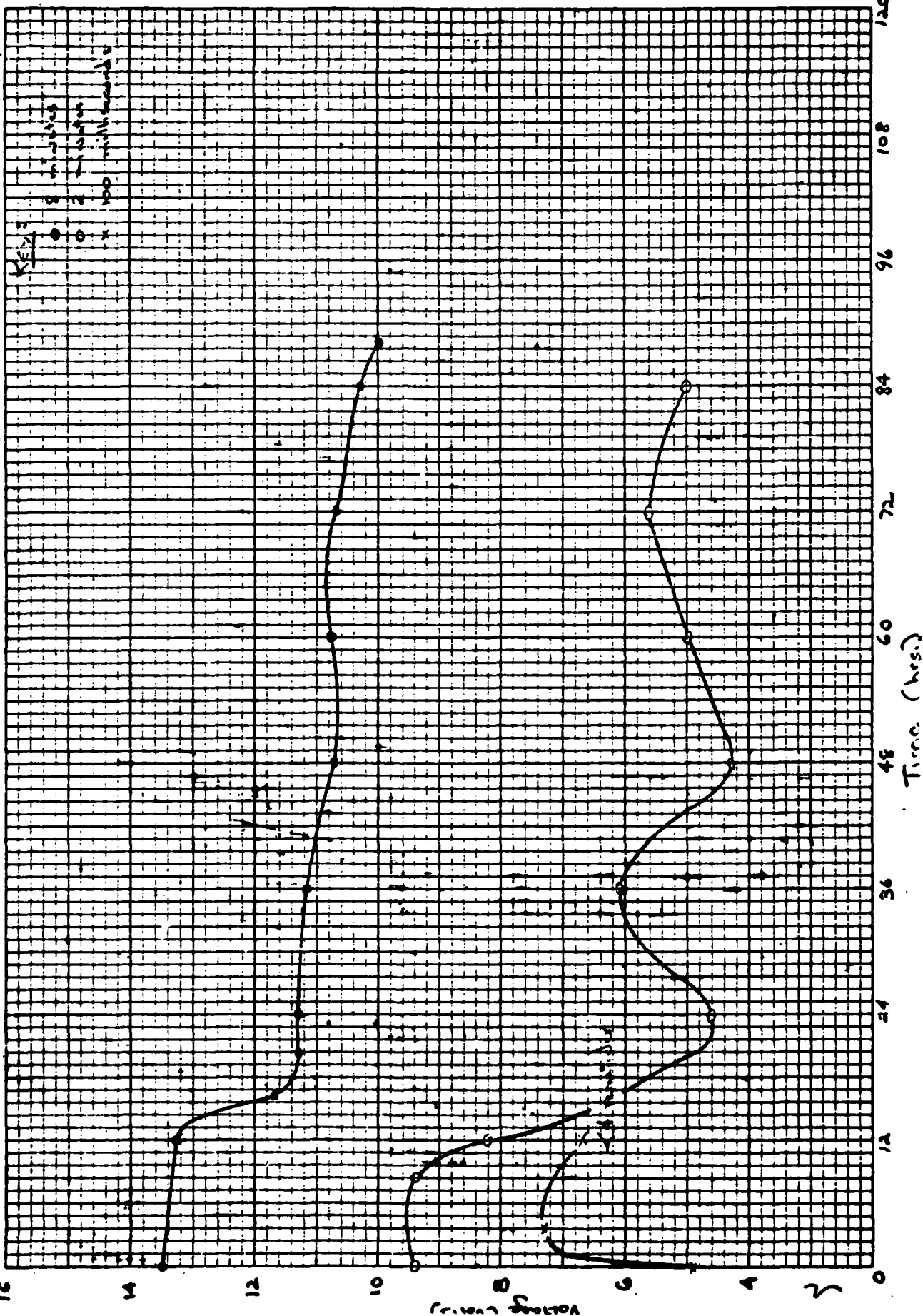
Unit # 37 Temp - RT of



-13823

Unit # 44

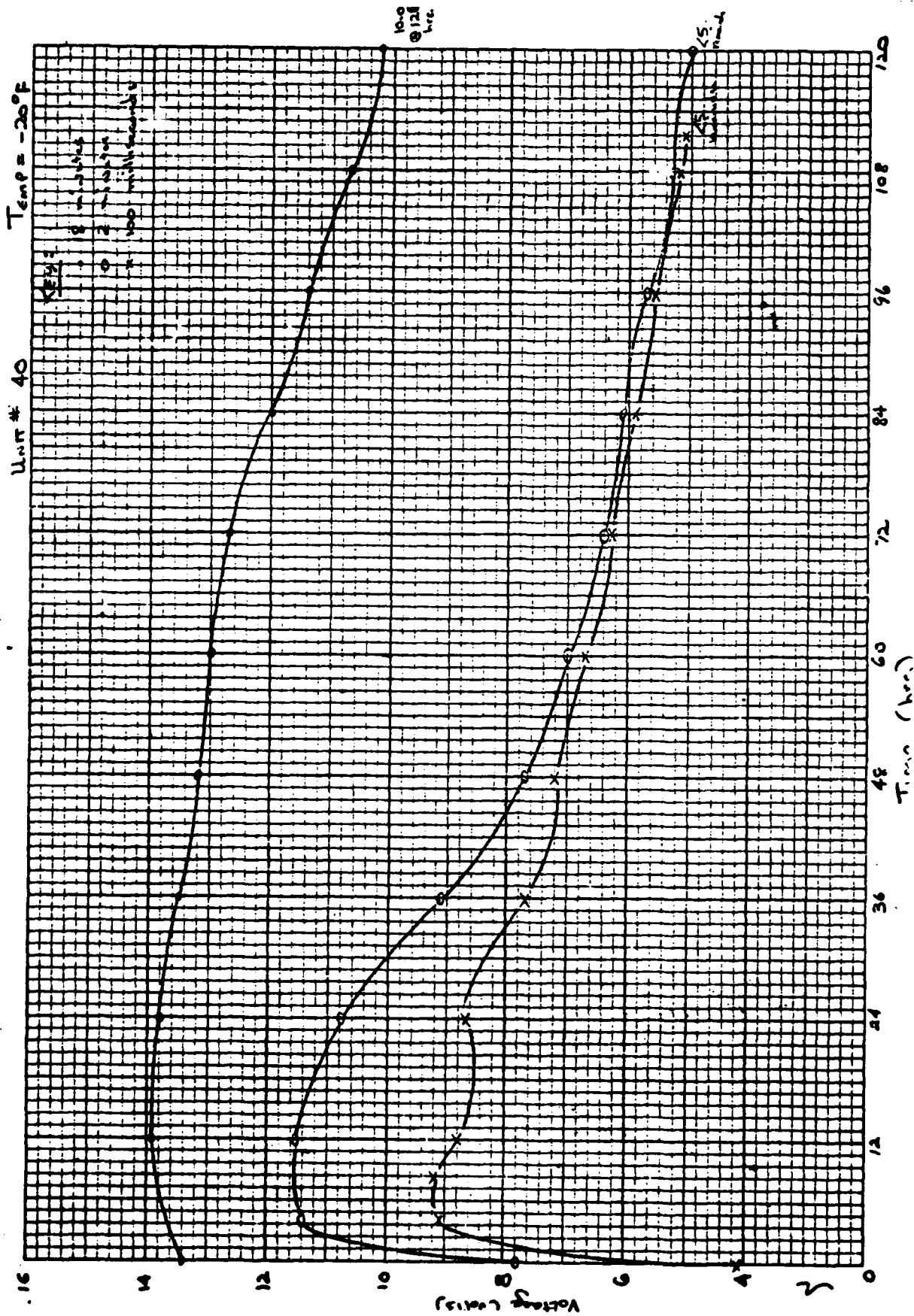
Temp = -20°F



NO. 3408-10 DIETZEN GRAPH PAPER
10 X 10 PER INCH

EUGENE DIETZEN CO.
MADE IN U. S. A.

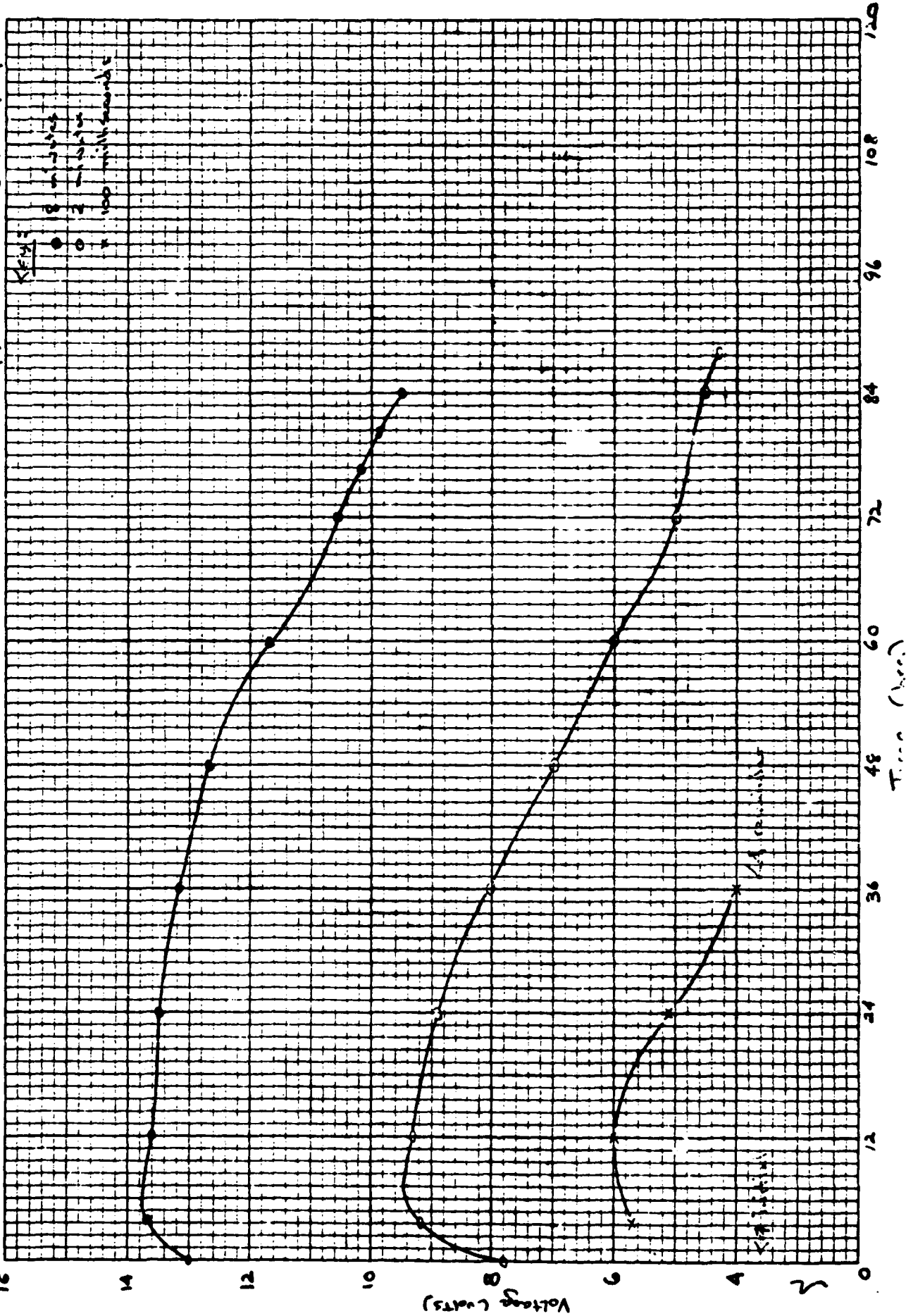
-4723



-15 823

Temp = -40°F

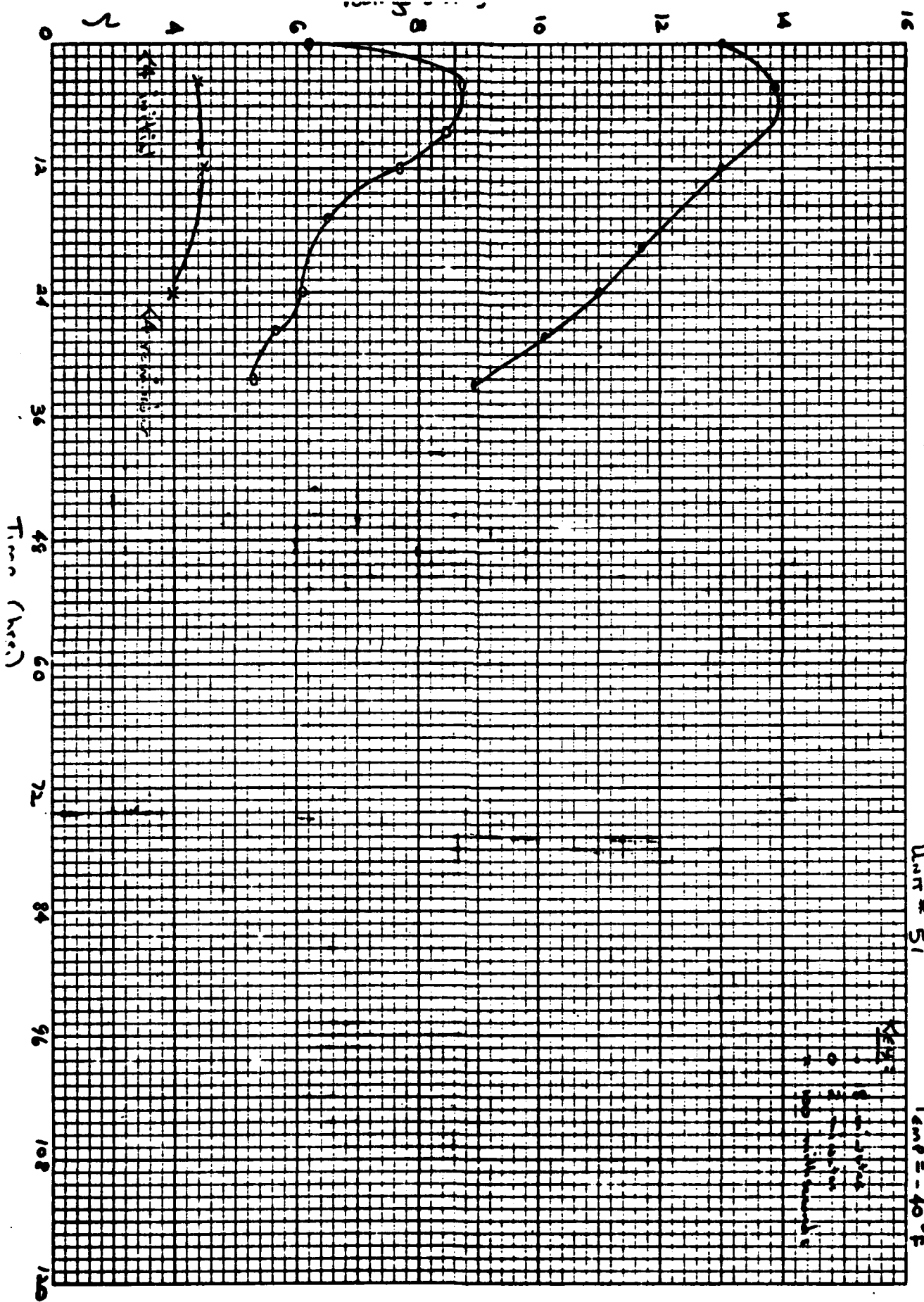
Unit # 49



-16 g 25

Unit # 51

Temp = -40° F



-17 of 23

Unit # 32

Temp = -40°F



INSPECTION PROCEDURE

21823

HONEYWELL INC.

MI-10
REV. 3
6/70

YES ☐ NO ☐		3 - 3/4	BA 6336		PAGE 4 OF 6	
VSP. DEPT.	CERTIFICATION REQ.	OP NUMBER	PART NAME	PART NUMBER	REV. NO.	
CHARACTERISTIC			CD	AQL	EQUIP	REF
4. TEMPERATURE TESTING - RANDOMLY SELECT GROUPS OF FOUR (4) & RANDOMLY ASSIGN TO FOLLOWING TEMPERATURE TESTS. (*CONDITION UNITS FOR EIGHT HOURS PRIOR TO COMMENCING TEST) 75°F ± 70°F 125°F ± 30°F * -20°F ± 30°F * -40°F ± 30°F * NOTE: UPON START OF DISCHARGE UNDER ANY TEST, TRANSIENT VOLTAGE BELOW 10.0 VOLTS. CANNOT EXCEED 0.1 SECOND DURATION. DURING TEST, END OF LIFE OCCURS AT 10.0 VOLTS. AFTER CONDITIONING TIME TEST UNITS					TEMP. CHAMBER UNICORDER	
Reproduced from best available copy.						
SERVICE NUMBER		SPECIFICATION		DATA REC. NO.		SAMPLING PLAN NO.
DATE		DATE		DATE		DATE
APPROVAL		APPROVAL		APPROVAL		APPROVAL
ISSUE		DATE		DATE		DATE
APPROVAL		APPROVAL		APPROVAL		APPROVAL
DATE		DATE		DATE		DATE

- 22823

INSPECTION PROCEDURE

HONEYWELL INC.

HI-10
REV. 3
6/70

PAGE 5 OF 6

YES	NO	3 - 3/4	OP NUMBER	PART NAME	CD	AQL	EQUIP	REF
☐	☐			B1 5281				
AS FOLLOWS USING THE A2 SECTION OF BATTERY LOAD CONDITION & SEQUENCE a. $4.8 \pm 10\%$ OHMS FOR 100 MINS b. $14.0 \pm 10\%$ OHMS FOR 2 MINUTES c. $291 \pm 10\%$ OHMS FOR 18 MINUTES. REPEAT CYCLE UNTIL BATTERY DISCHARGES TO 10.0 VOLTS, CONTINUE DISCHARGE FOR AT LEAST ONE HOUR AFTER THE 10.0 VOLT LEVEL OR UNTIL 9.0 VOLTS IS OBTAINED. REQUIREMENTS ARE 14.4 VOLTS NOMINAL, 16.6 VOLTS MAX & 10.0 VOLTS END OF LIFE REQUIRED LIFE IS 750 F = 108 HRS. 1250 F = 90 HRS. -200 F = 72 HRS. -400 F = 36 HRS. NOTIFY QUALITY ENGINEERING IMMEDIATELY ANY UNIT FAILS THESE REQUIREMENTS BUT CONTINUE TEST UNLESS OTHERWISE ADVISED. 6711								
REPRODUCED FROM BEST AVAILABLE COPY.								
DATE: 11-22-74 APPROVAL: [Signature] ISSUE: [Signature] DATE: 11-22-74 APPROVAL: [Signature] DATE: 11-22-74 APPROVAL: [Signature]								
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-23423

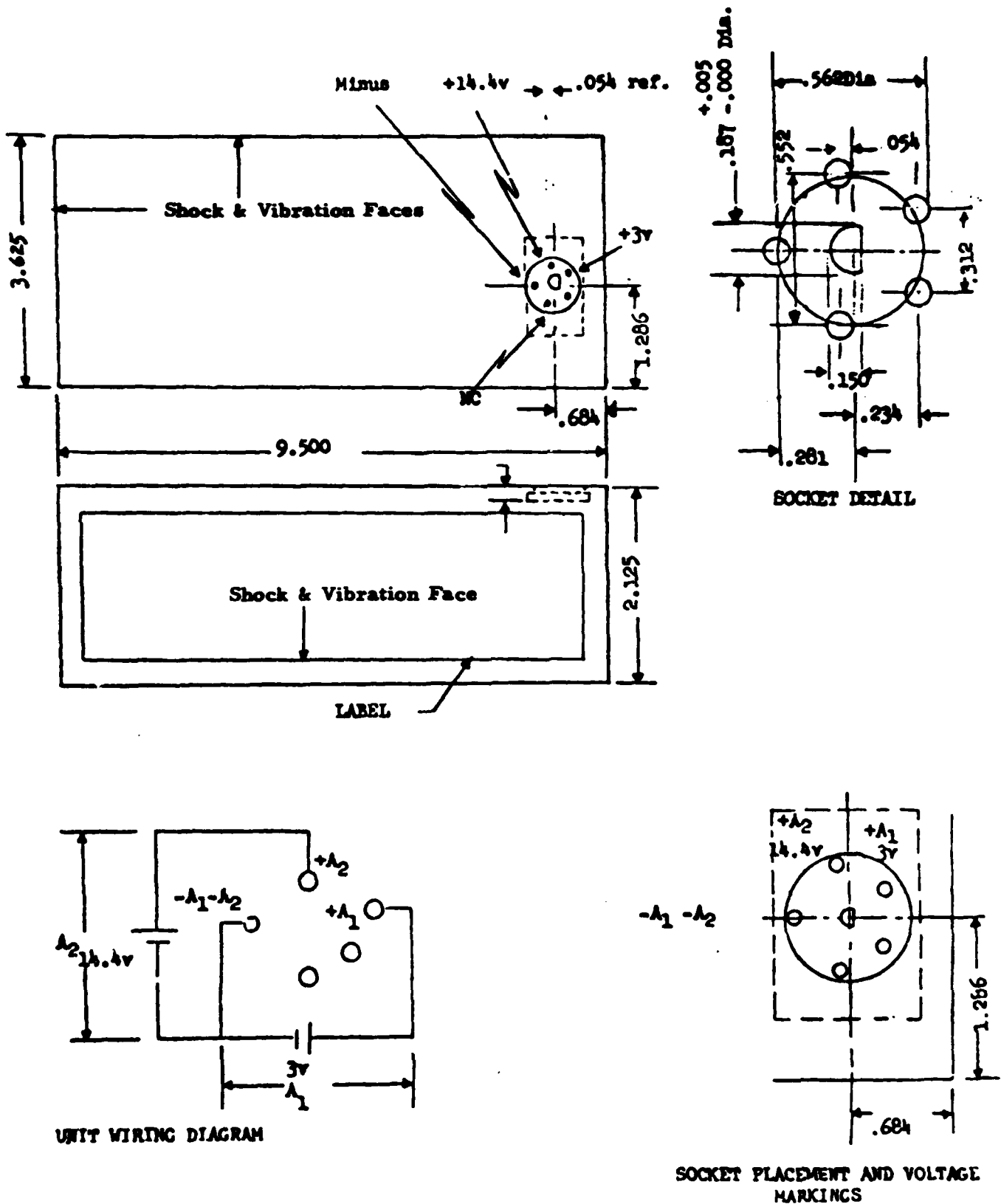


Figure 1. Battery, Primary, BA-5386(U)/U

APPENDIX B

GOVERNMENT AND AERONAUTICAL
PRODUCTS DIVISION

REPORT NO. 4509-3 (#1)

DEV. NO. BA 5386

COPY LIST:

B. C. Tierney
C. T. Dils
W. F. Kawalec
C. R. Walk
N. A. Remer
J. O. Crabb

ENGINEERING TEST REPORT

DATE 28 January 75

PAGE 1 OF 12

ISSUED BY: Power Sources Center

SUBJECT

Post-mortem Analysis of BA5386 Batteries Built under Contract No. DAAB07-71-C-0191.

This report covers the post-mortem examination of BA5386 batteries following high temperature storage, shock vibration and electrical discharge.

KEYWORDS:

SO₂
Batteries

ATTACHMENTS:

DATA BOOK NO. PAGE

REQUESTED BY
N. A. RemerDATE
1/13/75WRITTEN BY
J. R. BacklundDEPARTMENT
Products

400

APPROVED
N. A. Remer

I. INTRODUCTION

This study was undertaken to determine the cause of failure of BA5386 batteries tested in accordance with ECOM guidelines dated 15 April 1974. A lot of 66 batteries were built, of which 16 were to be tested and the remainder delivered.

The sixteen test batteries were subjected to high temperature storage, shock, and vibration. In addition, fourteen of these were put thru a temperature and humidity (T & H) cycle and all but one of these were electrically discharged.

The three batteries that were not electrically discharged were removed due to excessive electrolyte leakage.

None of the thirteen batteries discharged met this electrical requirement.

Due to the volume of these batteries, the high temperature storage was done in two chambers. On the twenty-third day of storage, one of the chambers went out of control and the temperature reached 190°F for 1.9 hours.

Two batteries were chosen for post-mortem analysis. One had not been electrically discharged or exposed to T & H, but was in the oven that went out of control. The other battery had been thru all of the environmental tests, shock, and vibration and electrically discharged. It was stored in the chamber that did not go above 165°F.

II. CONCLUSIONS

- 1) The batteries failed due to excessive cell leakage and the inability of some cells (over 20%) to discharge due to high terminal resistance.
- 2) Temperatures higher than the required 160°F test temperature substantially accelerated the leak rate even for short exposure time to higher temperature.
- 3) Leakage caused formation of a high resistance film between the cover and contact ring in the positive terminal.
- 4) Excessive leakage may be due to soldered connections.
- 5) Damage was confined to cells. There is no evidence of battery damage due to shock, vibration or any other tests done under this program.

III. RECOMMENDATIONS

- 1) Replace the plastic rupture disc with a thin aluminum rupture cup design for the cell closure. This eliminates the very thin vapor disc, and will provide a more solid support to prevent bowing of the back up ring or cover for the rupture cup. This design is currently being evaluated.
- 2) To prevent movement of the cell wrap, use a wider lead from the anode to the case with better and more welds to secure it. This modification is now in production. Additional protection could be achieved thru the use of two negative leads welded on opposite sides of the can.
- 3) To prevent any damage to the closure seal due to soldering, use welded connections.
- 4) Test four of the deliverable batteries (room temperature stand only) under ECOM load to determine whether batteries not subject to environmental testing perform differently than those subject to environmental conditions.

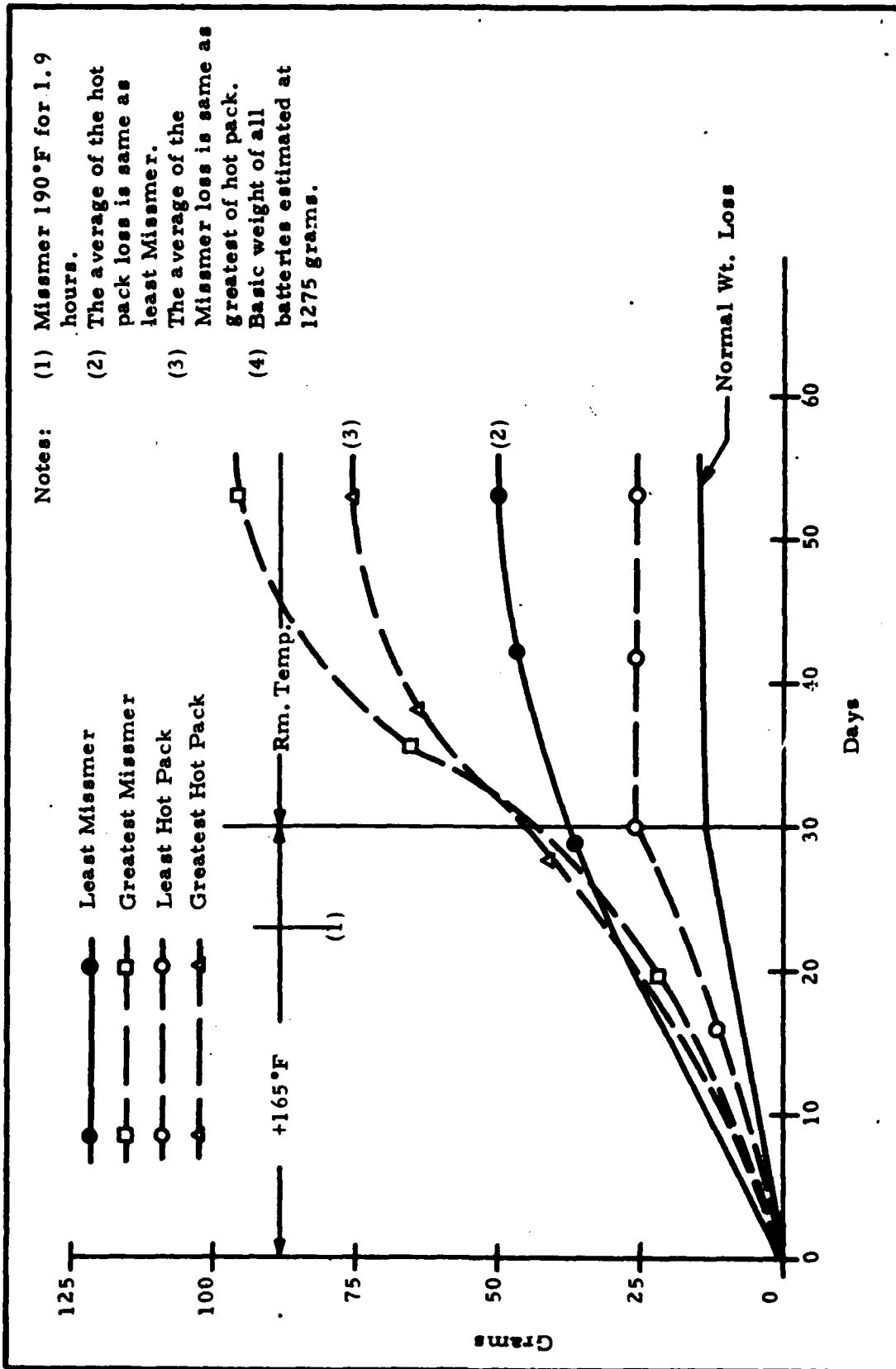
2 at -20°F

2 at room temperature

- 5) One battery on room temperature stand has an open by OCV check. PM this battery to determine reason.

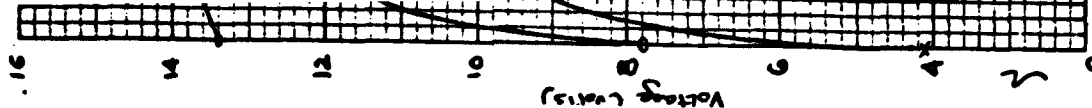
IV. DISCUSSION OF RESULTS

- 1) High temperature accelerates the leak rate. Batteries that were stored at 160°F and exposed to 190°F, even for a short time, leaked at a rate 50% greater than batteries not subject to the over-temperature condition. (Ref. Figure 1). This was caused by excessive bowing of the safety disc due to higher vapor pressure and softening of the plastic seal causing some breakdown of the seal at the edge of the safety disc.
- 2) Some cells had high resistance between the positive lead and the cover. This was attributed to electrolyte leakage between the safety disc, cover and the contact ring. This allowed the presence of a film of corrosive electrolyte between the contact ring and the cover causing a high resistance connection. This condition was checked against similar cells stored



COMPARISON WEIGHT LOSS VS. CHAMBER

FIGURE 1



ETR 4509-3 (#1)

Pg. 5 of 12

130 days at +165°F. These cells had resistances of 0.04 - 0.20 ohm indicating that the high resistances found in the battery test cells was caused by excessive leakage.

- 3) The soldering of the cell interconnections and diode leads onto the cover, may have changed the characteristics of the seal grommet due to localized heat thus contribution to leakage. Individual soldered units are currently in high temperature storage to check this condition.
- 4) There is evidence of corrosion of the aluminum foil vapor seal. This may have been accelerated by leaks in the crimp seal. The corrosion noted on these cells was compared with cells of similar construction, that were stored at +165°F for 130 days. These cells also all had corrosion of the aluminum foil disc but not to the degree noted in the battery test cells. In addition, three out of the four PM cells that had been exposed to excess storage temperature had corrosion holes plus tears at the edge of the recess in the safety disc.
- 5) Three of the eleven PM cells had internal open circuits; two of these were the positive lead and one the negative.

V. OBSERVATIONS

- 1) When the batteries on high temperature storage were weighed on the 23rd day, the units in the Missmer oven (that went to 190°F) showed a leak rate 17% higher than the batteries from the Hot Pack. The batteries exposed to the excessive high temperature continued to leak at a faster rate. A graph showing comparison of these leak rates (by weight loss) is included as Figure 1; also, a table of weights is included as Table I.
- 2) Eight batteries stored at room temperature were weighed on December 16 and again on January 21. Two units (#58 & #26) appear to have been misweighed and were dropped from the comparison. Analysis of this data (Table II) indicates a cell leakage rate of 5 mg/day vs. a normal rate (from cell tests) of 2.0 - 2.5 mg/day at room temperature. A graph showing room temperature leakage is shown in Figure 2.
- 3) Battery #15 was taken apart and the weight loss of each of the 15 cells was determined. The total of these losses was added to the weight of the battery at the time of post mortem. A table showing these weights plus other PM data is included as Table III. A graph analyzing weight loss for this battery is shown in Figure 3.

TABLE I
WEIGHT LOSS OF BATTERIES, HIGH TEMPERATURE
STORAGE, SHOCK, VIBRATION AND T & H

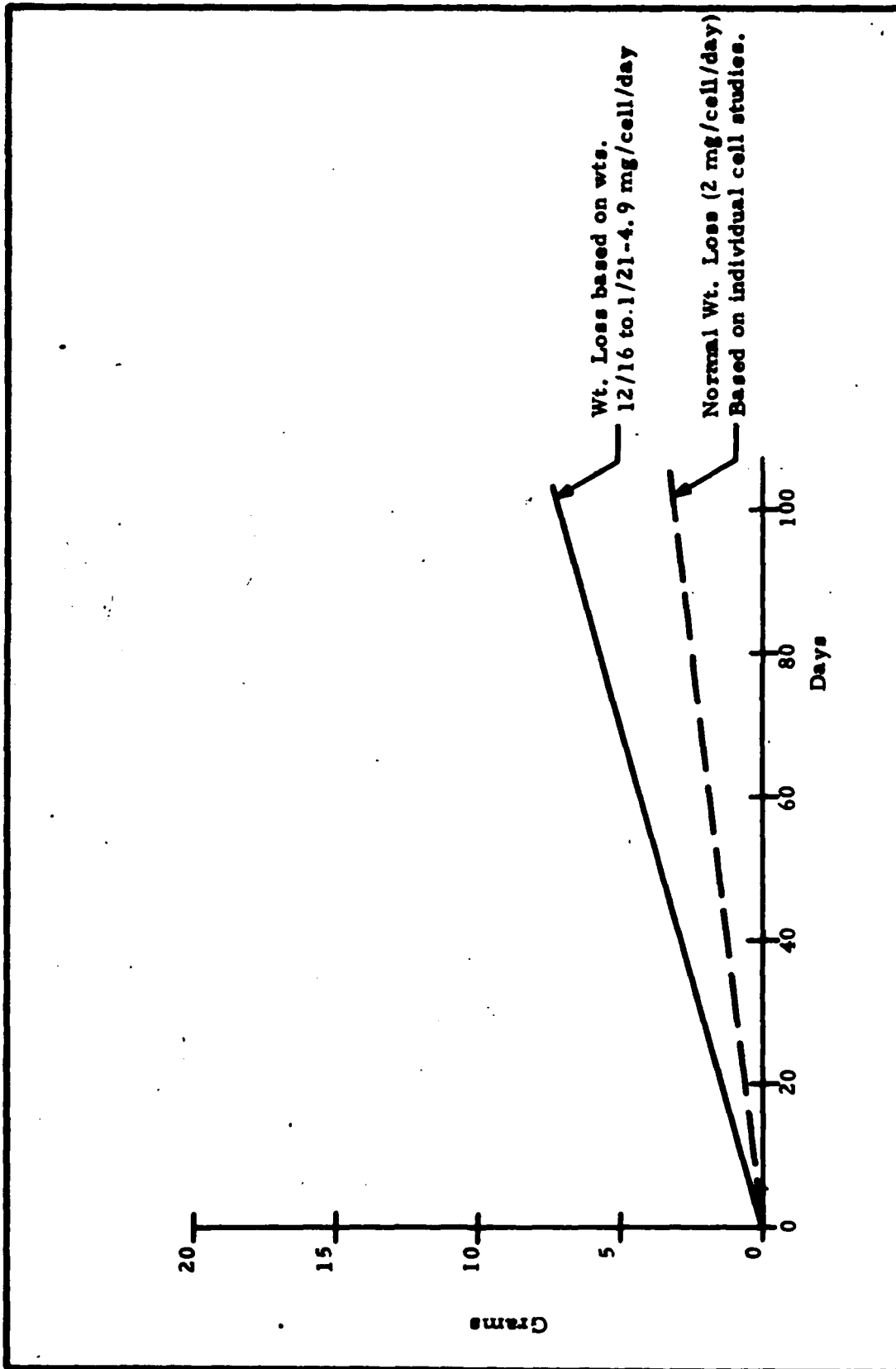
Batt. No.	(Weights in grams)					Loss 6 Days	After T & H	Loss 14 Days	1/15	Loss 29 Days	Est. Total Loss ⁽¹⁾
	12/16	12/22	12/30	12/30	12/30						
Mismer ⁽⁴⁾											
28	1235	1225	1209	1209	1203	10	1209	26	1203	32	72
51	1244	1237	1231	1231	1225	07	1231	13	1225	19	50
41	1228	1216	1192	1192	1178	12	1192	36	1178	50	97
15	1246	1232	1202 ⁽²⁾	1202 ⁽²⁾	1179 ⁽³⁾	14	1202 ⁽²⁾	44	1179 ⁽³⁾	67	96
44	1231	1218	1178	1178	1169	13	1178	53	1169	62	106
36	1233	1221	1218	1218	1207	12	1218	15	1207	26	68
16	1252	1239	1205	1205	1199 ⁽³⁾	13	1205	47	1199 ⁽³⁾	53	76
37	1251	1239	1228	1228	1223	12	1228	23	1223	28	52
Avg.	1240					11.6		32		42.1	77.1
Hot Pack											
40	1238	1235	1223	1223	1221	03	1223	15	1221	17	54
50	1252	1250	1252	1252	1248	02	1252	0	1248	4	27
49	1248	1245	1228	1228	1218	03	1228	20	1218	30	57
11	1238	1235	1219	1219	1208	03	1219	19	1208	30	67
08	1247	1242	1225 ⁽²⁾	1225 ⁽²⁾	1199 ⁽³⁾	05	1225 ⁽²⁾	22	1199 ⁽³⁾	---	---
61	1240	1236	1240	1240	1232	04	1240	0	1232	8	43
06	1256	1249	1251	1251	1249	07	1251	5	1249	7	26
32	1242	1228	1207	1207	1199	14	1207	35	1199	43	76
Avg.	1245					3.9		14.5		19.9	50

⁽¹⁾ Estimated average battery weight at final assembly 1275.

⁽²⁾ Did not go thru T & H.

⁽³⁾ Were not electrically discharged.

⁽⁴⁾ Chamber that went to 190°F for 1.9 hours.



PROJECTED WEIGHT LOSS PER BATTERY AT ROOM TEMPERATURE

FIGURE 2

TABLE II
WEIGHTS OF BATTERIES, ROOM TEMPERATURE STAND

(Weights in grams)

<u>Battery No.</u>	<u>Weighing Date</u>	<u>12/16</u>	<u>12/30</u>	<u>1/2</u>	<u>1/6</u>	<u>1/15</u>	<u>1/21</u>
21		1273	1272	1272	1272	1272	1272
14		1273	1269	1269	1271	1269	1269
17		1281	1278	1277	1278	1278	1278
18		1270	1268	1267	1269	1268	1268
19		1270	1267	1268	1268	1268	1268
13		1275	1271	1271	1271	1271	1271
58		1280	1274	1273	1274	1274	1273
26		1280	1272	1272	1272	1272	1272

TABLE III

CHART OF POST-MORTEM BATTERY RESULTS

Cell No.	Filled Wgt.gm	Wgt.at PM gm	Elec. Loss gm	Res. + Lead to Cover(Ω)	Holes in Vapor Shield	Open - Lead	Open + Lead	Evidence of Elec. Disch.	Remarks
Battery #6 - Hot Pack +165°F									
421	71.93	70.8	1.13	0	x	No	No	Yes	
425	71.48	70.3	1.18	9.1	x	No	No	Yes	
1018	71.63	70.35	1.28	580.0	x	No	No	None	
1078	72.54	71.69	0.85	33.0	x	Yes	No	None	
1109	72.58	70.53	2.06	9.9	x	No	Yes	None	
--	--	--	--	11.0	x	No	No	--	
--	--	--	--	104.0	x	No	No	Yes	Edge of contact disc folded
Battery 1275⁽²⁾ 1249 36									
Battery #15 - Mismmer +165°F (Subject to overtemperature)									
387	72.16	70.70	1.46	0.4	x ⁽¹⁾	No	--	None	
386	72.24	70.05	2.19	0.1	x ⁽¹⁾	No	--	None	
389	72.21	68.35	3.86	--	-	-	--	--	
1252	72.40	59.95	12.45	--	-	-	--	--	
1270	72.58	70.55	2.03	--	-	-	--	--	
1274	71.89	62.20	9.69	--	-	-	--	--	
1097	72.20	70.85	1.35	--	-	-	--	--	
1025	72.00	70.70	1.30	--	-	-	--	--	
1064	71.85	69.65	2.20	--	-	-	--	--	
1153	72.83	58.30	14.53	--	-	-	--	--	
1147	73.09	60.80	12.29	7.5	x ⁽¹⁾	No	Yes	None	

TABLE III (continued)

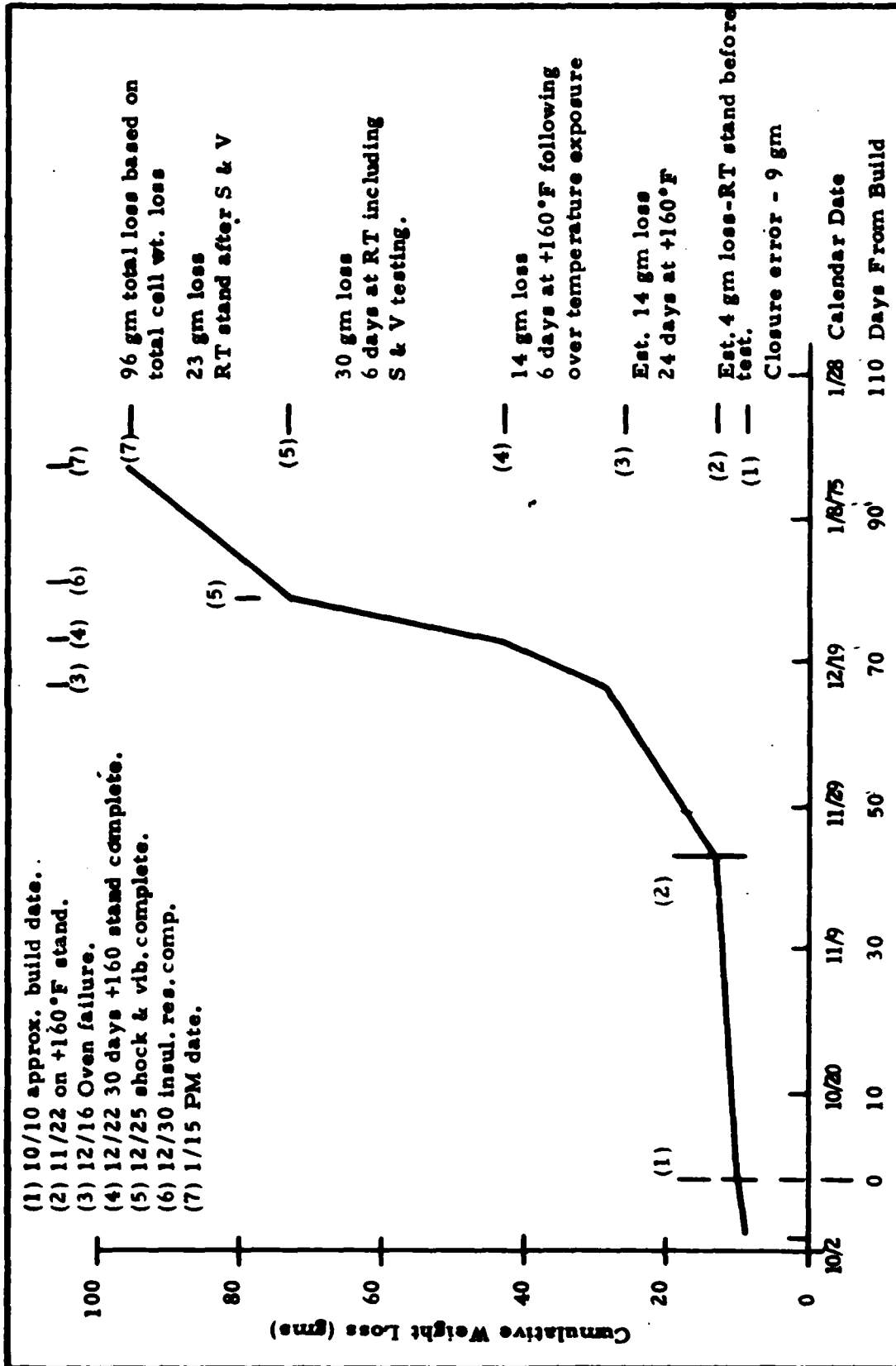
CHART OF POST-MORTEM BATTERY RESULTS

Cell No.	Filled Wgt. gm	Wgt. at PM gm	Elec. Loss gm	Res. + Lead to Cover (Ω)	Holes in Vapor Shield		Open - Lead	Open + Lead	Evidence of Elec. Disch.	Remarks
<u>Battery #15 - Mismar +165°F (cont'd)</u>										
1154	73.59	61.10	12.49	--	x		No	No	None	
997	71.84	69.70	2.14	--	-		--	--	--	
113	71.15	60.90	10.25	--	-		--	--	--	
757	70.54	69.10	1.44	--	-		--	--	--	
Battery 1275 ⁽²⁾		1179	96							

(1) Sheared at edge of recess in safety disc.

(2) Calculated full battery weight.

(3) Based on anode conditions.



BATTERY #15 WEIGHT LOSS ANALYSIS

FIGURE 3

- 4) A high electrical resistance was found between the contact ring and the cover on some cells. On ten assemblies checked, seven had a resistance over 7 ohms, and one as great as 580 ohm. A heavy residue was found between the edge of the safety disc and the contact ring and a light film of non-conductive material was found between the cover and the contact ring.
- 5) Some cells exhibited breaks in the aluminum foil vapor seal at the edge of the recess in the safety disc. These breaks were caused by excessive bowing of the center of the safety disc, due to exposure to the 190°F temperature. This allowed the foil to bow further into the cavity of the rupture disc and fracture at the sharp edge of the recess.
- 6) Internal open circuits were found in three cells. These were probably caused by movement of the cell wrap during shock and vibration. Cells that leak are more likely to fail during shock and vibration due to not having liquid electrolyte to dampen element movement. It has also been noted that in cells that are dry, the wrap tends to shrink and becomes a looser fit in the case.
- 7) One assembly (process) error was found. The side wall of the conductor ring was folded down. This collapsed section involved approximately 3/16" of the 3" circumference.
- 8) On one battery, where there had been excessive electrolyte leakage (#15) the copper wire connecting the cells in parallel was corroded.
- 9) The solder joints on all cells were good, but it was noted that, in general, the visible leakage of the cells was in close proximity to the solder joints on the cover.
- 10) There was no evidence of damage other than that caused by cell leakage. All cells, connectors, fuses, battery case, potting, etc. was intact.

VI. CHRONOLOGY

Aug. 15 - Oct. 15) Approx. date of assembly into batteries (ex. outside case).
 Nov. 22 - Batteries put on +160°F storage.
 Dec. 15 - One chamber (Missmer) out of control. Reached 190°F for 1.9 hours.
 Dec. 16 - 1st weighing of test and sample of RT stand batteries.
 Dec. 22 - Complete 30 day +160°F storage. Batteries weighed.
 Dec. 30 - Shock and vibration and electrical res. (T&H) complete - Test batteries weighed. Sample RT batteries weighed.
 Jan. 6 - All (50) room temperature stand batteries weighed.
 Jan. 15 - Post-mortem analysis.
 Jan. 21 - Sample of RT batteries weighed.

APPENDIX C

GOVERNMENT AND AERONAUTICAL
PRODUCTS DIVISIONREPORT NO. PTL-1338-1DEV. NO. BA5386/4509-3

COPY LIST:

J. O. Crabb
C. T. Dils
J. B. Jenkins
N. A. Remer
C. R. Walk
Central Files

DATE 2-11-75PAGE 1 OF 3

ISSUED BY:

Product Test Lab

Units Tested

Four (4) BA5386 ECOM batteries, identification numbers 27, 47, 56, and 58, PTL test numbers 750087 through 750090.

Purpose

To check failure analysis of ECOM batteries.

Procedure and Results

The batteries were put on test on 029-75 under the BA5386 test cycle (ECOM Test Cycle). Two units (27, 47) were tested at room temperature and the other two were tested at -20°F. The information was recorded on a Model 1508A Oscillograph and the records are in storage in the Test area. None of the units met their required run times of 80 hours for -20°F and 120 hours for room temperature. The following two pages show the results.

KEYWORDS:

ATTACHMENTS:

DATA BOOK NO. 1338

REQUESTED BY

J. R. Backlund

DATE

1-28-75

WRITTEN BY

B. F. Erwin

APPROVED BY

Products

APPROVED

W. F. Kawalec

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00-0000-000

TA 1238

-20°F

	56			52		
	100MS	2MIN	15MIN	100MS	2MIN	15MIN
00.0		15.0			15.0	
566.0	5.8	9.6	12.0	6.0	10.6	13.7
1HA	9.3	11.6	14.0	10.5	11.8	14.0
2HA	9.5	11.6	14.0	10.6	12.0	14.0
4HA	9.6	11.7	14.0	10.6	11.8	14.0
8HA	9.6	11.7	14.0	10.6	11.8	14.0
12HA	9.6	11.7	14.0	10.5	11.8	14.0
16HA	9.9	11.6	14.0	10.4	11.7	14.0
20HA	9.3	11.4	13.8	9.7	10.5	13.6
24HA	8.8	10.6	13.6	8.3	8.5	13.0
28HA	8.1	9.1	13.0	6.8	7.4	12.0
32HA	7.6	8.7	12.6	6.5	6.7	11.0
36HA	7.5	8.7	12.3	6.3	9.1	11.9
40HA	7.5	8.7	11.8	8.1	9.1	11.9
50HA	7.4	8.6	11.2	8.1	9.0	10.7
60HA	7.1	8.4	10.6	7.7	8.8	10.5
70HA	6.6	7.8	10.2	7.5	8.5	10.4
75HA	6.4	7.5	10.0	7.3	8.2	10.3
80HA	6.1	7.1	9.8	7.1	7.8	10.2
85HA	5.6	6.4	9.5	6.6	7.2	9.9
90HA	5.1	5.5	8.8	6.1	6.4	9.3
95HA	4.5	4.5	8.1	4.5	5.5	8.7
100HA	4.5	4.5	7.5	4.5	4.5	7.8
105HA	4.5	4.5	7.0	4.5	4.5	7.3
110HA	4.5	4.5	6.4	4.5	4.5	6.7
115HA	4.5	4.5	6.0	4.5	4.5	6.5
Rise Times (HAT - LWT)						
		75.0"		18.0"		84.0"

ROOM TEMP

	27			47		
	100RS	2MIN	1KMIN	100RS	2MIN	1KMIN
OCU		14.70			14.70	
ICCU		8.0	10.70	10.1	13.0	14.50
1HA	10.70	13.0	14.5	11.70	13.3	14.50
2HA	11.0	13.0	14.5	11.8	13.3	14.5
4HA	11.2	13.0	14.5	11.8	13.3	14.5
8HA	11.2	13.0	14.5	12.1	13.3	14.5
12HA	11.3	13.0	14.5	12.2	13.3	14.5
16HA	11.3	13.0	14.5	12.2	13.3	14.5
20HA	11.3	13.0	14.5	12.2	13.3	14.5
24HA	11.2	13.0	14.5	12.2	13.3	14.5
28HA	11.0	12.8	14.5	12.2	13.3	14.5
32HA	10.5	12.5	14.5	12.1	13.2	14.5
36HA	9.7	12.2	14.5	11.9	13.0	14.5
40HA	9.2	11.6	14.3	11.5	12.7	14.4
44HA	9.2	11.0	14.1	11.0	11.7	14.3
48HA	10.0	10.7	11.7	10.1	10.8	11.5
52HA	10.0	10.7	11.7	10.0	10.7	11.6
56HA	9.9	10.7	11.7	9.9	10.7	11.5
60HA	9.9	10.7	11.7	9.9	10.7	11.5
64HA	9.8	10.7	11.6	9.9	10.6	11.5
68HA	9.8	10.7	11.6	9.8	10.6	11.5
72HA	9.7	10.7	11.5	9.8	10.6	11.5
76HA	9.7	10.7	11.5	9.7	10.5	11.5
80HA	9.7	10.7	11.5	9.6	10.5	11.5
84HA	9.6	10.6	11.5	9.3	10.3	11.4
100HA	9.3	10.4	11.5	7.3	8.0	11.0
110HA	<5	5.8	9.7	<5	<5	5.8
115HA	<5	<5	6.5	<5	<5	<5
REP TIMES (HAS '910")	35'20"	103'40"	109'00"	63'0"	96'0"	102'40"

APPENDIX D

GOVERNMENT AND AERONAUTICAL
PRODUCTS DIVISIONREPORT NO. PTL 1255-1DEV. NO. BA 5386/4509

COPY LIST:

J. R. Backlund
J. O. Crabb
C. T. Dils
J. B. Jenkins
C. R. Walk
Central Files

ENGINEERING TEST REPORT

DATE 2-21-75PAGE 1 OF ISSUED BY:
Product Test LabUnits Tested

Six (6) BA5386 (ECOM) batteries, identification numbers 07, 20, 34, 46, 60, and 64, PTL Test numbers 750145 through 750150.

Purpose

No test purpose stated on Test Requisition.

Procedure and Results

The batteries were put on test on 045-75 under the ECOM load cycle (4.8 Ω for 100 MS, 14.2 Ω for 2 minutes and 291 Ω for 18 minutes repetitive until 10 volt minimum) at room temperature (units 07, 20 and 64) and -20°F (units 34, 46, and 60). The batteries were prepared by the Production department to enable the monitoring of the individual cell stacks within the batteries. The full battery voltages were monitored on the Visicorder and the individual cell stacks were monitored on the DATM. All charts are in storage in the Test area. Table I shows the full battery voltages versus time. Table II shows the first five hours readings of each cell stack and Table III shows the voltage readings of the cells over time. None of the batteries met the specified run times of 120 hours at room temperature and 80 hours at -20°F. The following is a summary of the results.

Battery #	Temp °F	OCV	Run Time
07	R	15.30	87 Hours 40 Minutes
20	R	15.30	49 Hours 00 Minutes
60	R	15.30	91 Hours 00 Minutes
34	-20	15.40	54 Hours 00 Minutes
46	-20	15.30	79 Hours 40 Minutes
60	-20	14.98	64 Hours 20 Minutes

ATTACHMENTS:

DATA BOOK NO. PAGE

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2-14-75

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DEPARTMENT

APPROVED

Products

W. F. Kawalec

TABLE I

[illegible]

TABLE I Cont'd

Cell #	64 (ROOM)			20 (ROOM)			07 (ROOM)			
Volts At	18M	2M	100MS	18M	2M	100MS	18M	2M	100-MS	
OCV	----	15.3	-----	----	15.3	-----	----	15.3	-----	
ICCV	14.8	13.0	TEF	14.9	13.1	11.8	14.9	12.6	10.6	
2ND Pulses	14.5	13.2	12.1	14.9	13.6	12.6	15.0	13.4	11.8	
Time (Hrs.)	1	14.5	13.2	12.2	14.9	13.1	11.8	14.9	12.6	10.6
	2	14.5	13.2	12.2	15.0	13.7	12.7	15.0	13.5	12.2
	3	14.5	13.3	12.2	15.0	13.7	12.7	15.0	13.6	12.2
	4	14.5	13.3	12.2	15.0	13.8	12.7	15.0	13.6	12.2
	5	14.5	13.3	12.2	15.0	13.8	12.8	15.0	13.6	12.2
	8	14.5	13.3	12.3	15.0	13.8	12.8	15.0	13.7	12.3
	12	14.5	13.4	12.4	15.0	13.9	12.9	15.0	13.8	12.5
	16	14.5	13.4	12.4	15.0	13.9	12.9	15.0	13.8	12.6
	20	14.5	13.5	12.5	15.0	13.9	12.9	15.0	13.8	12.6
	24	14.5	13.5	12.5	15.0	13.9	13.0	15.0	13.8	12.6
	28	14.5	13.5	12.5	15.0	13.9	13.0	15.0	13.8	12.6
	32	14.5	13.5	12.5	15.0	13.8	12.8	15.0	13.8	12.6
	36	14.5	13.5	12.5	15.0	13.7	12.7	15.0	13.8	12.6
	40	14.5	13.5	12.5	14.9	13.6	12.6	15.0	13.8	12.6
	44	14.5	13.5	12.5	14.7	12.9	12.1	15.0	13.8	12.6
	48	14.5	13.5	12.5	13.1	10.6	10.5	15.0	13.8	12.6
	52	14.5	13.4	12.5	----	----	----	15.0	13.8	12.6
	56	14.5	13.4	12.5				15.0	13.8	12.6
	60	14.5	13.4	12.4				15.0	13.7	12.6
	64	14.4	13.3	12.3				14.8	13.6	12.5
68	14.3	13.2	12.2				14.6	13.5	12.3	
72	14.3	13.2	12.1				14.6	13.4	12.1	
76	14.3	13.1	11.9				14.6	13.4	11.9	
80	14.2	13.0	11.7				14.5	13.2	11.7	
84	14.1	12.8	11.6				13.8	12.3	10.6	
88	14.0	12.6	11.1				----	----	----	
92	----	----	----				----	----	----	

TABLE I Cont'd

LAST FIVE HOURS ON EACH BATTERY

Cell #64 (Room)					Cell #20 (Room)					Cell #07 (Room)				
Hr	Cum. Hrs	Volts at			Hr	Cum. Hrs	Volts at			Hr	Cum. Hrs	Volts at		
		18M	2M	100MS			18M	2M	100MS			18M	2M	100MS
1	87	14.0	12.7	11.2	1	45	14.7	12.6	11.8	1	84	13.8	12.3	10.6
2	88	14.0	12.6	11.1	2	46	14.5	12.2	11.6	2	85	13.8	12.1	10.5
3	89	14.0	12.4	10.8	3	47	14.0	11.0	11.3	3	86	13.8	12.0	10.5
4	90	14.0	12.2	10.6	4	48	13.1	10.6	10.5	4	87	13.8	11.8	10.2
5	91	10.9	11.5	9.9	5	49	12.9	10.5	9.9	5	88	13.7	11.6	9.9

Cell #46 (-20°F)					Cell #60 (-20°F)					Cell #34 (-20°F)				
Cum.		Volts at			Hr	Cum.	Volts at			Hr	Cum.	Volts at		
Hr	Hrs	18M	2M	100MS			18M	2M	100MS			18M	2M	100MS
1	77	13.8	11.5	10.4	1	61	13.6	11.3	10.4	1	50	14.4	11.7	10.5
2	78	13.7	11.4	10.2	2	62	13.6	11.3	10.2	2	51	13.9	11.6	10.3
3	79	13.7	11.2	10.2	3	63	13.6	11.2	10.2	3	52	13.9	11.5	10.2
4	80	13.6	11.1	10.1	4	64	13.6	11.0	10.1	4	53	13.8	11.4	10.1
5	81	13.5	10.9	9.9	5	65	13.6	11.0	9.9	5	54	13.8	11.2	9.9

TABLE II

Unit #	Channel #	Time: 045-75				
		1700	1800	1900	2000	2100
20 RT	289	271	289	289	289	289
	290	265	287	287	287	287
	291	270	287	287	288	288
	292	269	286	286	287	287
	293	266	285	285	286	285
07 RT	294	267	287	288	289	289
	295	261	287	287	287	288
	296	269	286	287	287	287
	297	261	285	285	286	286
	298	265	285	285	285	285
64 RT	299	268	289	289	289	289
	300	268	287	287	289	289
	301	267	286	287	287	287
	302	269	286	287	287	287
	303	265	285	285	285	285
46 -20	257	253	284	286	285	286
	258	255	283	283	284	284
	259	252	279	280	281	281
	260	253	280	281	281	281
	261	248	279	280	280	281
60 -20	262	251	283	282	282	282
	263	297	297	297	297	297
	264	196	261	262	263	263
	265	251	281	282	283	282
	266	249	279	280	281	281
34 -20	267	252	281	282	283	283
	268	252	283	282	283	283
	273	250	280	281	281	281
	274	297	297	297	297	297
	275	174	256	257	257	257

TABLE III

[illegible]

TR 1255

25

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UNIT #	64	72	80	88	96	104	112	120	128	136	144	152	160	168	176	184	192	200	208	216	224	232	240	248	256	264	272	280	288	296	304	312	320	328	336	344	352	360	368	376	384	392	400	408	416	424	432	440	448	456	464	472	480	488	496	504	512	520	528	536	544	552	560	568	576	584	592	600	608	616	624	632	640	648	656	664	672	680	688	696	704	712	720	728	736	744	752	760	768	776	784	792	800	808	816	824	832	840	848	856	864	872	880	888	896	904	912	920	928	936	944	952	960	968	976	984	992	1000																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																
Channel #	299	299	295	293	293	293	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287	287

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TABLE III

1063

UNIT #	CHANNEL	-20									
		262	263	264	265	266		34	267	268	269
045-2344	297	297	297	294	294	294		297	297	297	297
100 854	000	297	297	180	245	242		242	247	248	297
046 0000	283	297	297	265	282	281		283	283	281	207
0800	282	297	297	263	282	281		283	283	281	297
1000	283	297	297	265	282	281		284	283	282	297
047 0000	281	297	297	261	282	281		283	282	282	297
0800	245	297	297	189	253	250		283	249	253	297
1000	278	297	297	255	282	280		283	280	281	297
043 0000	275	297	297	248	281	279		283	279	281	297
0800	272	297	297	241	281	279		282	279	281	297
1000	260	297	297	215	279	278		281	278	279	297
049 0000	223	297	297	146	279	279		281	277	279	297
0800	161	297	297	0.31	279	279		282	278	278	297
1000	104	297	297	—	279	278		279	276	278	297
0000	—										
0800	177			177							177
1000	177			177							177
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0800	—										
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