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# HEAT-STERILIZABLE, REMOTELY ACTIVATED BATTERY DEVELOPMENT PROGRAM PHASE II

Fifth Quarterly Report

Period: July 1, 1969 to September 30, 1969

Contract No. 952214
NAS7-100

October 25, 1969

JET PROPULSION LABORATORY
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Electronics Division
Couples Department
Joplin, Missouri 64801

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# BATTERY DEVELOPMENT PROGRAM

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"This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, as sponsored by the National Aeronautics and Space Administration under Contract NAS7-100."

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## ABSTRACT

This report discusses the progress during the fifth quarter of the development of a heat sterilizable, sealed, remotely activated battery per contract number 952214 between the Jet Propulsion Laboratory and Eagle-Picher Industries, Inc. The work is being conducted under Phase II of the contract which is the assembly of components selected from Phase I into a battery.

A brief cell study was conducted to determine the most efficient design for the requirements. The tests consisted of separator studies with wet stand life and discharge rates as test parameters. The results show that 2409 cotton webril is an efficient separator if the wet stand life is not greater than 30 minutes. If the no-load activated stand is in excess of one hour but less than 72 hours, a combination of 4366T hemp and .010 inch thick asbestos is more efficient. Between the 30 minute and one hour period, the two appear to be essentially equal in performance. These determinations are based on the 10 and 24 minute discharge rates described in the contract's statement of work.

Ignitors (NEI-3) manufactured by Network Electronics were proven capable of heat sterilization. Fifty units were subjected to sinusoidal vibration at levels up to 30 g's, no-fired at 0.55 ampere for 16 seconds while stabilized at 165°F, heat sterilized and subjected to a Bruceton test. The results show that the ignitors will function with a reliability of 0.997 at a current level of 1.682 amperes.

Components for the initial prototype battery have been fabricated or procured. The design consists of 22 cells in series. The separator system is 2409 webril. As defined now, the physical size of the battery is 6.62 inches by 7.12 inches by 6.03 inches.

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## 1.0 INTRODUCTION

This report presents the results of work during the fifth quarter ending 30 September 1969. Various cell configurations leading towards the fabrication of a remotely activated heat sterilized battery were studied. Additional testing was performed with ignitors for use as the initiating mechanism of the battery. A preliminary layout of the first prototype battery has been made.

## 2.0 TECHNICAL DISCUSSION

### 2.1 Cell Design

As a continuation of the cell study described in the fourth quarterly report, tests were conducted on various design configurations. The tests involved discharged at one of two rates along with activated stands of varying length. The two rates were 46.2 amperes (1200 watts) and 19.2 amperes (500 watts). All of the cells tested were enclosed in fabricated polysulfone cell cases. In order to remove excess solvent from the polysulfone seals, each cell was subjected to vacuum while in an ambient of 85°C before being heat sterilized.

The first series of tests were actually a continuation of those reported in the fourth quarterly report. Four silver-oxide and five zinc plates were used in each cell. The positive plates had a nominal weight of 2.4 grams per square inch and an average thickness of .028 inch. There were two types of negative plates used. Three of the five negative plates averaged 1.18 grams per square inch and .027 inch thick. The two outside negative plates were .066 gram per square inch and .018 inch thick. Each plate was separated with single layers of .010 inch thick asbestos and 4366T hemp. The asbestos was positioned against the positive plate. Each cell was activated with a 1.30 specific gravity solution of potassium hydroxide.

2.1 Cell Design (Continued)

The cells were then discharged at the time intervals (wet stand) and amperages listed below:

| Cell Number | Wet Stand | Discharge Rate |
|---|---|---|
| 8 | 30 minutes | 46.2 amps |
| 9 | 45 minutes | 19.2 amps |
| 10 | 72 hours | 46.2 amps |
| 11 | 144 hours | 46.2 amps |
| 12 | 216 hours | 46.2 amps |
| 13 | 288 hours | 46.2 amps |

Results of the discharges indicated that there was some capacity loss with respect to wet stand time. This can be seen by the curves depicted in Figures I through VI. Cells having a short stand life performed satisfactorily at both the 1200 and 500 watt rates. However, at the end of 72 hours, discharges at both rates showed a capacity loss of approximately 75 percent over those cells subjected to 30 minute stand lives. Plate voltages were approximately .15 to .2 volts lower after more lengthy wet stands. One cell (number 13) was completely self-discharged after 180 hours of open circuit. Cell number 12 had a four minute discharge life at the end of 260 hours. The remaining cells performed at least 11.75 minutes at 46.2 amperes. In each case the voltage cutoff was 1.0 volts. After discharge the expended cells were disassembled in an attempt to visually determine possible failure modes. No evidence of a direct short was found. The positive electrodes had a smooth cream texture which is representative of a completely discharged cell. In view of this, it was theorized that the degradation of the cell was a result of the separator becoming loaded with silver effecting a high resistance short between the positive and negative plates. This type of failure would require a lengthy period of time to discharge the cell and the cause of failure would be difficult to find. Examination of the separators removed

Cell No. 8
Discharge Characteristics
After
Heat Sterilization
Separation - 4366T Hemp and .010 Asbestos
Wet Stand - 30 Minutes

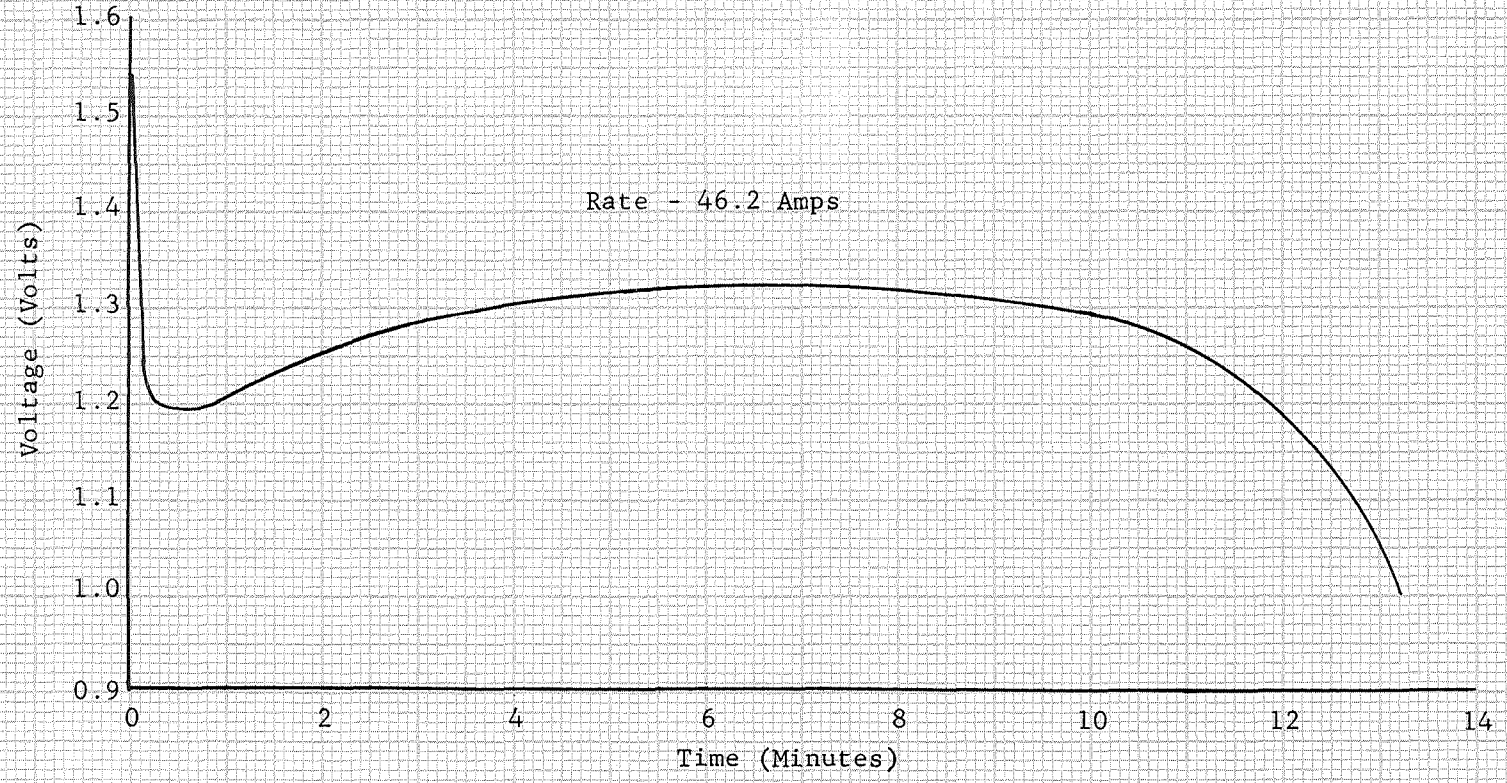



FIGURE I

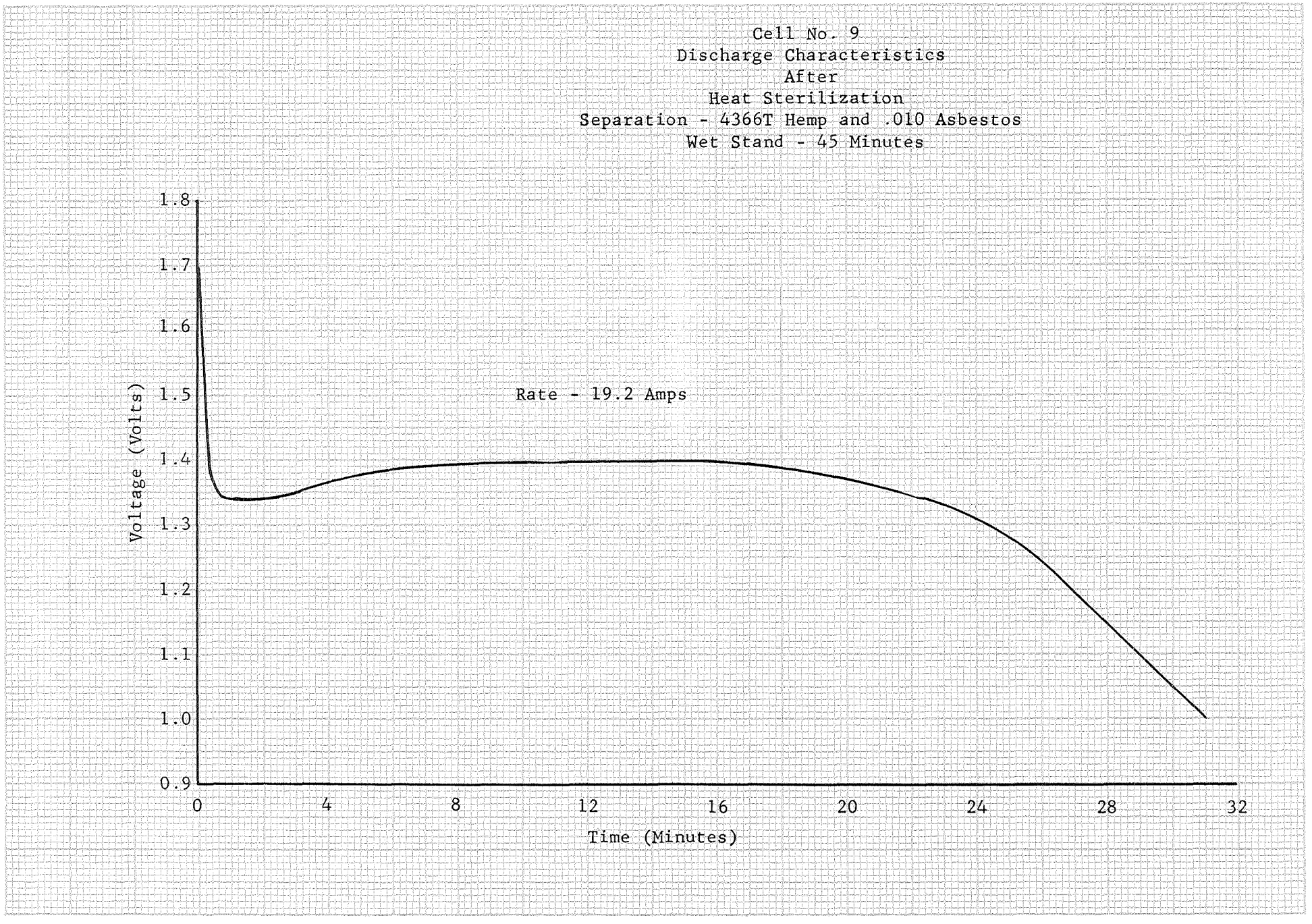

Cell No. 9
Discharge Characteristics
After
Heat Sterilization
Separation - 4366T Hemp and .010 Asbestos
Wet Stand - 45 Minutes
Rate - 19.2 Amps
Voltage (Volts)
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0
4
8
12
16
20
24
28
32
Time (Minutes)

FIGURE II

Cell No. 10
Discharge Characteristics
After
Heat Sterilization
Separation - 4366T Hemp and .010 Asbestos
Wet Stand - 72 Hours

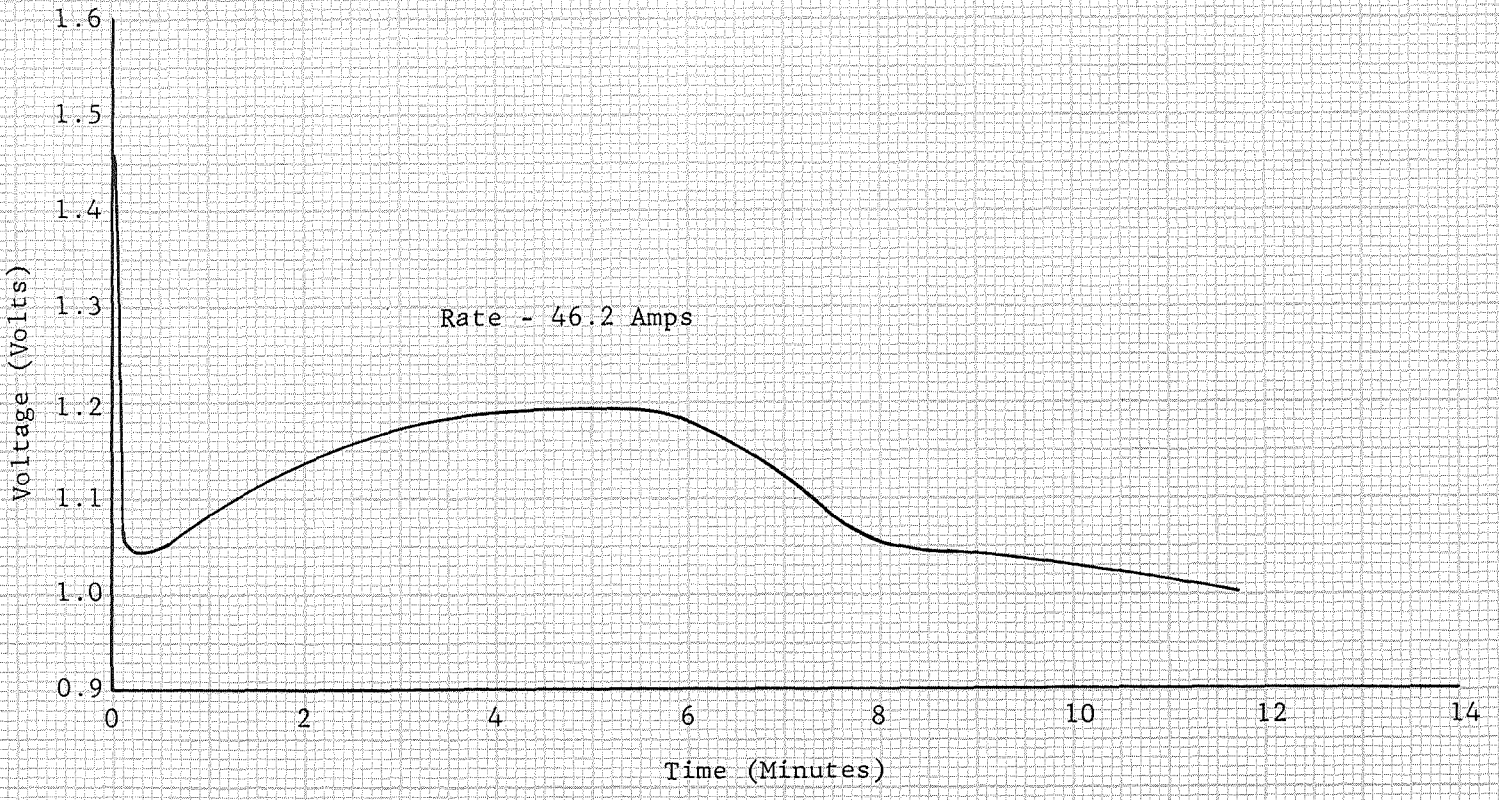



FIGURE III

Cell No. 11
Discharge Characteristics
After
Heat Sterilization
Separation - 4366T Hemp and .010 Asbestos
Wet Stand - 144 Hours

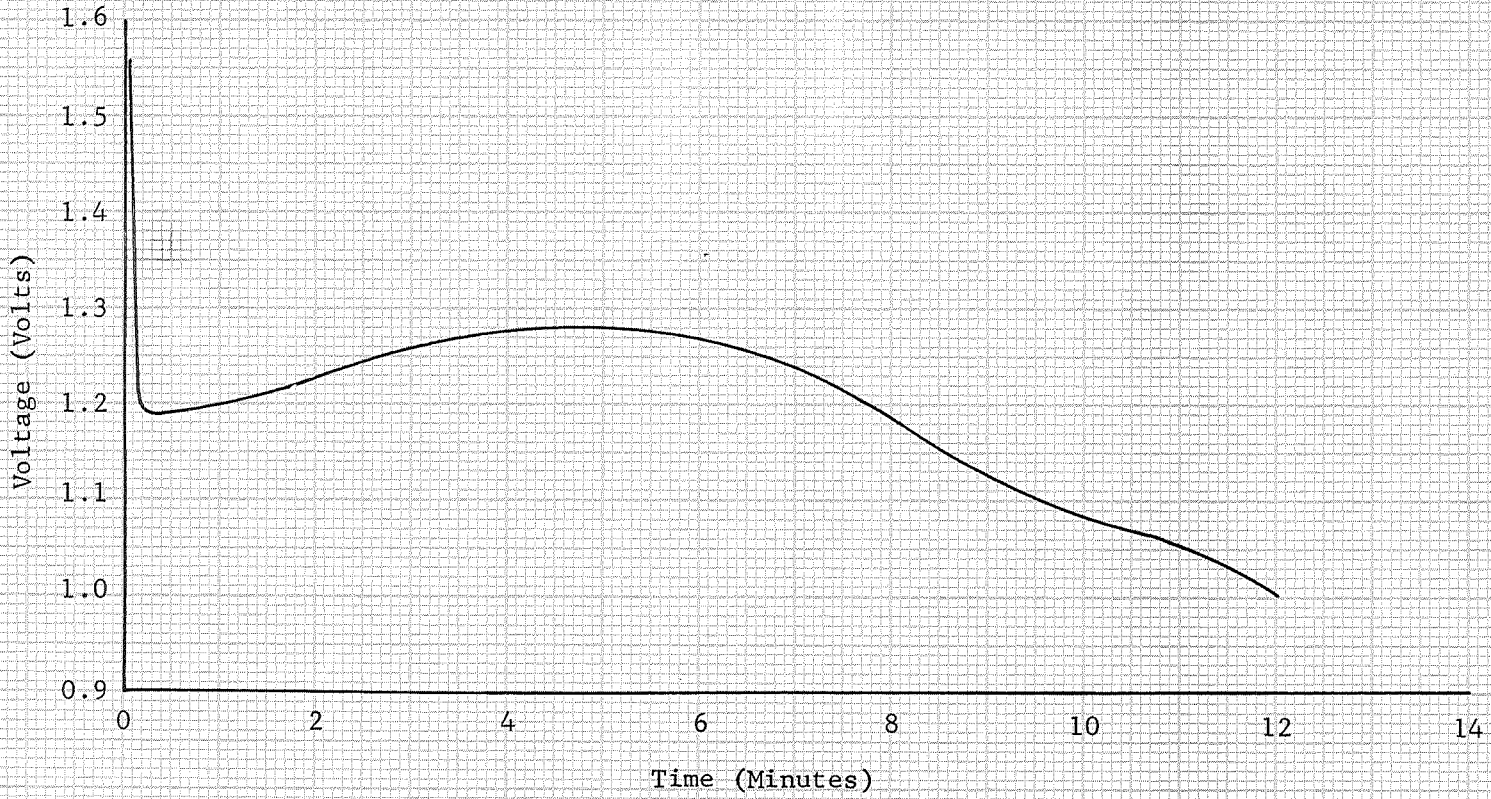



FIGURE IV

Cell No. 12
Discharge Characteristics
After
Heat Sterilization
Separation - 4366T Hemp and .010 Asbestos
Wet Stand - 168 Hours

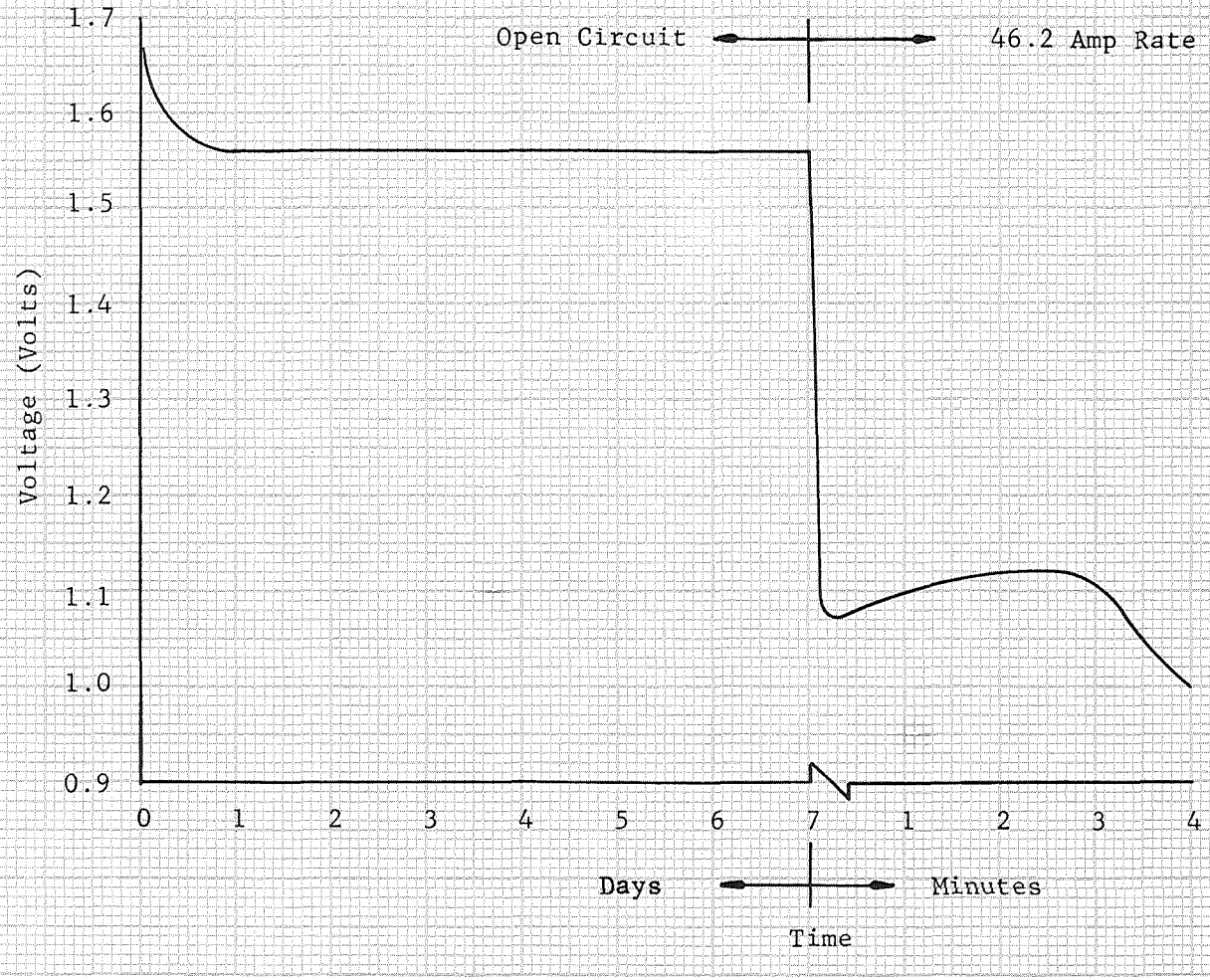



FIGURE V

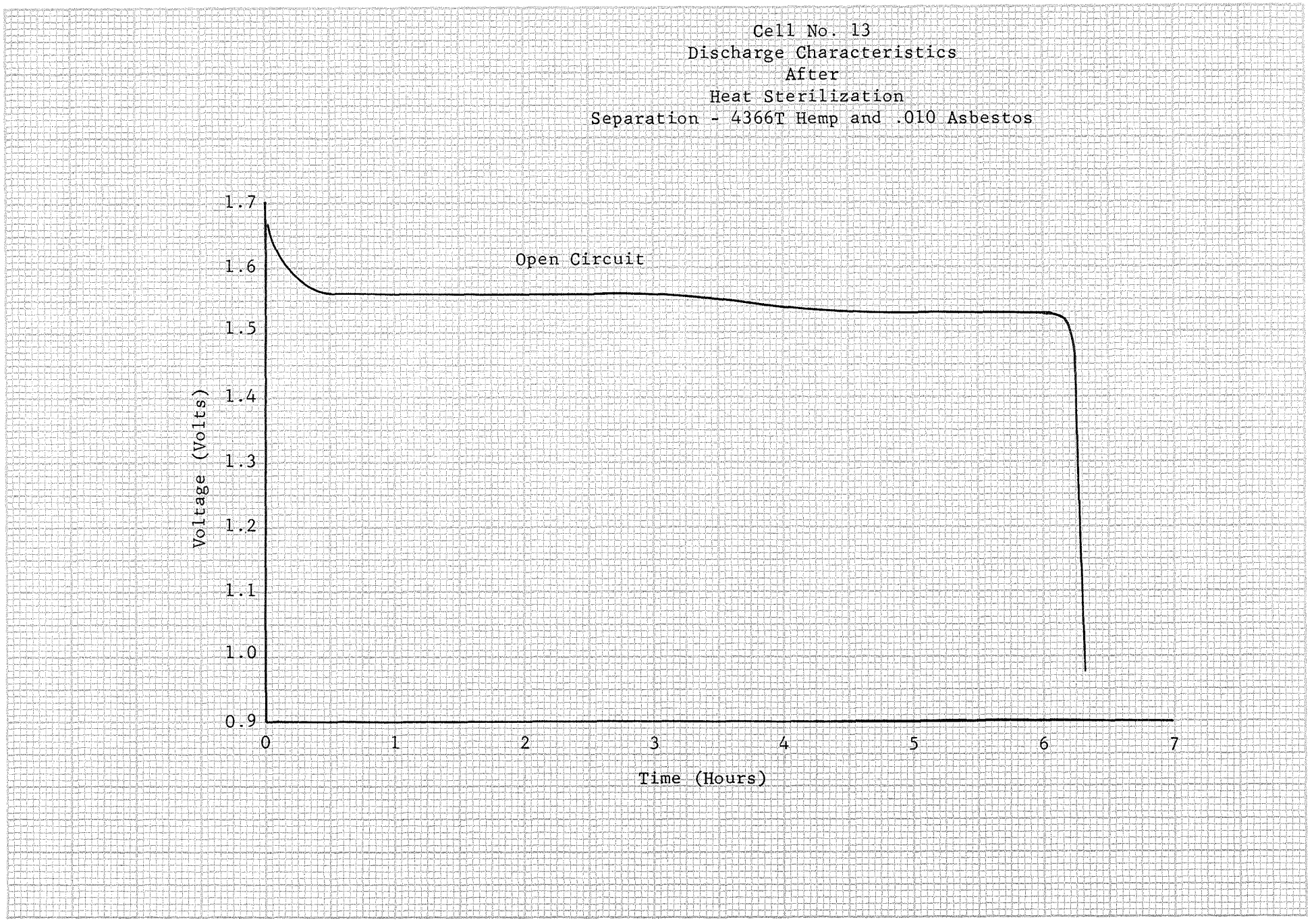

Cell No. 13
Discharge Characteristics
After
Heat Sterilization
Separation - 4366T Hemp and .010 Asbestos
Open Circuit
Voltage (Volts)
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0
1
2
3
4
5
6
7
Time (Hours)

FIGURE VI

2.1 Cell Design (Continued)

from cells subjected to long stands did disclose some silver inclusion. These tests indicated that cells separated with a hemp and asbestos combination should be capable of wet activated lives of at least 72 hours.

The second series of tests were made in order to establish a direct comparison between the hemp-asbestos combination and 2409 cotton webril. The cell designs were identical to the first series with the exception of separators. These cells were subjected to various activated stand periods and discharged at either 1200 or 500 watt rates. The results of the tests are shown in Figures VII through XII. Cells discharged after 10 minutes of activated life revealed that those separated with 2409 webril exhibited better discharge characteristics than those separated with hemp and asbestos. However, at the end of 30 minutes at the 500 watt rate the discharge characteristics for both separator types were essentially the same. Cell number 19 (Figure XII) showed some degradation in performance after one hour of wet life. This cell was separated with the 2409 cotton webril. From the data it may be concluded that the cotton separator offers a better cell performance with wet stands of 30 minutes or less. Beyond this point cotton apparently tends to degrade. With wet stands in excess of 30 minutes and less than 72 hours the hemp-asbestos combination should be satisfactory. In the design application for this contract the webril separation should be satisfactory. One less cell would be required to meet the 26 volt requirement if webril is used instead of hemp and asbestos.

2.2 Pyrotechnics

During the past quarter evaluation was made of an electric initiator manufactured by Network Electronics of Chatsworth, California. This ignitor, although similar physically to those presently used at Eagle-Picher, is new

Cell No. 14
Discharge Characteristics
After
Heat Sterilization
Separation - 4366T Hemp and .010 Asbestos
Wet Stand - 10 Minutes

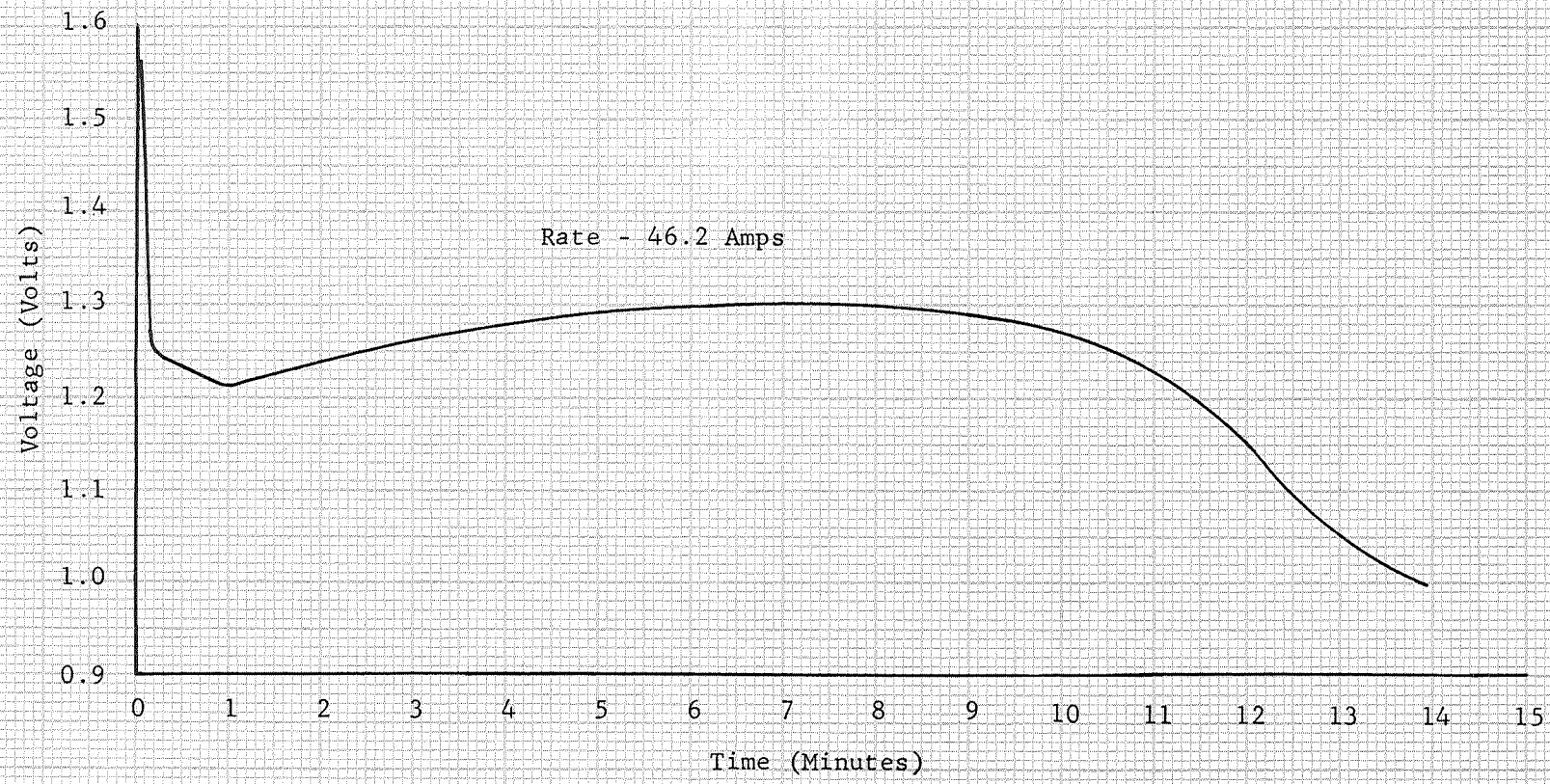



FIGURE VII

Cell No. 15
Discharge Characteristics
After
Heat Sterilization
Separation - 2409 Webril
Wet Stand - 10 Minutes

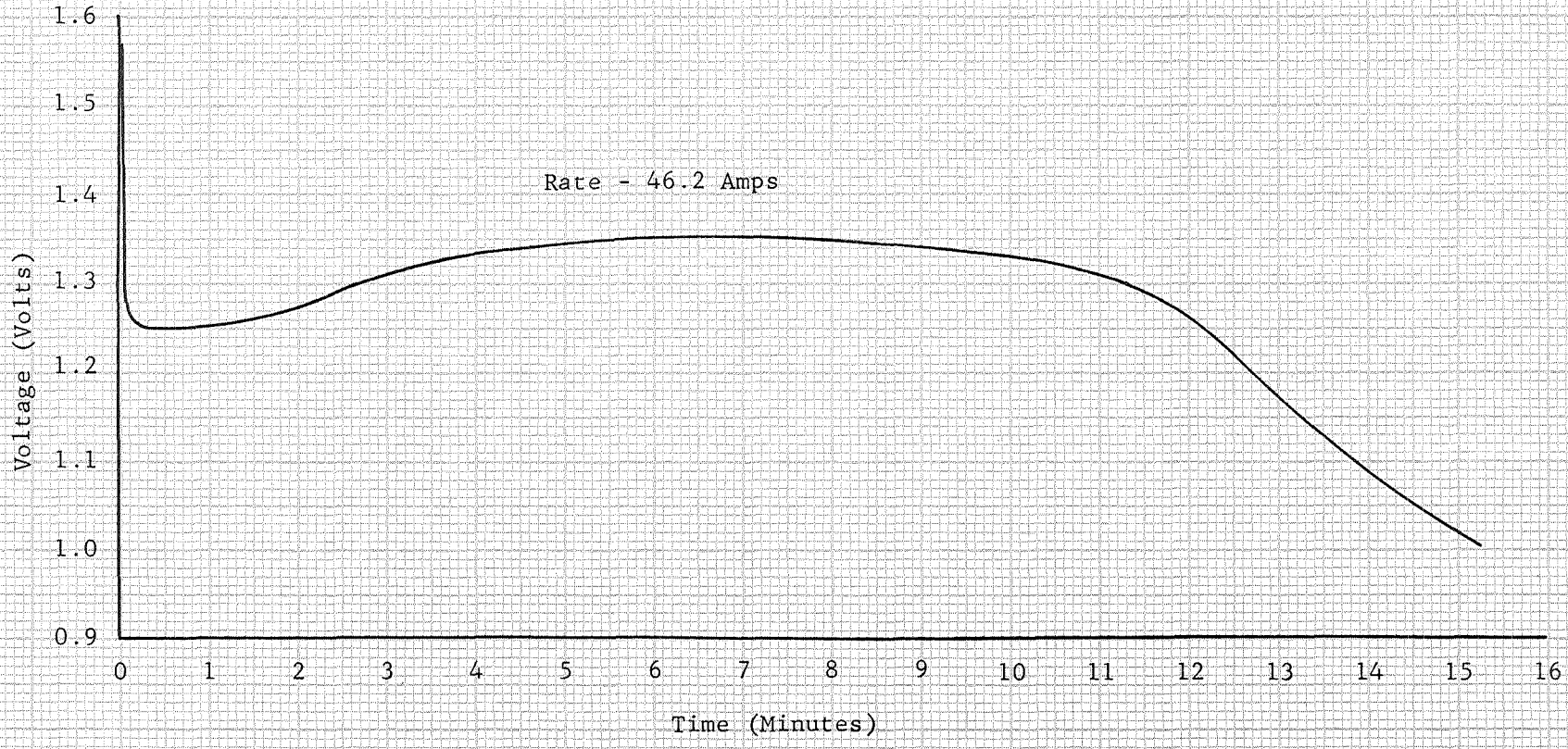



FIGURE VIII

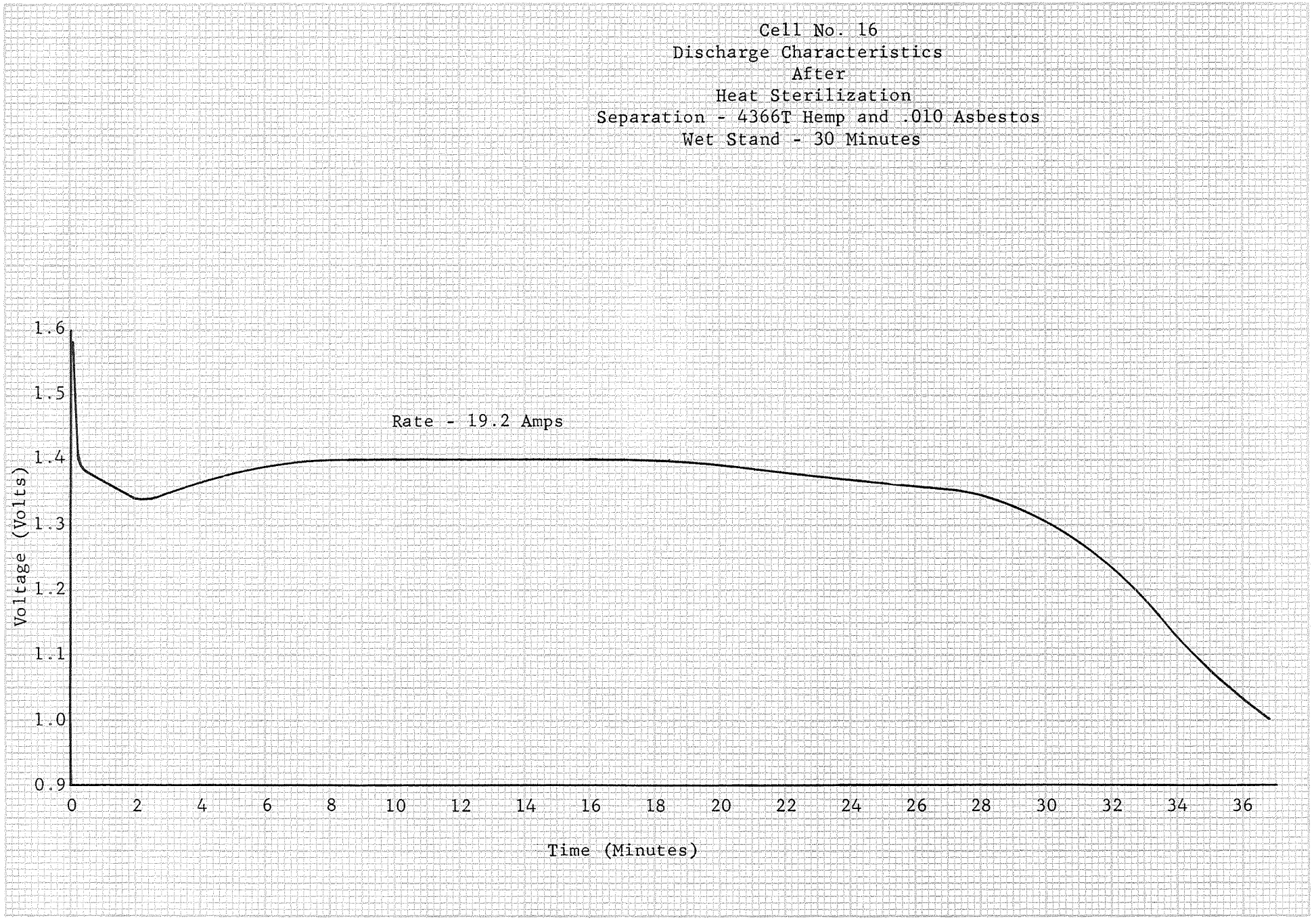

Cell No. 16
Discharge Characteristics
After
Heat Sterilization
Separation - 4366T Hemp and .010 Asbestos
Wet Stand - 30 Minutes
Rate - 19.2 Amps
Voltage (Volts)
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
Time (Minutes)

FIGURE IX

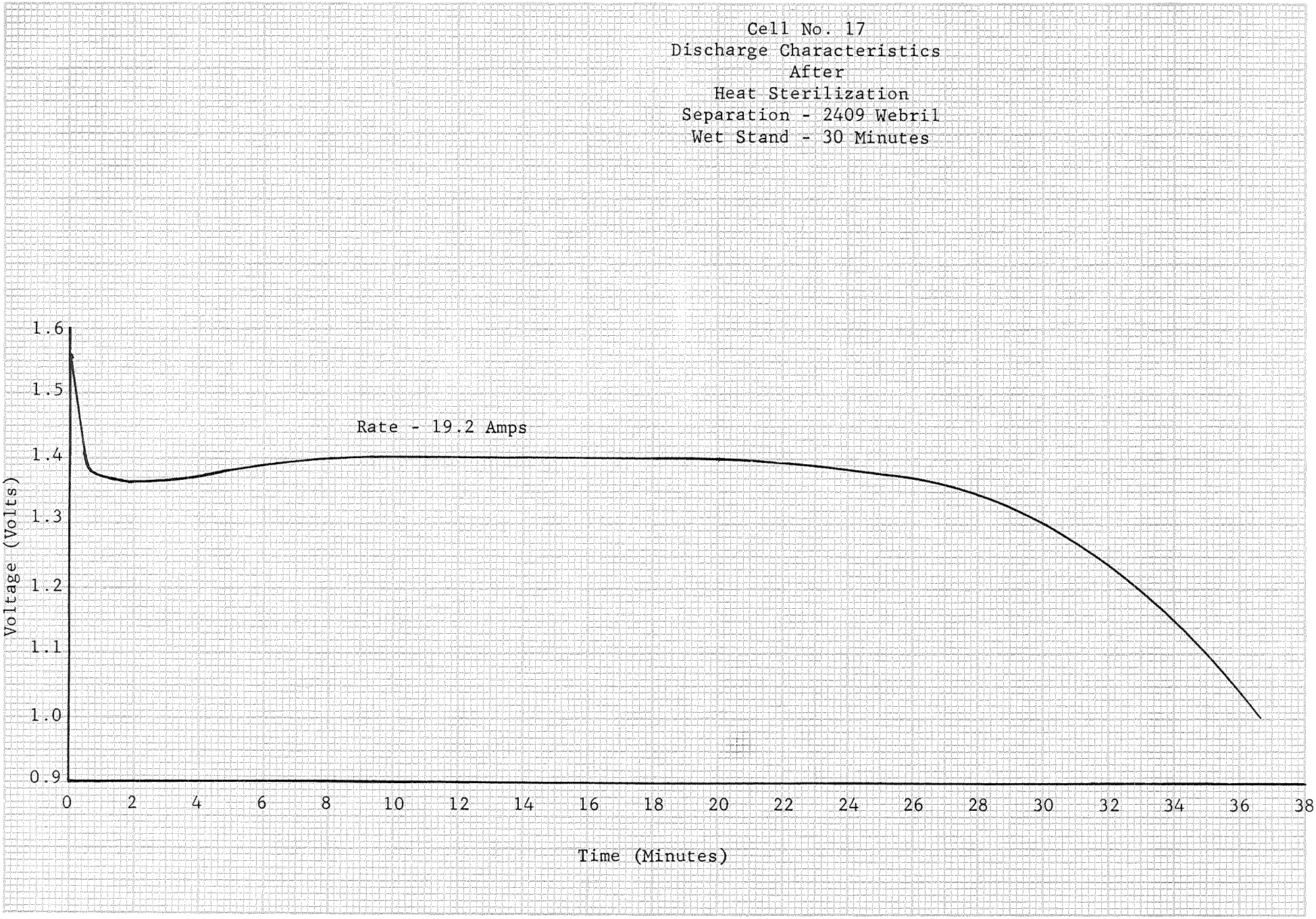

Cell No. 17
Discharge Characteristics
After
Heat Sterilization
Separation - 2409 Webril
Wet Stand - 30 Minutes
Rate - 19.2 Amps
Voltage (Volts)
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
Time (Minutes)

FIGURE X

Cell No. 18
Discharge Characteristics
After
Heat Sterilization
Separation - 4366T Hemp and .010 Asbestos
Wet Stand - 30 Minutes

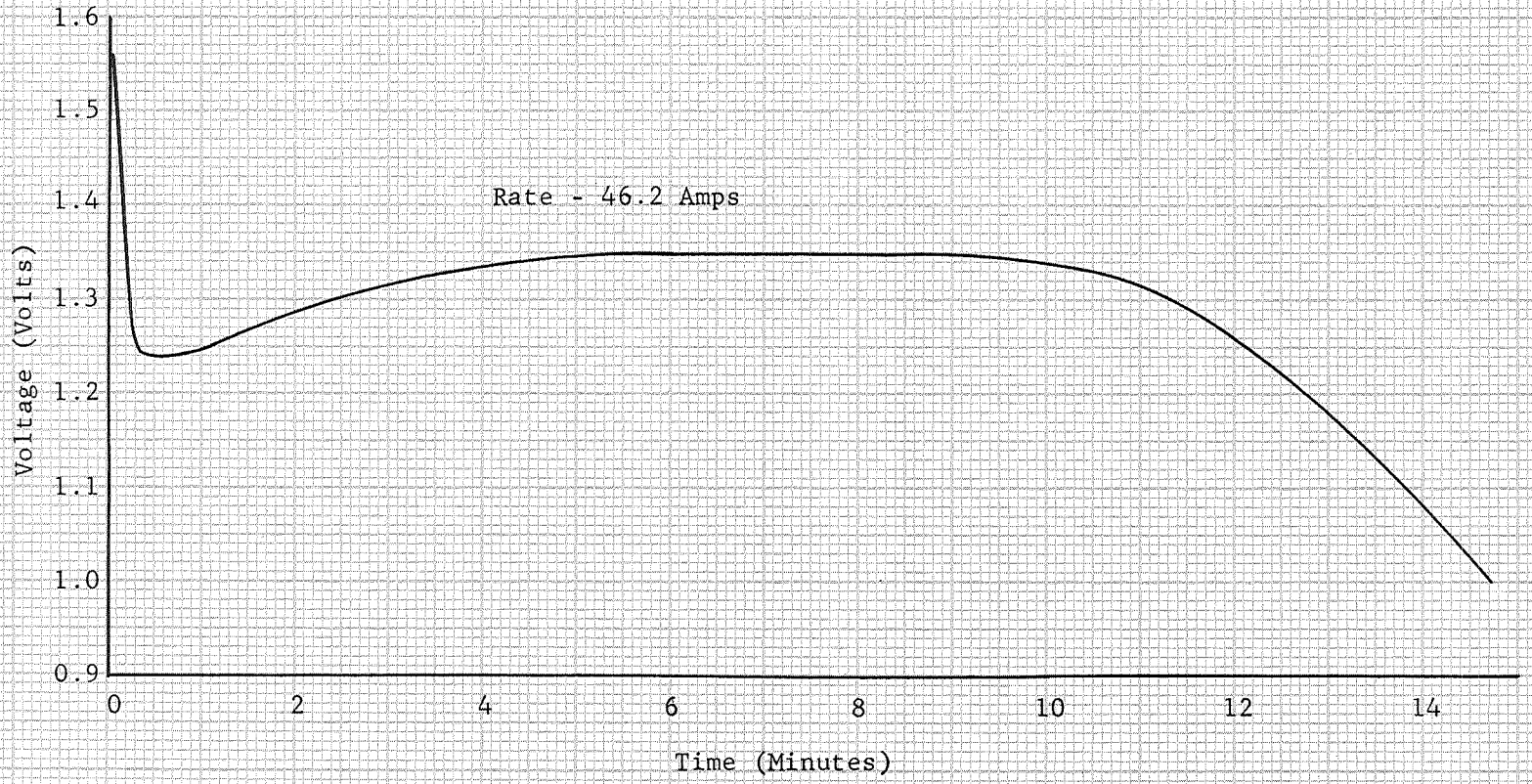



FIGURE XI

Cell No. 19
Discharge Characteristics
After
Heat Sterilization
Separation - 2409 Webril
Wet Stand - 1 Hour

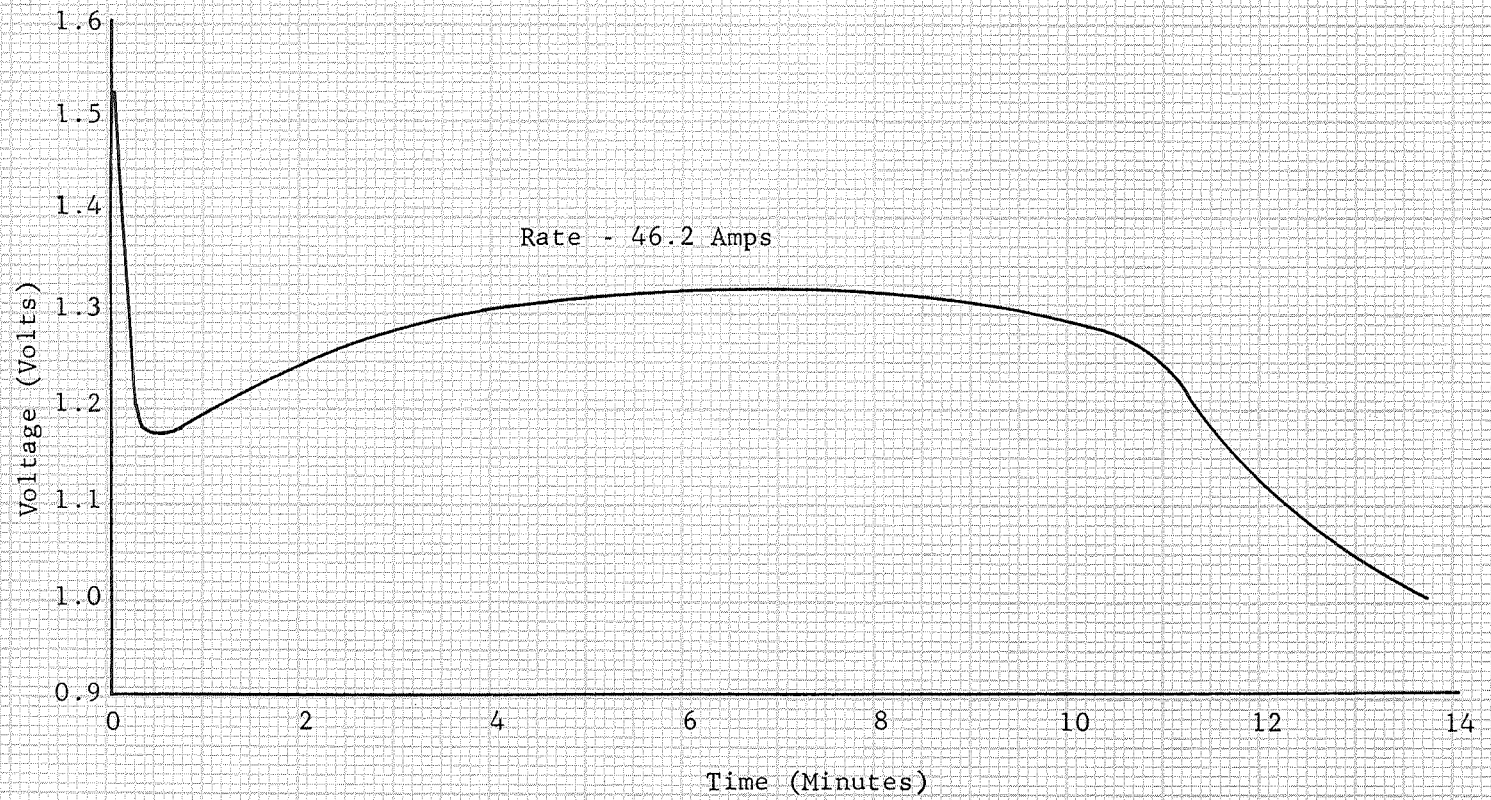



FIGURE XII

2.2 Pyrotechnics (Continued)

in that the bridgewire is made of pyrofuze. The electrical characteristics of the ignitor consist of a 0.55 ampere no-fire for 16 seconds at 165°F and a guaranteed all-fire of 1.75 amperes at 130°F. Several of these units were sterilized, no-fired and then fired at Eagle-Picher without any failures. In order to verify the capabilities of the ignitor to satisfactorily perform after heat sterilization a Bruceton test was performed with 50 of the NEI-3 ignitors. This test is designed to establish statistically the reliability of the unit at specific current levels. The test also provides an indication of the safety margin between no-fire and fire levels.

The procedure by which a Bruceton test is performed involved a selection of a starting point and an increment of change. In this case the starting point was 1.6 amperes and the increment was 0.1. The first unit is subjected to the 1.6 ampere current. If it fires, the second ignitor is selected and subjected to a current one increment lower (1.5 amperes). Should the second unit not fire, the current is increased one increment (1.6 amperes) and the third unit is tested. However, if the second unit does fire, the current level is again decreased by one increment. Each match that fails to fire is set aside. This procedure is continued until each unit has been subjected to test. After all units have been tested those which did not fire are subjected to a current level at which all the ignitors should fire (1.7 amperes). This is to demonstrate that none of the units are duds. Prior to actual performance of the Bruceton test each ignitor was subjected to certain tests among which was a 100 percent no-fire of 0.55 ampere for 16 seconds while stabilized at 100°F. This test was performed subsequent to the matches having undergone vibration of 10 and 30 g's sinusoidal and 135°C heat sterilization. The results of the 30°F Bruceton test were as follows:

2.2 Pyrotechnics (Continued)

1. Mean value of fires = 1.446 amperes
2. Sigma ( $\delta$ ) value = 0.0786
3. Mean plus three sigma = 1.682 (0.997 reliability)
4. All units not fired were fired at 1.7 amperes.

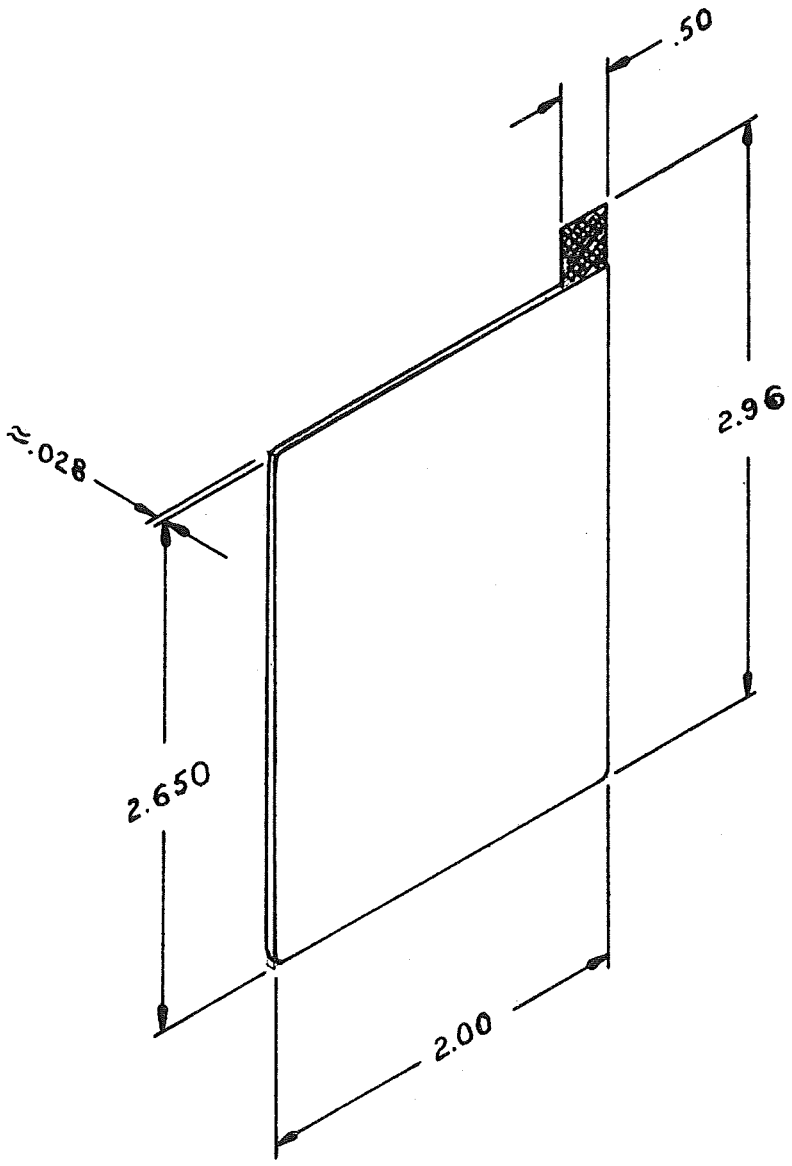
The results of the Bruceton test indicate that the matches are capable of meeting the requirements.

2.3 Battery Design

The effort expended during the latter part of the past quarter was directed towards the design and fabrication of components for prototype batteries. The cell components were selected from the data accumulated during the testing described in paragraph 2.1 of this report. Each component of the battery was then designed in accordance with the cell design. The various components shall be described separately. The basic design consists of 22 cells using the webril separator. The assembly shall be encapsulated and contained within a fabricated stainless steel housing.

2.3.1 Positive Plate

Silver-oxide electrodes were pasted and electrically formed to a weight of 2.40 grams per square inch. The average density is approximately 85 grams per cubic inch. Each plate was cut to dimensions slightly under those required to allow for a permanent increase in size. Each plate was then exposed to a partial heat sterilization cycle to stabilize its physical size and minimize gassing in the battery. The final plate size is shown in Figure XIII. Five plates are used per cell. Assuming losses due to cell efficiency (25% of theoretical) and heat sterilization (30% of theoretical) the theoretical positive capacity is 9.5 ampere-hours.




GAP 4374 PLATE SIZE
FIGURE XIII

### 2.3.2 Negative Plate

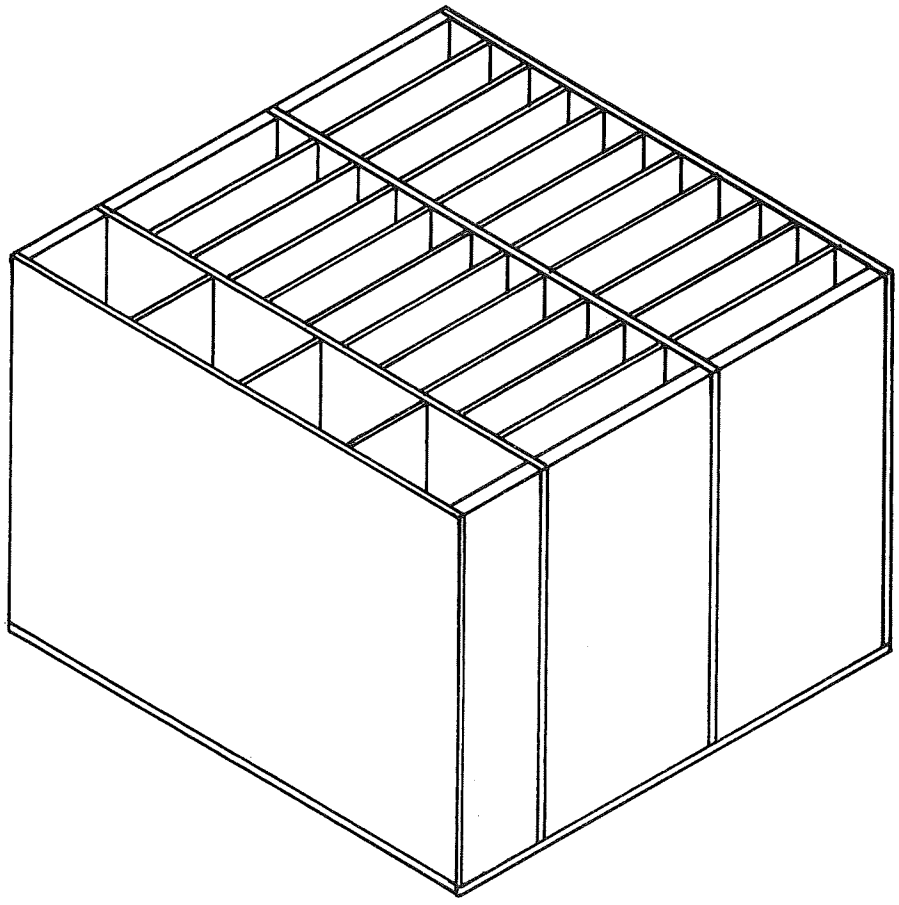
The negative electrode was electroformed to a weight of 1.25 grams per square inch and pasted to a density of 48 grams per cubic inch. No special treatment was required prior to assembly of the cell since the zinc plate is relatively stable through heat sterilization. Six plates are used per cell. With expected losses deducted, the zinc capacity of the cell is estimated to be approximately 13 ampere-hours. The plate size is shown in Figure XIII.

### 2.3.3 Separator

As a result of tests performed and in consideration of the wet life requirements of the work statement, 2409 cotton as manufactured by Kendall Mills is being used as the separator. This material offers total wet life capabilities of 1.5 hours. The work statement requires a maximum wet stand under no-load of 30 minutes followed by a maximum discharge time of 24 minutes. The cotton separator's capabilities under these conditions have been verified during tests described in paragraph 2.1. A single layer of separator shall be folded around the lower edge of the positive plate. No separation shall be used around the negative. By using the cotton separator better cell efficiency should be realized.

### 2.3.4 Cell Case

The cell case is a 22 cavity fabricated polysulfone box with four cavities on the side. The four cavities shall be used to contain any excess electrolyte. A pictorial view of the cell case is shown in Figure XIV. The solvent used in the fabrication process was ethylene dichloride. In order to assure satisfactory bonds after heat sterilization, the solvent retained in the plastic was removed by vacuum in an ambient of 85°C.



GAP 4374 CELL BLOCK
FIGURE XIV

2.3.4 Cell Case (Continued)

The battery manifold was machined of polysulfone. Figure XV provides a description of the part without the cell entry holes. These shall be match drilled before attachment of the manifold to the cell case. A manifold cover plate (See Figure XVI) shall be bonded to the manifold as the final seal. These seals must also be subjected to the thermal vacuum to remove all residual solvent.

2.3.5 Electrolyte Reservoir

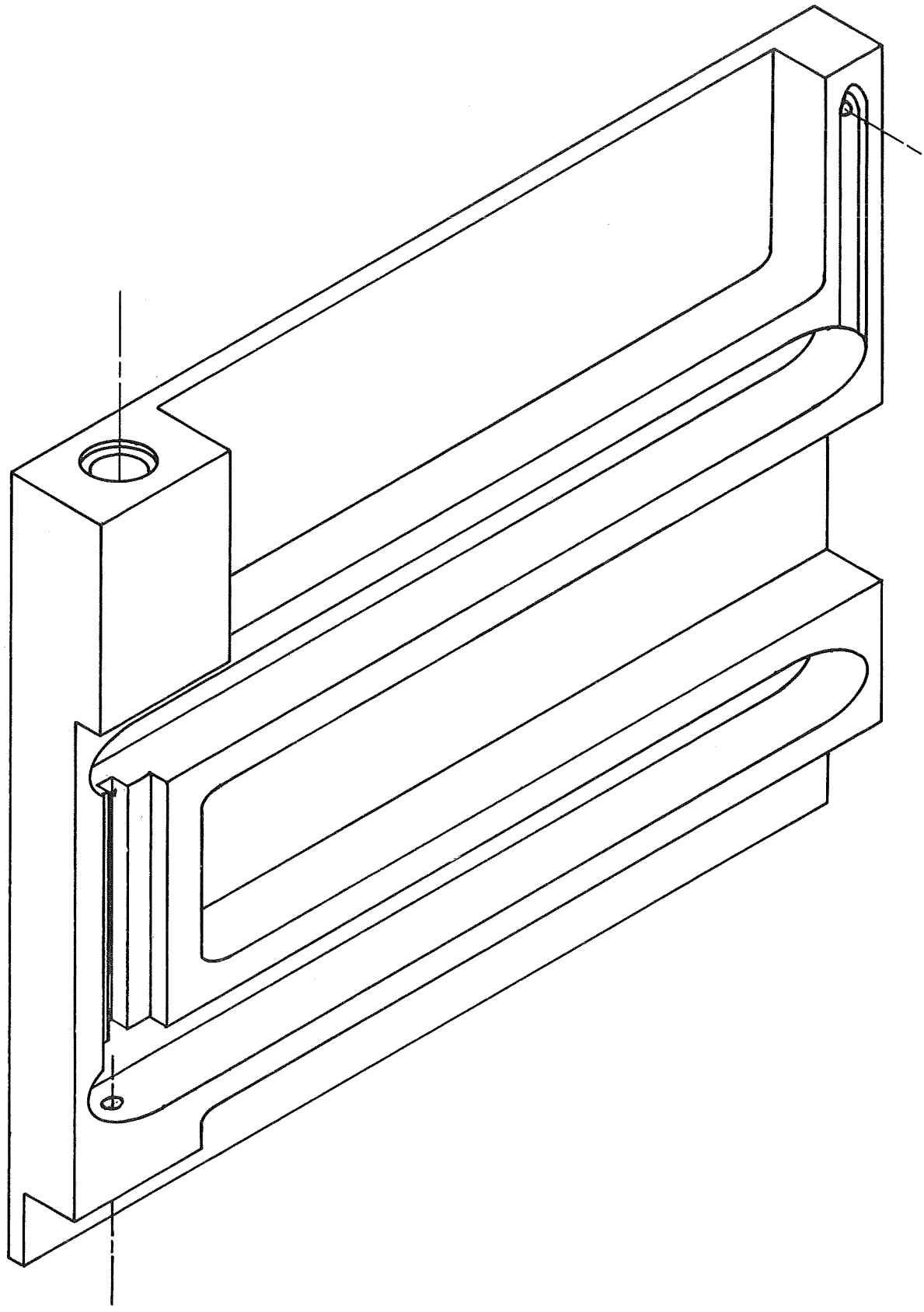
A tubular copper reservoir capable of holding approximately 800 cc's of electrolyte has been fabricated. The connection between the reservoir and the battery manifold shall be made through the use of an O-ring seal coupled with a threaded fastener. The O-ring material is ethylene propylene. A high temperature epoxy, EC 2214, shall be used to effect a redundant seal on the connections. The electrolyte is contained within the reservoir by two .004 inch thick copper diaphragms at each end of the reservoir. A five percent void was left in the reservoir to allow for any expansion during heat sterilization.

2.3.6 Electrolyte Solution

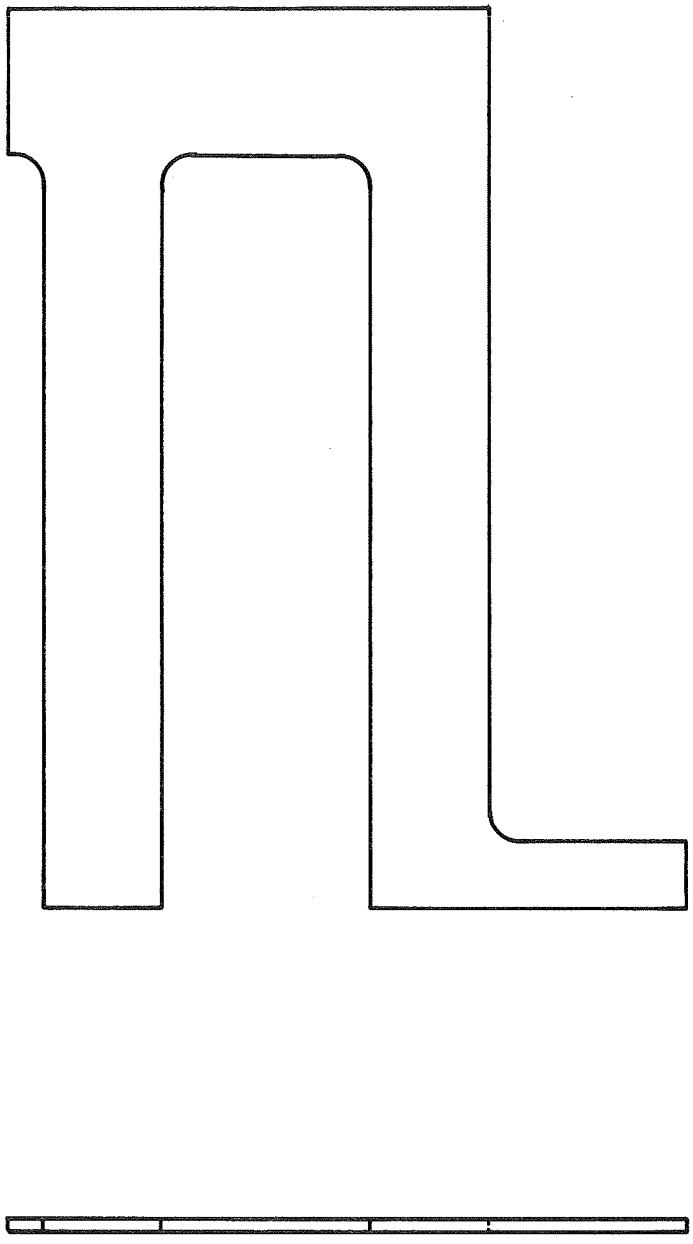
A solution of potassium hydroxide with a specific gravity of 1.30 was used to fill the reservoir. The cell design requires approximately 30 cc's per cell for 100 percent activation. However, due to losses expected both in the reservoir and in the battery proper, approximately 36 cc's per cell shall be used.

2.3.7 Gas Generator

The initial prototypes shall be activated by gas generators consisting of the NEI ignitors described previously and the Aerojet General AN583AF



GAP 4374 MANIFOLD
FIGURE XV



GAP 4374 MANIFOLD COVER
FIGURE XVI

2.3.7 Gas Generator (Continued)

propellant. The designed gas output as determined in a water displacement fixture (See Third Quarterly Report) is approximately 3500 cc's. The housing for the gas generator is stainless steel. An orificing device is used to maintain sufficient pressure on the burning propellant as well as to restrain it from being expelled into the electrolyte.

2.3.8 Container

The container shall be made of .025 inch thick 304 stainless steel. The cover shall be welded to the container to effect a hermetic seal. A glass-to-metal seal connector shall be brazed onto the container to provide electrical continuity through the container wall.

## 3.0 CONCLUSIONS

From the results of studies made during the past quarter the following conclusions may be made: The 2409 cotton webril separator provides the best performance with activated no-load stands of less than 30 minutes. With wet stand periods in excess of one hour the hemp-asbestos combination is better. Cells separated with webril and allowed to stand wet for one hour suffered an apparent loss in capacity of approximately ten percent accompanied by a noticeable reduction in on-load voltage. Performance of cells separated by hemp and asbestos appeared to degrade approximately 72 hours of wet stand.

The ability of the Network Electronics ignitor, NEI-3, to survive heat sterilization and meet design requirements has been verified by the performance of the Bruceton test. The results of the test indicate that all units will fire with a reliability of 0.997 at a current level of 1.682 amperes. Also the ability of the units to withstand a no-load current of 0.55 ampere for 16 seconds in an ambient of 165°F without dudding has been proven.

## 4.0 RECOMMENDATIONS

Prototype batteries as described in this report shall be manufactured for testing under Phase II of the contract.

## 5.0 NEW TECHNOLOGY

No new technology was developed during the fifth quarter of this contract.