SECOND AND THIRD QUARTERLY REPORTS
COMBINED

# LOW TEMPERATURE BATTERY

by

George M. Armstrong

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

CONTRACT NAS 3-8503



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# LOW TEMPERATURE BATTERY

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## ABSTRACT

The system, $Mg/KSCN\text{-}NH_3/HgSO_4{:}S$, has been studied in both prismatic and bobbin type cells for the purpose of achieving 72 hour operation over a temperature range of +20° to -90° C. A discharge cycle of 0.3 watts for 54 minutes and 1.5 watts for 6 minutes is required for each hour.

This 72 hour goal has been exceeded at -90° C in both cell configurations with $HgSO_4{:}S{:}C$ and with S: C cathodes. A prismatic cell with a S: C cathode also performed well at -63° C. In the bobbin structure, both types of cathodes exhibited the capability of satisfactory performance throughout a temperature range of -40° to -90° C. However, the formulation containing $HgSO_4$ was much superior to the one having only sulfur and carbon.

The design of a self-contained cell in full hardware was approved. Such a cell was built and tested. Its performance at -73° C was satisfactory.

## SUMMARY

The purpose of this program is to develop a self-contained, low temperature cell, excluding activator, based upon the battery system $Mg/KSCN-NH_3/HgSO_4$:S. It shall have the capability of operating for at least 72 hours with an alternating hourly discharge cycle of 0.3 watts for 54 minutes and 1.5 watts for 6 minutes. The desired discharge temperature range is +20°C to -90°C. An extensive investigation of the system was carried out initially at -90°C in conventional prismatic cells, followed by the construction and testing of special cells to aid in the transition from prismatic to bobbin structures. The next step was the development of a practical bobbin configuration in which the performance of the system could be studied and perfected. After satisfactory operation has been achieved, full hardware was designed and evaluated.

### Prismatic Cell Experiments

Separation: No. M-1365 Webril paper was used in multiple layers (0.004 inches/layer). Five layers (0.020") were found to be sufficient, as demonstrated by a cell that ran for 93 hours at -90°C to 1.3 volts.

Electrolyte Studies: Thirty-four (34) weight percent KSCN in liquid ammonia is a satisfactory electrolyte for use at -90°C and has been adopted for use over the entire temperature range.

A number of salts were examined for solubility and freezing characteristics in liquid ammonia at -87°C. Sodium and lithium perchlorates, fluoroborates and hexafluorophosphates may warrant further studies.

Cathode Collector Grid Materials: Silver-plated copper Exmet is satisfactory for use at -90°C, but the plating was corroded severely at temperatures of -63° and -40°. Gold-plated copper Exmet or aluminum Exmet is recommended for use in this type of cell, especially at the higher temperatures.

Cathode Composition: Numerous combinations of components, including $HgSO_4$, sulfur, graphite, acetylene black and paper pulp, were tested in prismatic cells. The best compostion on the average for discharge at -90°C appeared to be that containing 70 percent sulfur and 30 percent graphite.

Cathode Plate Thickness: The thickness of the cathodes ranged from 1/16 to 5/8 of an inch with the resistive load prorated accordingly. A thickness of 1/8 inch produced the best results.

Transition from Prismatic to Bobbin Cell Structures: Since the geometry of a bobbin structure usually involves single-sided discharge and possibly greater cathode depths, a variety of special designs were studied, including among others:

1. Single-sided discharge employing only one working anode and cathode thicknesses of 1/8 and 1/4 inches.

2. Multiple anodes and separately loaded cathodes with all anodes stacked on one side and all cathodes on the other, rather than in the conventional alternate method of stacking.

3. Cells containing reference electrodes, and

4. A single cathode with a separately-loaded anode on each side.

A large mass of informative data was collected which indicated among other things, that the cell performance was limited by anode polarization. In the cells with triple cathodes, failure was not due to the multiplicity of cathodes, but rather to anode current density.

Resistance and capacitance measurements were made on numerous cells. Three observations were made:

1. The origin of the capacitance values obtained appeared to be concentrated in the anode.

2. The addition of $HgSO_4$ to the cathode seemed to reduce the anode polarizing film substantially.

3. Capacitance values decrease markedly near end of cell life.

## Bobbin Cell Design, Construction and Testing

Preliminary Designs for Task I: The cell configuration that was evolved and adopted for the bobbin cell experiments comprised a central star-shaped anode with ten longitudinal fins and a cylindrical cathode located between the seperator and a conductive case. The space between the fins served as an electrolyte reservoir.

Electrolyte Studies at -90°C: The use of "spent" electrolyte from discharged cells gave the longest life, but its use was discontinued in favor of 34 weight percent KSCN in liquid ammonia when the attempts to synthesize it were unsuccessful.

Cathode Compositions: No. 1. In the absence of $HgSO_4$, the longest life at -90°C (68 hours to 1.5 volts, 76 hours to 1.3 volts) was obtained from a mixture of 50 percent sulfur, 40 percent graphite and 10 percent acetylene black. No. 2. The addition of about 10 percent of $HgSO_4$ to the above mixture yielded excellent results, as follows:

| Discharge Temp. °C | Hours to:* 1.5V | 1.3V |
|---|---|---|
| -90 | 97 | 110 |
| -63 | 158 | 176 |
| -40 | 97 | 127 |

*Under heavy load.

Task I-B: Specifications for the construction and testing of the five ammonia cells most likely to operate at -90°C for 72 hours were prepared and approved. The design was similar to that used in the preceeding experimental work, and the formulation was that shown in No. 1, above since No. 2 had not yet been developed. Upon discharge, an average life of 64 hours to 1.3 volts was achieved.

Task II, Design: A self-contained ammonia cell in full hardware, excluding activator, was designed to meet the specifications of Task II-A for the purpose of building a number of such cells for test or delivery to NASA. The system, $Mg/KSCN\text{-}NH_3/HgSO_4:S$, including the design drawings and the cathode formulation (formulation No. 2), was proposed and approved.

Task III, Test and Redesign: Based upon the approved design of Task II, mockup cells were constructed and then evaluated by discharge at -73°C. The average life was 84 hours to 1.5 volts and 99 hours to 1.3 volts.

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# 1. INTRODUCTION

The purpose of this program is to develop a low temperature cell with the capability of delivering 1.5 watts for six minutes and 0.3 watts for fifty-four minutes each hour for a minimum of 72 hours.

Task I, "Minus 90°C Study and Test," was initiated in the first quarter. The object of this phase of the work was a study and experimental investigation of methods of extending ammonia cell operation at -90°C from the one day previously achieved* to the goal of 72 hours. During the first quarter, the scope was limited to Method 1, the development of pasted-plate cathodes for use in the system, $Mg/KSCN:NH_3/HgSO_4:S:C$. As of the close of the first three months, considerable progress had been made. Of the fifty cells tested, eight $HgSO_4:S:C$ cells had performed at -90°C under cyclic loading to the 1.3 volt cut-off for periods ranging from 71 to 117 hours, while four S:C cells ran under the same conditions from 71 to 113 hours. Task I was completed during this reporting period by the following plan of attack:

1. Development of prismatic cells in order to establish the best conditions for long life.

2. Construction and testing of a group of prismatic research cells of special design to aid in the transition to bobbin-type structures. Since the latter are usually discharged from only one side of each electrode, a number of cells were designed to study the mechanism of single-sided discharge. Some comprised only one anode and one cathode, while others had multiple anodes and cathodes.

3. The evolution of a bobbin cell design through the application of the knowledge gained from the prismatic cell studies and from experimentation with variations in bobbin structures, methods of construction, cathode compostion and electrolyte concentration and type.

Task II, "Design," required the design of a self-contained ammonia cell, excluding activator, for the purpose of fabricating a number of such cells for test or delivery to NASA. This was accomplished during the third quarter.

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*Contract NAS 3-6009

Task III, "Test and Redesign." In the first part of this task, a full-scale cell mockup was constructed and evaluated with satisfactory results. This concluded the activities of the third quarter and placed the project in good position to complete Task III during the fourth quarter.

Supporting data for all cells are provided in Appendix A which includes:

Notes to Tables

Materials Identification

Table I - Electrochemical Cell Tests, Pasted-plate Configuration

Table II - Electrochemical Cell Tests, Bobbin Configuration

Table III-A - Periodic Cell Voltages, Pasted-plate Configuration

Table III-B - Periodic Cell Voltages, Bobbin Configuration

Cell construction, illustrations and drawings are included in Appendix B.

## 2. PRISMATIC CELL EXPERIMENTS

The method of construction and a drawing of a typical prismatic (or pasted-plate) cell may be found in Appendix B. The test results are discussed in the following sections.

### 2.1. Separation

The effect of variations in separator thickness are shown in Table I.

TABLE I

Separation Thickness Studies*

| Cell No. P- | $HgSO_4$ g | S g | C g | Electrolyte Vol. (cc) | Separator Thickness (in.) | Hours** to 1.3V |
|---|---|---|---|---|---|---|
| 51 | 20 | 4 | 12 | 150[a] | 0.020 | 70 |
| 52 | 20 | 4 | 12 | 100 | 0.020 | 93 |
| 59 | 20 | 4 | 12 | 100 | 0.028 | 26 |
| 60 | 20 | 4 | 12 | 100 | 0.028 | 56 |
| 62 | 0 | 11 | 11 | 100 | 0.008 | 64 |

*Webril No. M-1365.
**Under heavy load.
[a]100 cc initially: added 50 cc after 2 days, at which time the heavy load voltage recovered from 1.53 to 1.83.

The increase in thickness from 20 to 28 mils was detrimental, possibly because of increased resistance. A decrease in thickness to 8 mils in a S/C cell yielded moderately good results. The optimum was not established definitely because of the limited number of tests, but the 20 mil thickness has been adopted as a suitable standard. This is made from 5 layers at 4 mils each.

## 2.2. Electrolyte Studies

Twenty-five and 34 weight percent KSCN in liquid ammonia and partially "spent" electrolytes were used in a number of cells. Other variables were cathode composition, discharge temperature and collector grid materials. The results are summarized in Tables II and III.

TABLE II

Electrolyte Concentration Variations (No. 1)

| Cell No. P- | Wt. % KSCN | Temp. °C | Hours to* 1.5V | Hours to* 1.3V |
|---|---|---|---|---|
| 120 | 34 | -40 | 35 | 51 |
| 121 | 34 | -40 | 29 | 38 |
| 118 | 34 | -63 | 32 | 38 |
| 119 | 34 | -63 | 35 | 39 |
| 125 | 25 | -63 | 41 | 43** |
| 130 | 25 | -63 | 25 | 30 |

*Under heavy load.
**Aluminum Exmet collector grid: silver-plated copper Exmet used in all other cells.

Corrosion was more evident at higher temperatures; and the silver-plate was destroyed, thereby exposing the copper Exmet grid. Neither the substitution of aluminum Exmet or the use of more dilute electrolyte proved to be substantially beneficial.

TABLE III

Electrolyte Concentration Variations (No. 2)

| Cell No. P- | S % | C % | Electrolyte Wt. % as KSCN Virgin | "Spent"[1] | Temp. °C | Hours to* 1.5V | 1.3V |
|---|---|---|---|---|---|---|---|
| 131 | 70 | 30 | 25 | --- | -63 | 45 | 82** |
| 132 | 70 | 30 | 25 | --- | -63 | 57 | 83** |
| 128 | 70 | 30 | --- | 25 | -90 | 25 | 110 |
| 129 | 70 | 30 | --- | 25 | -90 | 90 | 113 |
| 76 | 70 | 30 | 34 | --- | -90 | 99 | 141 |
| 77 | 70 | 30 | 34 | --- | -90 | 100 | 120 |
| 126 | 85 | 15 | 25 | --- | -90 | 0 | 95 |
| 127 | 85 | 15 | 25 | --- | -90 | 17 | 89 |
| 58 | 85 | 15 | 34 | --- | -90 | 53 | 89 |

*Under heavy load.
**Aluminum Exmet collector grid: silver-plated copper Exmet in all other cells.
[1] "Spent" electrolyte is the residual electrolyte from a similar cell after discharge.

The S:C cells (P-131 and 132) ran at -63°C almost twice as long as P-125 (Table II) which contained $HgSO_4$. Aluminum Exmet grids were used in these three cells. At -90°C, P-128 and 129 ran well with "spent" electrolyte, but not nearly as long as P-76 and 77 in which 34 Wt. % KSCN was used.

The use of only 15 percent graphite in conjuction with 25 percent KSCN (cells P-126 and 127) yielded very short runs to 1.5V, but long life to 1.3V at -90°C. However, the use of 34 percent KSCN in a similar cell, P-58, provided better performance to the 1.5V cut-off.

Therefore, the results are strongly in favor of the use of 34 Wt. % KSCN in liquid ammonia as the electrolyte for pasted-plate cells having S:C cathodes.

### 2.2.2. Electrolyte Volume and Level

It has been demonstrated in Cell No. 51 (Table I), and in some latter cell tests that the volume and level of electrolyte are important factors that must be checked throughout discharge. The required quantity cannot be predicted accurately because different cathode mixtures absorb or consume different amounts of electrolyte and because the plastic envelope cell containers vary somewhat in size. If the level is above the connections of the lead wires to the electrodes, the connections are attacked and may be destroyed even if they are coated with such materials as Krylon or rubber cement. In order to eliminate this problem, longer anode and cathode collector tabs were adopted. This permits the use of a safe excess of electrolyte. If the electrolyte level is too low, the cells suffer in life span.

### 2.2.3. Electrolyte Salts Other Than KSCN

It would be desirable to have available solutions of salts in liquid ammonia that would have lower freezing points and better electrical conductivities than presently obtainable with KSCN. Some preliminary experiments were made on solutions of eight salts in liquid ammonia. A sufficient weight of each salt to produce a 30 percent solution was added to ammonia at -40°C. After the maximum amount of salt had dissolved, each solution or mixture was cooled to -87°C and the behavior was noted. The observations are summarized below:

| Salt | Concentration at 40° | Observations at -87° |
|---|---|---|
| Lithium chloroaluminate ($LiAlCl_4$) | Negligible | ------- |
| Potassium chromate ($K_2CrO_4$) | Negligible | ------- |
| Sodium bromide (NaBr) | 30% | Solution froze. |
| Sodium perchlorate ($NaClO_4$) | 30% | Did not freeze completely-lower portion fluid. |
| Lithium perchlorate ($LiClO_4$) | 30% | Did not freeze. |
| Lithium fluorosulfonate ($LiSO_3F$) | 30% | Solution froze. |
| Lithium tetrafluoroborate ($LiBF_4$) | 30% | Partial freezing-upper portion fluid. |
| Lithium hexafluorophosphate ($LiPF_6$) | 30% | Did not freeze. |

The perchlorates showed promise but are potentially dangerous when confined in cell hardware. The last three salts appeared to generate some gas which indicated possible instability, and only the last two did not freeze completely. It would seem, therefore, that a more thorough study of only the last two salts and others as yet untried could be justified.

## 2.3. Cathode Collector Grid Materials

Table IV presents the comparative performance of several grid materials with changes in cathode composition and discharge temperature.

TABLE IV

Cathode Collector Grid Materials Studies

| Cell No. P- | $HgSO_4$ % | S % | C % | Temp. °C | Collector Material (Superscripts defined in Appendix A notes | Ave. hrs. to 1.5V | 1.3V |
|---|---|---|---|---|---|---|---|
| 52 | 55.6 | 11.1 | 33.3 | -90 | Ag-plated Cu Exmet[w] | 81 | 93 |
| 63 | 55.6 | 11.1 | 33.3 | -90 | Ag Exmet[x] | 54 | 66 |
| 130 | 55.6 | 11.1 | 33.3 | -63 | Ag-plated Cu Exmet[w] | 25 | 30 |
| 125 | 55.6 | 11.1 | 33.3 | -63 | Aluminum Exmet[zz] | 41 | 43 |
| 58, 70 | 0 | 85 | 15 | -90 | Ag-plated Cu Exmet[w] | 54 | 87 |
| 74, 75 | 0 | 85 | 15 | -90 | Ag Exmet[x] | 2 | 41 |
| 99, 105 | 0 | 85 | 15 | -63 | Ag-plated Cu Exmet[w] | 50 | 75 |
| 108 | 0 | 85 | 15 | -63 | Perforated Aluminum[yy] | 0 | 0 |
| 109 | 0 | 85 | 15 | -40 | Perforated Aluminum[yy] | 0 | 0 |
| Typical | 0 | 70 | 30 | -90 | Ag-plated Cu Exmet[w] | 85 | 111 |
| 100 to 104 | 0 | 70 | 30 | -63 | Ag-plated Cu Exmet[w] | 43 | 55 |
| 106, 107 | 0 | 70 | 30 | -63 | Lead Exmet[xx] | 40 | 55 |
| 110 | 0 | 70 | 30 | -63 | Perforated Aluminum[yy] | 15 | 44 |
| 112, 113 | 0 | 70 | 30 | -63 | Au-plated Cu Exmet[ww] | 64 | 74 |
| 131, 132 | 0 | 70 | 30 | -63 | Aluminum Exmet[zz] | 51 | 82 |
| 116, 117 | 0 | 70 | 30 | -40 | Ag-plated Cu Exmet[w] | 19 | 23 |
| 111 | 0 | 70 | 30 | -40 | Perforated Aluminum[yy] | 13 | 37 |
| 114, 115 | 0 | 70 | 30 | -40 | Au-plated Cu Exmet[ww] | 36 | 45 |

*Under heavy load.

It was concluded in the first quarter that silver-plated copper Exmet was a satisfactory collector grid for use at -90°C. This was formed by expanding a 20 mil sheet to yield strands 30 mills in width and small openings. Subsequent, tests were made on pure silver Exmet which was expanded from 5 mil sheet to form 8 mil strands and relatively large openings in the mesh. It is believed that the open-mesh pure silver Exmet did not function well because of poor conductivity in the cathode mixture of cells P-74 and 75, which contained only 15 percent carbon in the S/C cathodes. This is substantiated partially by the better performance of the $HgSO_4$/S cell, No. P-63.

At higher temperatures, such as -63° and -40°, there was a general trend toward shorter cell life and increased corrosion of most grids and anodes. Gold-plated copper Exmet (Nos. P-112 to 115) was superior to the silver plate, and aluminum Exmet was also somewhat better than the silver plate (P-125 vs 130). In the latter instance, at -63° the silver was removed, possibly due in part to the presence of $HgSO_4$. However, in cells P-116 and 117, which contained no $HgSO_4$ but which were discharged at -40°, all of the silver-plate was removed, and the copper grid was almost destroyed. Lead Exmet lasted for over two days but was found to be completely disintegrated after four days. There was no corrosion resistance of aluminum and to secure better adhesion of the paste to the grid, it was used in the form of Exmet in cells P-131 and 132. The life of 82 hours to 1.3 volts indicated it to be quite satisfactory for use at -63° with the 70:30 S/C mix.

It is concluded from the available data that either gold-plated copper or aluminum in the form of Exmet should be used in any future pasted-plate fabrication.

## 2.4. Cathode Composition

The proportions of $HgSO_4$, sulfur, graphite, acetylene black and paper pulp have been varied in the cathode mix. The test cells were of standard construction with silver-plated copper Exmet collector grids. The electrolyte was 34% KSCN in liquid ammonia. A number of tests from the first quarter are included to provide a more complete picture.

## 2.4.1. $HgSO_4$/S/Carbon Cathodes

TABLE V

Cathode Variations with Mercuric Sulfate

| Cell No. P- | Mol ratio S:$HgSO_4$ | $HgSO_4$ % | S % | C % | Temp. °C | Hours to* 1.5V | Hours to* 1.3V |
|---|---|---|---|---|---|---|---|
| 17, 22, 29, 35 | | 0.0 | 41.4 | 58.6 | -90 | 57 | 66 |
| 18, 23, 30, 36 | 4:1 | 40.8 | 17.7 | 41.5 | -90 | 54 | 64 |
| 19, 28 | 2:1 | 51.5 | 11.2 | 37.3 | -90 | 58 | 66 |
| 9-14, 51, 52 | 1.86:1 | 55.6 | 11.1 | 33.3 | -90 | 58 | 66 |
| 25, 31, 37 | 1.1 | 60.0 | 6.4 | 33.6 | -90 | 59 | 65 |
| 21, 27 | 0 | 70.8 | 0.0 | 29.2 | -90 | 38 | 41 |
| 118, 119 | 1.86:1 | 55.6 | 11.1 | 33.3 | -63 | 34 | 38 |
| 120, 121 | 1.86:1 | 55.6 | 11.1 | 33.3 | -40 | 32 | 45 |

*Under heavy load.

At -90°c, all of the above combinations, except the one without sulfur, yielded about the same average life and had at least one cell in each group that met the three day requirement. Without sulfur, the performance was erratic and unpredictable. Reproducibility was best in the absence of $HgSO_4$.

At the highest temperatures, -63° and -40°, corrosion of the collector grids was severe, and the performance was unsatisfactory.

It would have been desirable to have established the most effective ratio of oxidant to graphite for each combination of oxidants. An example of such a determination may be found in the next section, 2.4.2.

## 2.4.2 Sulfur/Carbon Cathodes

TABLE VI

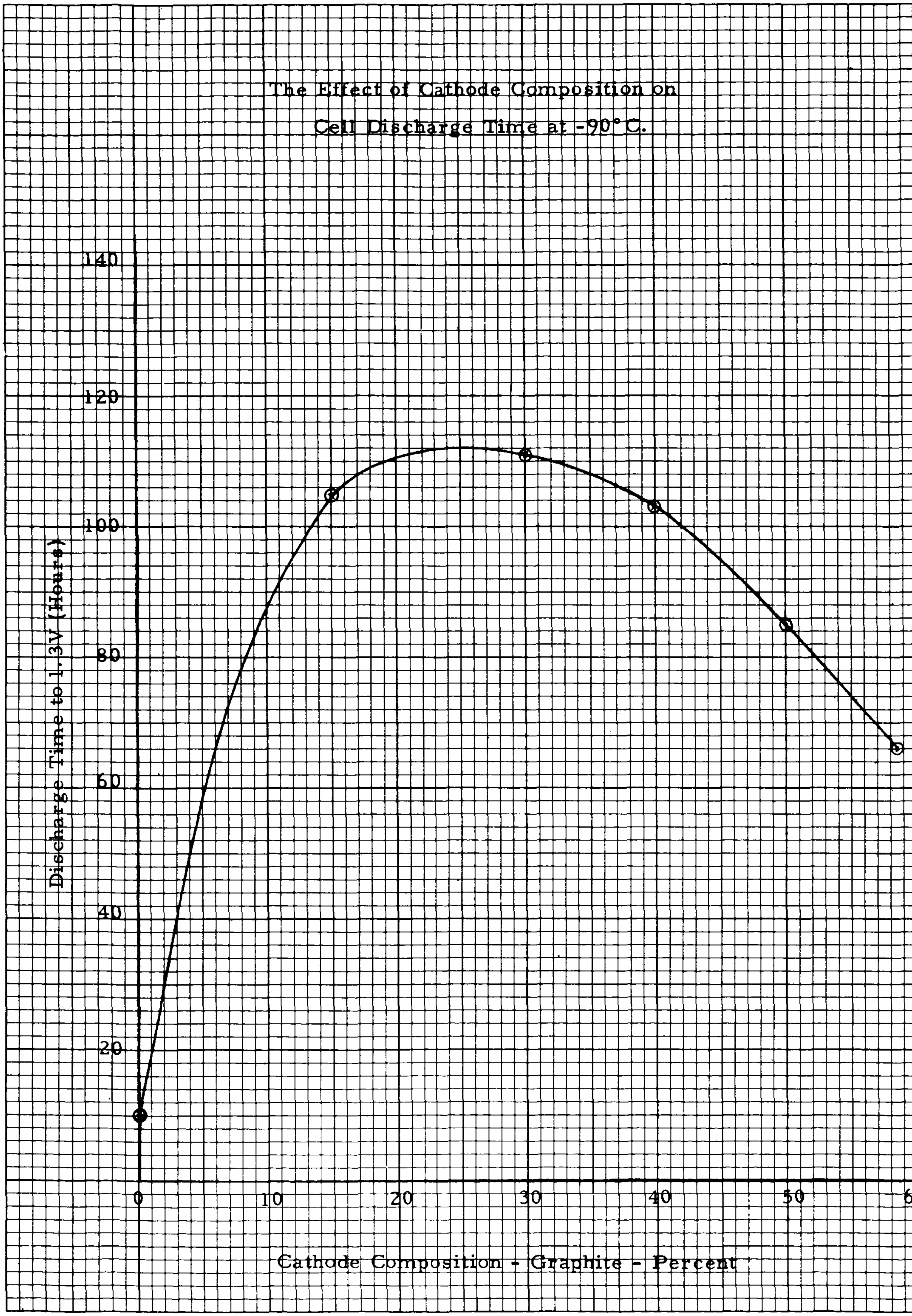
Cathode Variations without Mercuric Sulfate

| Cell No. P- | S % | C % | Temp. °C | Hours to* 1.5V | Hours to* 1.3V |
|---|---|---|---|---|---|
| 17, 22, 29, 35 | 41.4 | 58.6 | -90 | 57 | 66 |
| 34 | 50.0 | 50.0 | -90 | 79 | 85 |
| 78, 79 | 60.0 | 40.0 | -90 | 93 | 105 |
| 76, 77, 96, 97 | 70.0 | 30.0 | -90 | 85 | 111 |
| 33, 38, 58 | 85.0 | 15.0 | -90 | 79 | 105 |
| 32 | 100.0 | 0.0 | -90 | 0 | 8 |
| 100 to 104 | 70.0 | 30.0 | -63 | 43 | 55 |
| 99, 105 | 85.0 | 15.0 | -63 | 50 | 75 |
| 116, 117 | 70.0 | 30.0 | -40 | 19 | 23 |

*Under heavy load.

This table and the accompanying graph, Figure 1, show the optimum composition of a S/C cathode for discharge at -90° to be about 70 percent sulfur and 30 percent graphite.

Eighty-five percent sulfur appears to be better for discharge at -63°. However, one cell (P-102) in the 70 percent S group ran for 66 hours to 1.5V and for 75 hours to 1.3V.



The Effect of Cathode Composition on
Cell Discharge Time at -90°C.
Discharge Time to 1.3V (Hours)
140
120
100
80
60
40
20
0
10
20
30
40
50
60
Cathode Composition - Graphite - Percent


Figure 1

## 2.4.3. Acetylene Black

In Table VII, the results of substituting acetylene black for part of the graphite are summarized. All cells were discharged at -90°C.

TABLE VII

Graphite/Acetylene Black Variations

| Cell No. P- | S g | Graphite g | Acet. Black g | Total Carbon % | Electrolyte Vol. (cc) | Ave. Hours* to 1.3V |
|---|---|---|---|---|---|---|
| 76, 77 | 17 | 7.3 | 0 | 30 | 125 | 130 |
| 96, 97 | 17 | 7.3 | 0 | 30 | 100 | 93 |
| 83 | 17 | 6.6 | 0.7 | 30 | 125 | 87 |
| 91 | 17 | 6.6 | 0.7 | 30 | 100 | 80 |
| 84 | 17 | 5.9 | 1.4 | 30 | 125 | 108 |
| 92 | 17 | 5.9 | 1.4 | 30 | 100 | 86 |
| 33, 38 | 21 | 3.7 | 0 | 15 | 100 | 105 |
| 58 | 21 | 3.7 | 0 | 15 | 100 | 105 |
| 81 | 21 | 3.3 | 0.4 | 15 | 125 | 118 |
| 89 | 21 | 3.3 | 0.4 | 15 | 100 | 72 |
| 82 | 21 | 2.9 | 0.8 | 15 | 125 | 121 |
| 90 | 21 | 2.9 | 0.8 | 15 | 100 | 85 |

*Under heavy load.

Only those cells containing equal amounts of electrolyte can be compared with each other, for it is evident that this factor had a greater influence on performance than the additive. It is difficult to draw a definite conclusion from these data. Every cell, however, met or exceeded the 72-hour requirement.

## 2.4.4. Paper Pulp

Table VIII is a summary of the test results at -90°C on cells in which paper pulp was added to the cathode composition.

TABLE VIII

Paper Pulp Additive

| Cell No. P- | S g | C g | C % | Paper Pulp g | Electrolyte Vol. (cc) | Ave. Hours* to 1.3V |
|---|---|---|---|---|---|---|
| 76, 77 | 17 | 7.3 | 30 | 0 | 125 | 130 |
| 96, 97 | 17 | 7.3 | 30 | 0 | 100 | 93 |
| 85 | 17 | 7.3 | 30 | 0.25 | 100 | 89 |
| 86 | 17 | 7.3 | 30 | 0.75 | 120 | 109 |
| 33, 38 | 21 | 3.7 | 15 | 0 | 100 | 105 |
| 58 | 21 | 3.7 | 15 | 0 | 100 | 105 |
| 87 | 21 | 3.7 | 15 | 0.25 | 110 | 100 |
| 88 | 21 | 3.7 | 15 | 0.75 | 130 | 69 |

*Under heavy load.

No advantage can be attributed to the addition of paper pulp, and it seemed to have a harmful effect, particularly on Cell No. P-88. Additional electrolyte had to be added to compensate for absorption by the pulp.

## 2.5. Cathode Plate Thickness

The thickness of the pasted plates normally used for most of this work has been about 1/8 inch, regardless of the composition. In the experiments shown in Table IX, the thickness was varied. Since the area was constant, the cathode weights necessarily changed, and the resistive loads were adjusted accordingly. The peak anode current density varied approximately in proportion to the applied load.

TABLE IX

Positive Electrode Thickness Variations

| Cell No. P- | Thickness in. | $HgSO_4$ g | S g | C g | Loads, Ω | Peak C. D. $mA/cm^2$ | Hours to* 1.3V |
|---|---|---|---|---|---|---|---|
| 13 cells | 1/8 | 20 | 4 | 12 | 13.5/68 | | |
| | | | Maximum | | | 0.81 | 117 |
| | | | Minimum | | | 0.70 | 28 |
| | | | Average | | | 0.76 | 63 |
| 43 | 5/8 | 100 | 20 | 60 | 2.7/13.5 | 3.67 | 38 |
| 44 | 5/8 | 100 | 20 | 60 | 2.7/13.5 | 2.91 | 20 |
| 54 | 5/8 | 100 | 20 | 60 | 2.7/13.5 | 3.42 | 30 |
| 46 | 1/16[a] | 5 | 1 | 3 | 48/240 | 0.22 | 49 |
| 47 | 1/16[a] | 5 | 1 | 3 | 48/240 | 0.22 | 48 |
| 61 | 1/16[b] | 5.95 | 1.19 | 3.57 | 48/240 | 0.22 | 82 |

*Under heavy load.
[a]Just enough paste to fill pores of collector grid.
[b]Grid surface covered somewhat better than in (a).

The life span of $HgSO_4$/S cells has been highly erratic and unpredictable, and the factors affecting it have not been identified with certainty. However, these data and other observations which will be reported later indicate that anode current density is a limiting factor.

Cells P-46 and 47, in which the grids were not completely covered, ran for a relatively short time in comparison with No. P-61. This and the relation between grid corrosion and cell life, which was evident in tests at higher temperatures, lead one to the opinion that grid corrosion in some way poisons a cell.

## 2.6. Transition from Prismatic to Bobbin Cell Structures

A conventional prismatic or pasted-plate cell (as described and illustrated in Appendix B, pages B-1 and B-2) may be comprised of a single cathode with a Mg anode on each side. Most cells were designed to provide 1/5 of the capacity required by a full-sized cell. The experiments covered in this section were conducted primarily to gain the information required for the design of a bobbin cell with the capability of satisfactory operation at -90°C.

### 2.6.1. Single-Sided Discharge

The geometry of a bobbin cell usually involves what may be termed single-sided discharge between an anode and a cathode. This is contrasted to the multiple flat-plate structure sometimes referred to as prismatic where, with the exception of the outside plates, all electrodes are discharged from two surfaces towards the center. In single-sided discharge, one flat plate cathode may be discharged against a flat plate anode. In this case the current from the side of the cathode which is nearest the anode need not travel through the depth of the porous cathode structure. On the other hand, the electrolytic current from the cathode side facing away from the anode must pass through the pores of the complete cathode thickness. This characteristic may be a limiting factor in the operation of bobbin type cathodes. The greater cathode thickness inherent in the bobbin cell was explored in a rather unique fashion by means of a similar construction employing more than one porous cathode or anode grouped together to simulate a single thick porous cathode and anode. However, the individual plates in several cases were electrically insulated permitting the recorded data to be, in effect, stratified as to cathodic thickness. These exploratory structures were quite useful in defining some of the limiting factors of the magnesium/KSCN: $NH_3$/S:$HgSO_4$:carbon cell as it applies to bobbin type structures.

Not only was it possible, by this means, to determine the effect of electrode thickness upon discharge characteristics, but the location of porous reference electrodes between a working cathode and a working anode of the flat plate type permits a clear definiation from the standpoint of geometry as to which electrode is controlling the increase or decrease of cell voltage, including the effect of porous electrode thickness. The following paragraphs, 2.6.1.1. through 2.6.1.3., describe such cells and the conclusions which were drawn therefrom.

### 2.6.1.1. Single Cathode, Single Working Anode

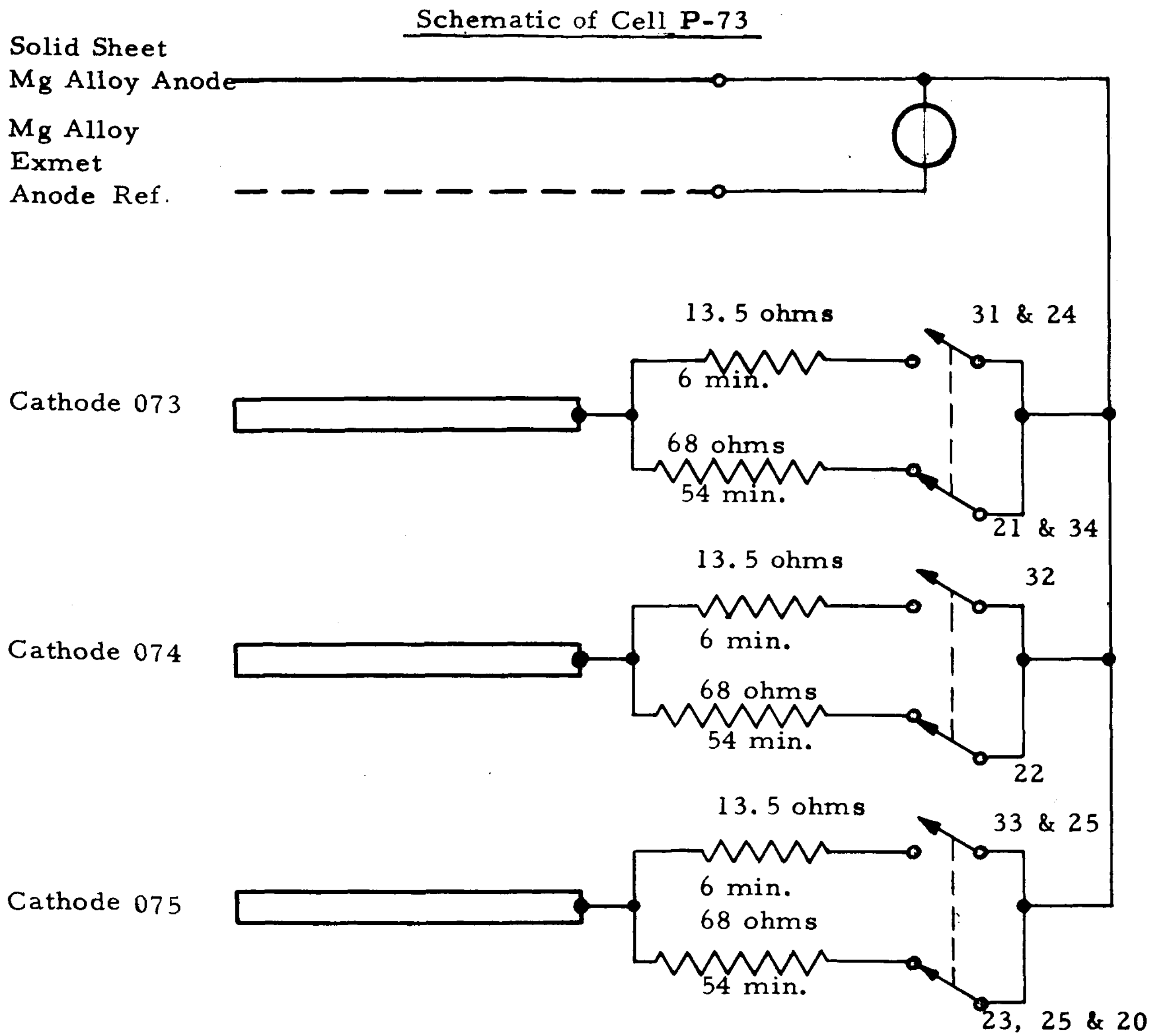
In the first quarter, a cell, No. B-50, was discharged at the full prorated load from one anode while the other anode was utilized as a reference. Difficulties were encountered with the reference electrode, indicating working anode cut-off.

Cells P-94 and 95 were constructed with only one anode and one cathode, thereby doubling the normal anode current density. As a result, the life span was reduced drastically to an average of about 56 hours.

In a further investigation of the effect of electrode geometry, cells were constructed with cathodes on which the applied paste was localized on one side for cells P-65 and P-66, and which was 1/4" thick (double thickness) for cells P-71 and P-72. It had been expected that cell P-65, wherein the cathode mixture was loaded onto the anode side of the silver-plated cathode collector, would be superior. However, cell P-66 which was the converse of this, was decidedly better. Both cells might, of course, be considered to be limited by the effect of anode polarization at double the design center current density. The 1/4" thick cathode cells, P-71 and P-72, were discharged with single anodes, and it is presumed now in the light of additional data that the reduced service hours were due to anode polarization at four times design center current density resulting from the prorating of the load upon cathode theoretical capacity.

### 2.6.1.2. Triple Cathodes, Single Working Anode Flat-Plate Equivalent of a Bobbin Cell

Cell P-73 consisted of a flat anode, a reference Exmet anode, and three separately loaded cathodes, all on the same side of the working anode. The load current of all three cathodes was, therefore, channeled through the inside working cathode. It is interesting to note that the performance of this cell, while substantial, was limited not by the multiplicity of cathodes, but rather by anode current density. Refer to Figure 2 and Table X. For example, in Table X at 42 hours channels 31-33 show the significant effect of anode current density upon output voltage.




DIGITAL RECORDER CHANNEL NUMBERS

| | | | |
|---|---|---|---|
| Cathode 073 | 21 | Heavy load for 6 min./hour<br>24 31 | 34 |
| Cathode 074 | 22 | Heavy load for 6 min./hour<br>32 | |
| Cathode 075 | 20 23 | Heavy load for 6 min./hour<br>25 33 | 35 |

FORM FM-100

Figure 2

# TABLE X

## PERIODIC CELL VOLTAGES

### Cell No. P-73

| Elapsed Time (Hours) | Channel Numbers | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 21 | 22 | 23 | 24 | 25 | 31 | 32 | 33 | 34 | 35 |
| First | 1.91 | 1.82 | 1.65 | 1.39 | 1.13 | 1.33 | 1.45 | 1.46 | 1.88 | 1.84 |
| 6 | 1.56 | 1.11 | 0.80 | 0.66 | 0.54 | 0.67 | 0.86 | 0.95 | 1.61 | 1.53 |
| 12 | 1.43 | 0.91 | 0.58 | 0.46 | 0.40 | 0.56 | 0.75 | 0.85 | 1.60 | 1.50 |
| 18 | 1.72 | 1.47 | 1.15 | 0.90 | 0.75 | 0.79 | 0.92 | 1.02 | 1.62 | 1.55 |
| 24* | 1.83 | 1.63 | 1.35 | 1.15 | 1.08 | 1.35 | 1.55 | 1.47 | 1.85 | 1.77 |
| 30 | 1.85 | 1.75 | 1.53 | 1.26 | 1.15 | 1.24 | 1.46 | 1.44 | 1.85 | 1.79 |
| 36 | 1.82 | 1.57 | 1.27 | 0.97 | 0.86 | 0.95 | 1.22 | 1.29 | 1.83 | 1.75 |
| 42 | 1.69 | 1.32 | 0.96 | 0.69 | 0.59 | 0.75 | 1.03 | 1.12 | 1.86 | 1.88 |
| 48** | 1.87 | 1.80 | 1.59 | 1.34 | 1.23 | 1.28 | 1.48 | 1.40 | 1.85 | 1.78 |
| 54 | 1.90 | 1.83 | 1.60 | 1.29 | 1.16 | 1.21 | 1.42 | 1.36 | 1.82 | 1.79 |
| 60 | 1.81 | 1.65 | 1.38 | 1.12 | 1.01 | 1.07 | 1.30 | 1.27 | 1.77 | 1.72 |
| 66 | 1.79 | 1.61 | 1.32 | 1.04 | 0.95 | 0.99 | 1.22 | 1.21 | 1.75 | 1.68 |
| 72 | 1.78 | 1.57 | 1.26 | 1.01 | 0.91 | 0.96 | 1.19 | 1.17 | 1.74 | 1.68 |
| 78 | 1.75 | 1.52 | 1.20 | 0.96 | 0.86 | 0.92 | 1.14 | 1.14 | 1.71 | 1.65 |

* Switched from flat Mg to expanded Mg at 23rd hour.

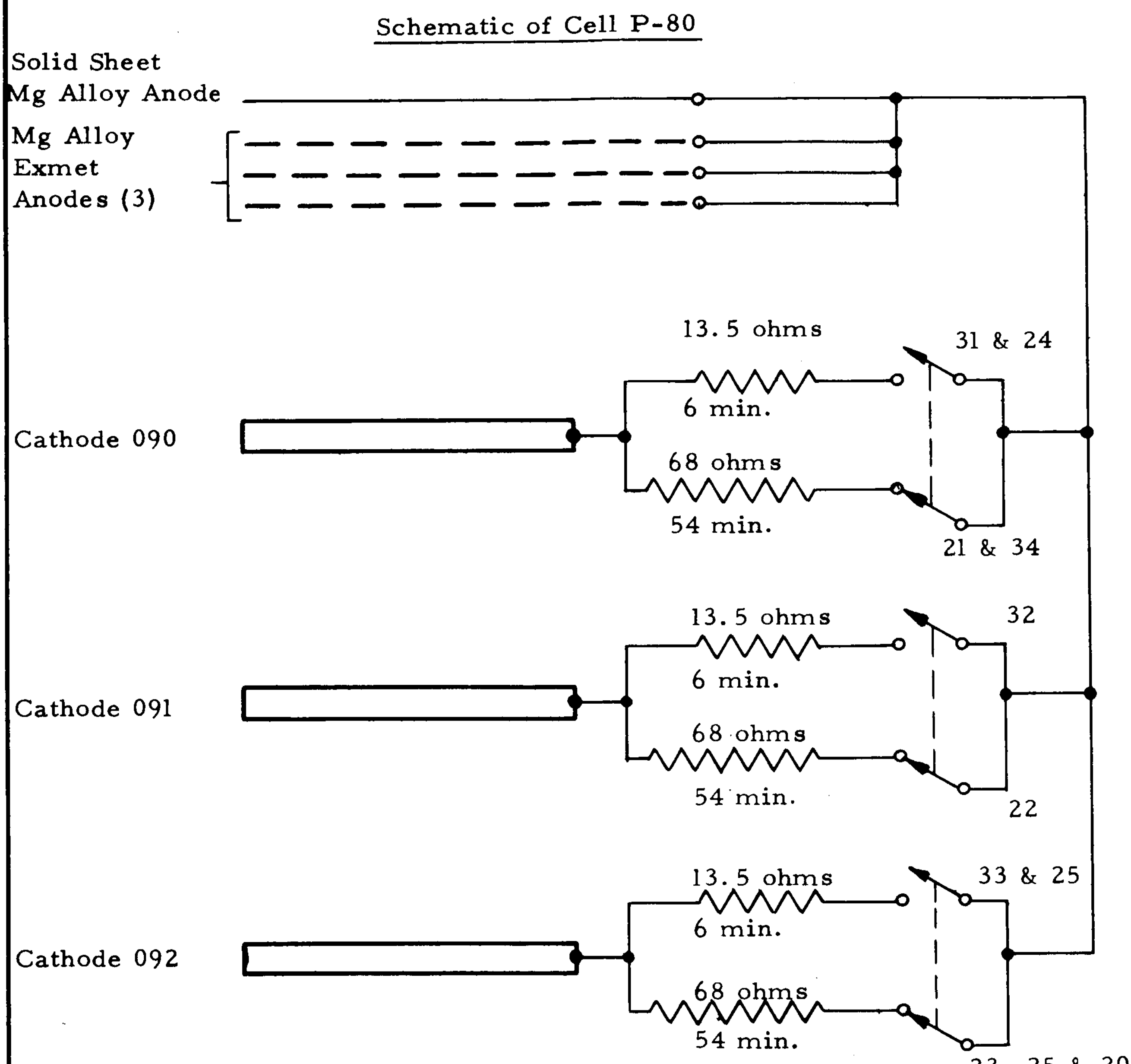
** Discharging from both flat and expanded Mg at 43rd hour.

Note: Both flat and expanded Mg electrodes on one side of the three cathodes.

### 2.6.1.3. Triple Cathodes, Multiple Anodes, Cells P-80 and 93

Schematic drawings of the arrangement of the multiple electrodes, the electrical loading and the sequence of the digital recorder voltage channels in relation to the load programming are shown in Figures 3 and 4. Table XI is a display of voltage recordings on each channel at six-hour intervals. Channels 20, 21, 34, and 35 represent voltages when all cathodes are under light load; numbers 24, 25, and 31 print when all are under heavy load. A comparison of 24 with 25, and 34 with 35 shows the effect of cathode location under heavy and light loads, respectively. The recordings on 21 and 31 were used to compute the cell output as shown in Table I of the Appendix. The anode current density was based on the combined areas of one face of each anode.

Cell P-73 was anode limited. Cell P-80 was approximately balanced with respect to anodes and cathodes. Cell P-93 featured extra anodes. At 42 hours the differences between channels 31 and 33 were 0.37, 0.18, and 0.07 volts respectively showing that high anode current density is most detrimental but that the cathode may be even three layers thick without excessive voltage loss. Note the current for the last cathode must pass through the electrolyte pores of the first and the second!



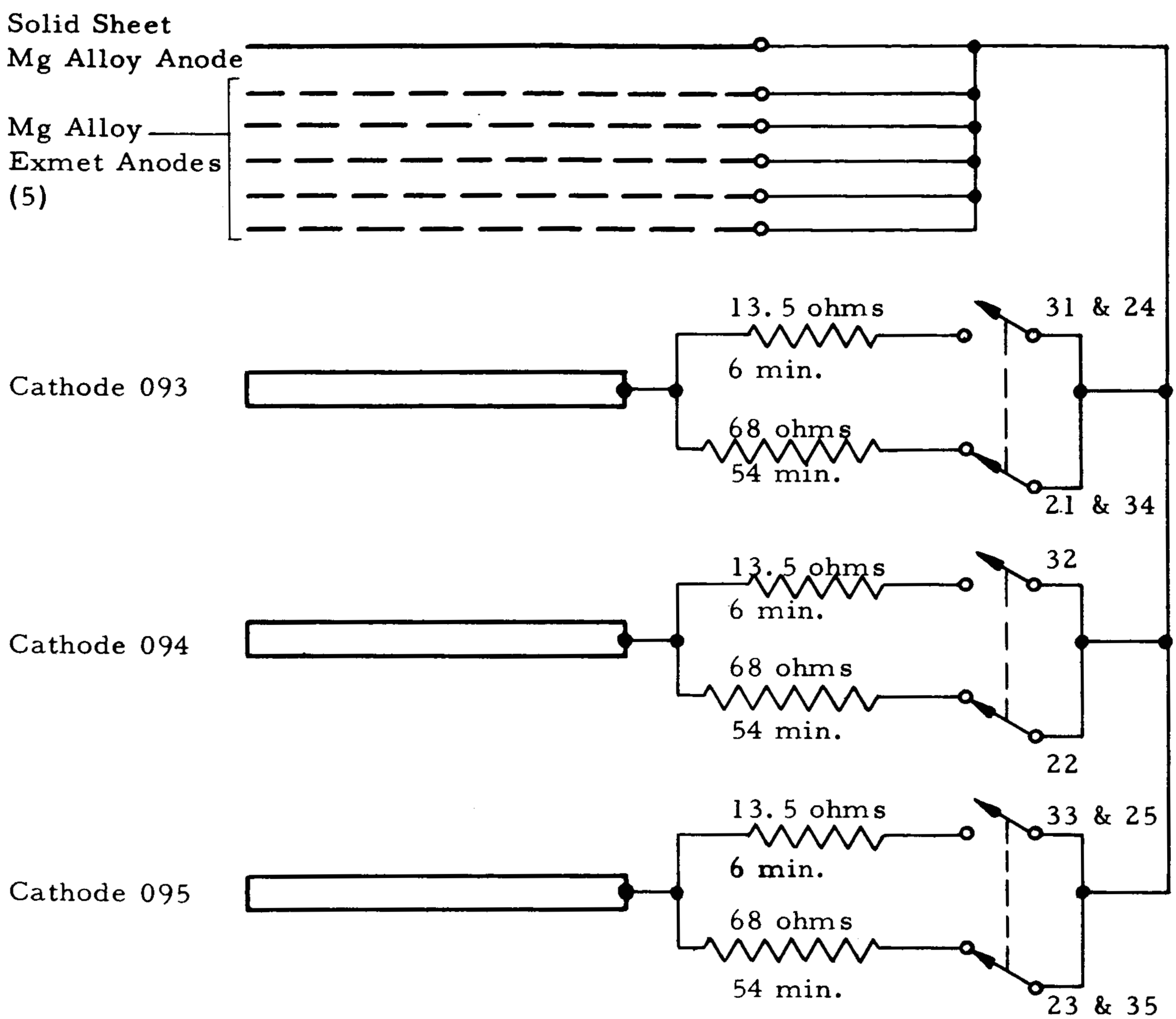

DIGITAL RECORDER CHANNEL NUMBERS

| | | | |
|---|---|---|---|
| Cathode 090 21 | Heavy load for 6 min./hour<br>24 | 34 | |
| Cathode 091 22 | Heavy load for 6 min./hour<br>32 | | |
| Cathode 092 20 23 | Heavy load for 6 min./hour<br>25 33 | 35 | |

FORM FM-100

Figure 3

Schematic of Cell P-93




DIGITAL RECORDER CHANNEL NUMBERS

| | | Heavy load for 6 min./hour | |
|---|---|---|---|
| Cathode 093 | 21 | 24 31 | 34 |
| Cathode 094 | 22 | 32 | |
| Cathode 095 | 23 | 25 33 | 35 |

FORM FM-100

Figure 4

# TABLE XI

## PERIODIC CELL VOLTAGES

### Cell No. P-80
Refer to Figure 3

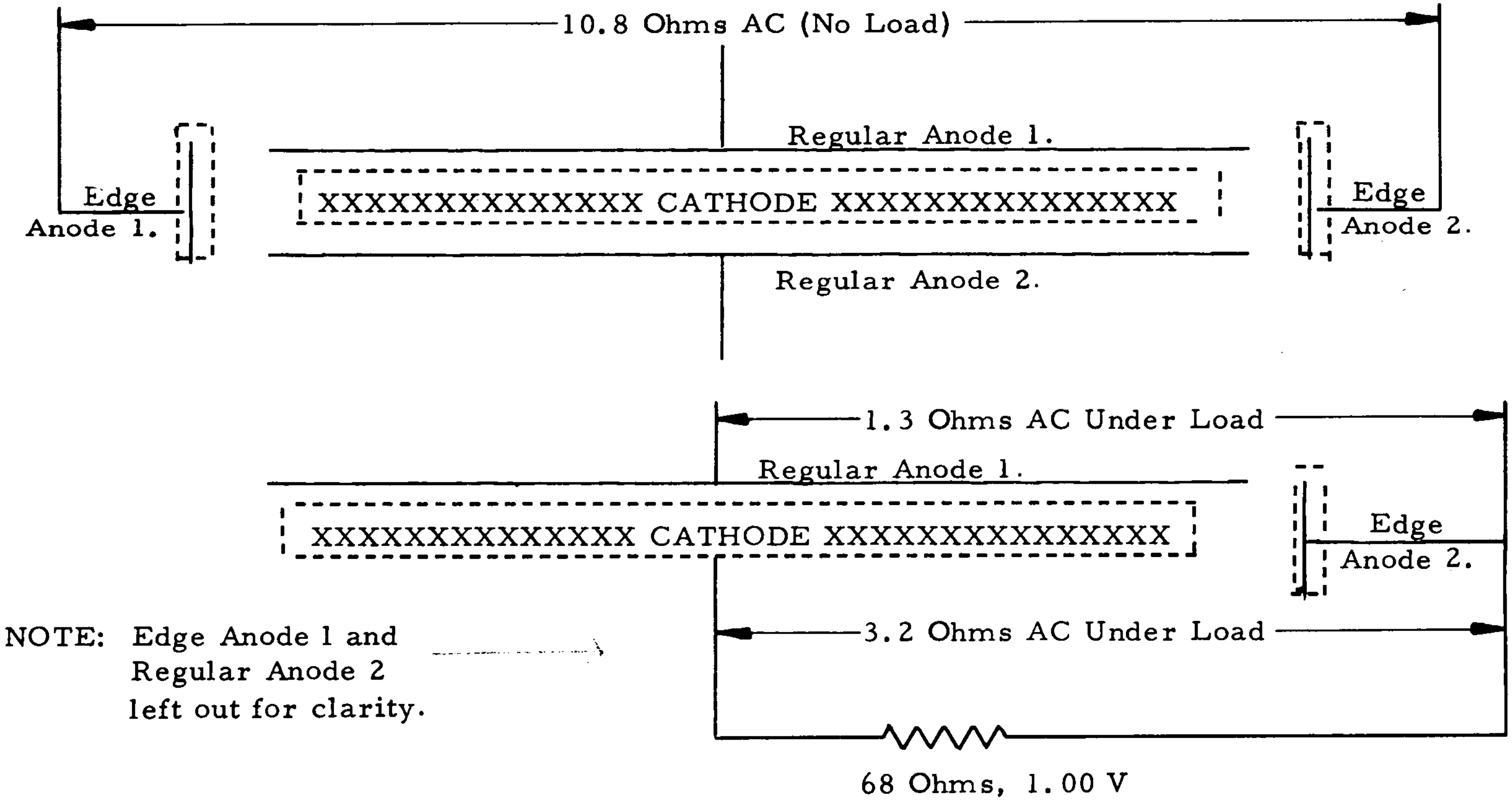
| Elapsed Time (Hours) | Channel Numbers | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 20 | 21 | 22 | 23 | 24 | 25 | 31 | 32 | 33 | 34 | 35 |
| First | | 1.92 | 1.84 | 1.68 | 1.72 | 1.65 | 1.76 | 1.72 | 1.74 | 1.91 | 1.87 |
| 6 | | 1.95 | 1.90 | 1.80 | 1.77 | 1.66 | 1.75 | 1.74 | 1.75 | 1.93 | 1.90 |
| 12 | | 1.95 | 1.89 | 1.81 | 1.76 | 1.65 | 1.70 | 1.71 | 1.72 | 1.92 | 1.89 |
| 18 | | 1.93 | 1.90 | 1.79 | 1.75 | 1.62 | 1.63 | 1.65 | 1.69 | 1.91 | 1.88 |
| 24 | 1.92 | 1.94 | 1.90 | 1.78 | 1.72 | 1.62 | 1.62 | 1.63 | 1.67 | 1.90 | 1.88 |
| 30 | 1.91 | 1.94 | 1.89 | 1.76 | 1.69 | 1.58 | 1.56 | 1.59 | 1.64 | 1.88 | 1.87 |
| 36 | 1.89 | 1.90 | 1.83 | 1.70 | 1.58 | 1.48 | 1.49 | 1.54 | 1.61 | 1.86 | 1.85 |
| 42 | 1.86 | 1.86 | 1.75 | 1.59 | 1.45 | 1.37 | 1.34 | 1.41 | 1.52 | 1.81 | 1.80 |
| 48 | 1.84 | 1.83 | 1.70 | 1.54 | 1.37 | 1.30 | 1.28 | 1.38 | 1.50 | 1.80 | 1.79 |

### Cell No. P-93
Refer to Figure 4

| | 20 | 21 | 22 | 23 | 24 | 25 | 31 | 32 | 33 | 34 | 35 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| First | | 1.93 | 1.86 | 1.75 | 1.71 | 1.61 | 1.76 | 1.73 | 1.69 | 1.92 | 1.89 |
| 6 | | 1.95 | 1.89 | 1.78 | 1.67 | 1.57 | 1.77 | 1.73 | 1.71 | 1.93 | 1.89 |
| 12 | | 1.96 | 1.91 | 1.79 | 1.69 | 1.49 | 1.72 | 1.73 | 1.71 | 1.92 | 1.90 |
| 18 | | 1.94 | 1.88 | 1.73 | 1.67 | 1.50 | 1.66 | 1.69 | 1.68 | 1.91 | 1.88 |
| 24 | | 1.91 | 1.84 | 1.70 | 1.65 | 1.50 | 1.62 | 1.66 | 1.65 | 1.90 | 1.84 |
| 30 | | 1.91 | 1.84 | 1.68 | 1.63 | 1.48 | 1.60 | 1.64 | 1.62 | 1.90 | 1.85 |
| 36 | | 1.90 | 1.81 | 1.65 | 1.60 | 1.45 | 1.55 | 1.59 | 1.58 | 1.88 | 1.81 |
| 42 | | 1.86 | 1.73 | 1.57 | 1.50 | 1.37 | 1.46 | 1.50 | 1.53 | 1.83 | 1.78 |
| 48 | | 1.82 | 1.67 | 1.50 | 1.41 | 1.28 | 1.37 | 1.41 | 1.47 | 1.80 | 1.74 |
| 54 | | 1.79 | 1.62 | 1.45 | 1.34 | 1.22 | 1.30 | 1.35 | 1.43 | 1.76 | 1.71 |
| 60 | | 1.75 | 1.55 | 1.30 | 1.25 | 1.15 | 1.21 | 1.28 | 1.38 | 1.72 | 1.68 |

## 2.6.2. Edge Discharge, Cell No. P-55

This was a conventional $HgSO_4/S/C$ prismatic cell with a single cathode and an anode on either side. In addition, narrow anodes were located to face two opposite edges of the cathode. Figure 5 is a cross-sectional schematic of this exploratory cell. The edge anodes were initially used as the working anodes against the cathode located perpendicularly and lengthwise to the edge anodes. Despite the long and narrow electrolyte path between the edge anodes and the working cathode, the early cell cut-off was attributed to anode polarization rather than electrolyte IR drop as indicated by Table XII. Subsequent to the initial discharge, the normal anodes were utilized as working anodes, the edge anodes used as references, and cell performance resumed for a substantial period of time. Since the reference electrodes were not in a favorable position to differentiate between anode polarization and electrolyte IR drop, it was not certain that anode polarization was responsible. The reference electrode should be placed in a favorable position between the working anode and cathode in order to discriminate between anode and cathode polarization. The reference in that case has to be perforated (Exmet). A complex cell, including this feature and several others, is presented under the next subsection.




CROSS-SECTIONAL SCHEMATIC OF CELL P-55

Figure 5

## TABLE XII

## REFERENCE READINGS, CELL NO. P-55

After 23 hours discharge via edge anodes, large anodes (reference) and small anodes (working) at 68 ohm load:

| | |
|---|---|
| Cathode to Small Anodes | 1.00V |
| Cathode to Large Anodes | 2.10V |
| Large Anodes (+) to Small Anodes (-) | 1.10V |

Same readings with cell on open circuit for 10 minutes:

| | |
|---|---|
| Cathode to Small Anodes | 2.23V |
| Cathode to Large Anodes | 2.10V |
| Large Anodes (-) to Small Anodes (+) | 0.12V |

Calculations (Refer to Figure 5):

$$I = \frac{E}{R} \quad \text{where}$$

I = Cell current
E = Working cell voltage
R = External load resistance

I = 1.00/68 = 0.0147 amperes.

Ir where I = Cell current above
r = Cell ohmic resistance determined by ac measurements

Internal Ir loss = 0.0147 x 3.2 = 0.047 volts.

Consequently, the potential of the cell has been reduced by ohmic polarization at the small anodes, not by Ir drop in the cathode.

### 2.6.3. Exploratory Flat-Plat Cell No. P-57

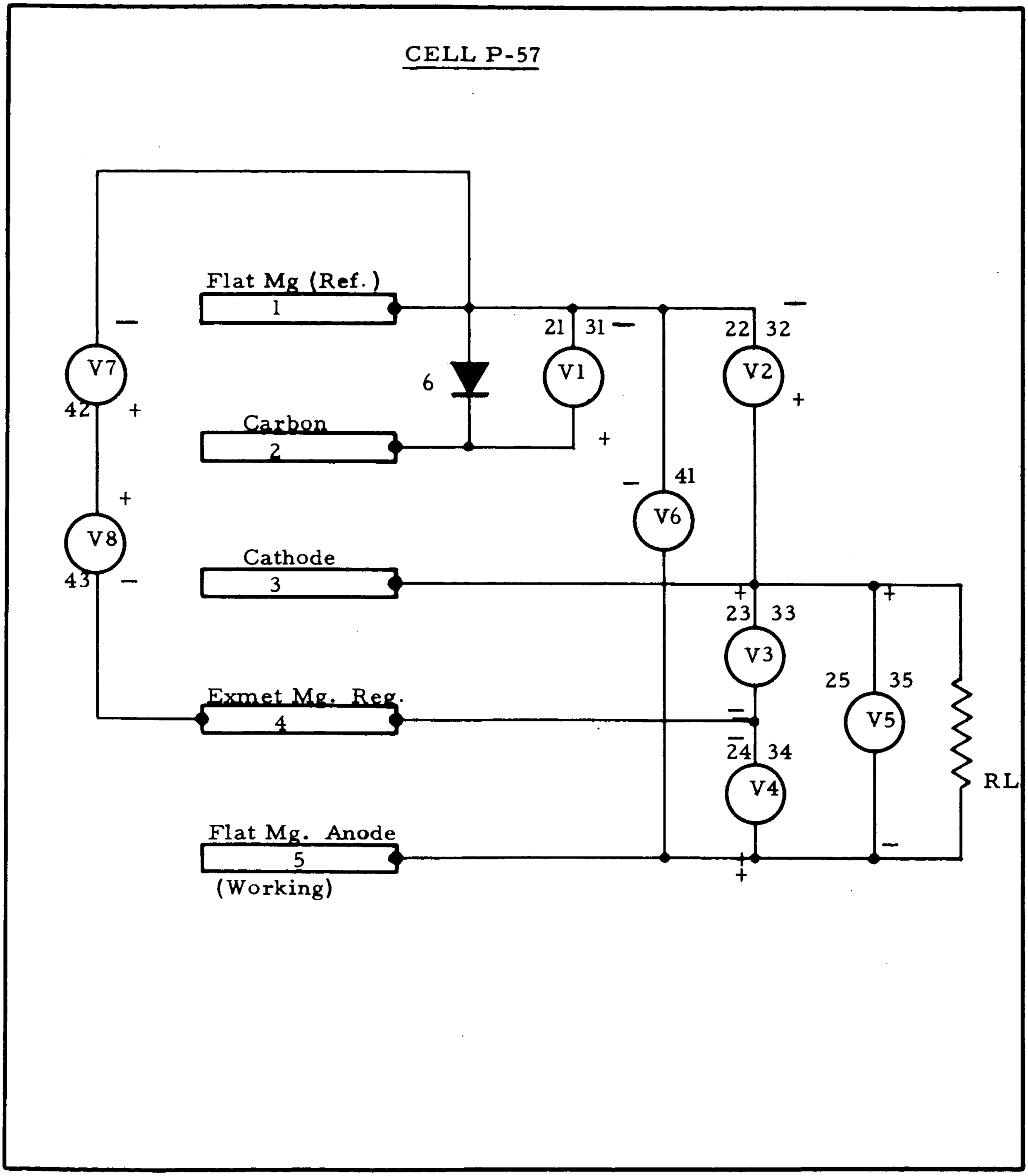
This cell (Figure 6) incorporated two flat magnesium anodes (1 and 5) and a design center cathode (3)[1]. However, in between one anode (1) and the cathode (3) a pasted carbon electrode (2) was inserted, and between the other anode (5) and the cathode (3) an expanded magnesium anode (4) was located. The actual load was applied between the cathode (3) and the working anode (5). This was the anode (5) which was separated from the cathode (3) by means of the expanded magnesium reference electrode (4). As mentioned under paragraph 2.6.2., this reference electrode (4) which was between the cathode (3) and the single working anode (5), indicated clearly that voltage decline was due to loss of potential at the anode under load (5). The carbon electrode (2) was loaded by means of a diode (6) in the forward mode in order to determine the presence of soluble oxidants emanating from the cathode (3). While considerable current could be drawn from this carbon electrode (2) in the 1-volt region, little capacity was available in the 1.5 volt region. Considerable data was collected on this cell, but the significant points have been described, and these points will be further discussed in specific cells designed to illuminate these particular properties.

### 2.6.4. Pasted Carbon Third Electrode Between Working Electrodes

The purpose of the following was to determine if sulfur or other oxidizing value was going into solution in the electrolyte and becoming lost to the cathode. In cell P-69, a porous carbon electrode was located between the single working anode and the single working cathode. The heavy 6-minute load was connected between the cathode containing sulfur only as the oxidant and the anode. The carbon electrode was connected to the anode via the light load which was left in place continuously. The carbon electrode did not show evidence of soluble oxidizing value until late in the run. This was certainly an informative and unexpected turn of events since the higher polysulfides are soluble in liquid ammonia.

---

[1] (Refer to Figure I, Appendix B, page B-2. A "design center cathode" consists of 20 grams of $HgSO_4$, 4 grams of sulfur and 12 grams of graphite and has the capability of providing 1/5 of the capacity required of a full-sized cell at -90°C. Examples of cells with this cathode are P-14, 51, and 52.




FORM FM-100

Figure 6

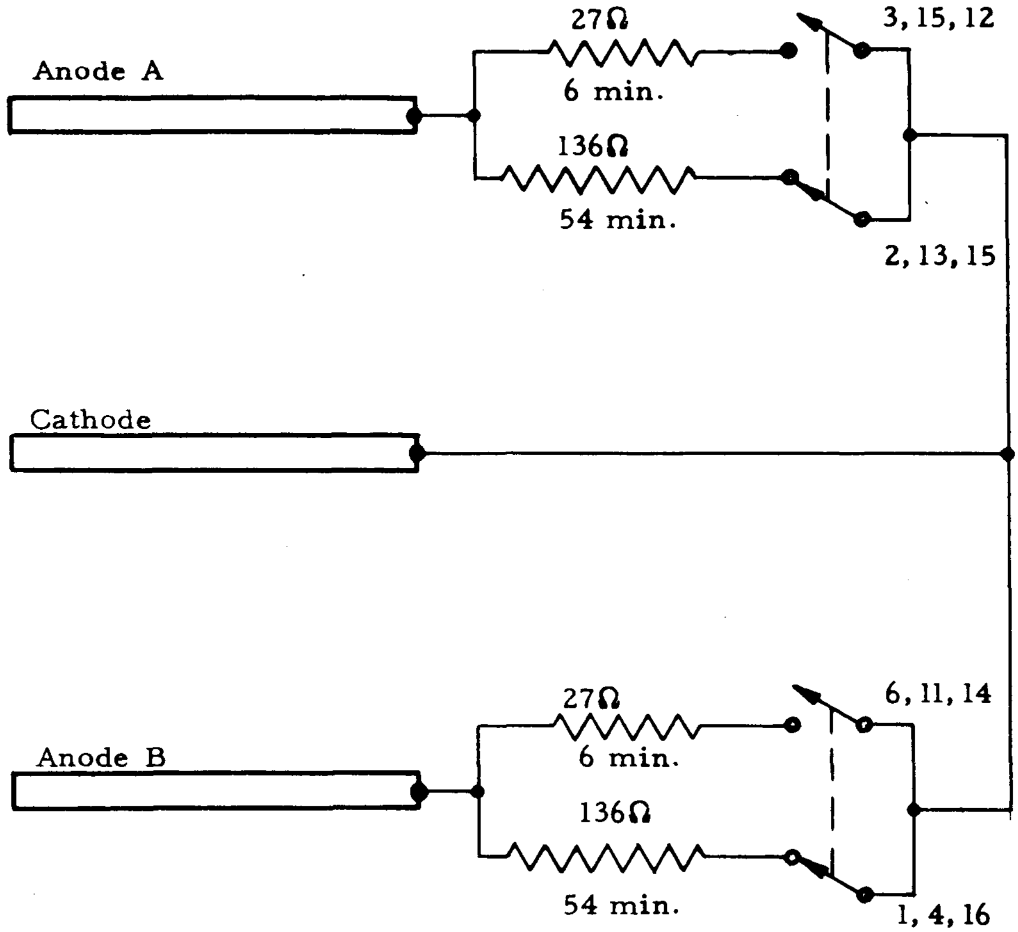
## 2.6.5. Single Cathode, Two Anodes Loaded Individually-Cell No. P-134

Since each anode was loaded with one half of the normal total, the overall current density was the same as that of a conventional prismatic cell. The heavy and light loads were applied sequentially to each anode, and the performance of each was monitored continuously. Figure 7 is a schematic drawing of the electrodes and the electrical loading and shows the sequence of the digital voltage recordings. Table XIII is a display of the voltages on each channel at twelve hour intervals. The normal duration of the heavy load is six minutes (10 channels x 36 seconds per channel). In this case, only 50 percent of the heavy load was applied to the cathode during the print-out of channels 3, 4, 13, and 14; and 100 percent during the print-out of channels 5 through 12. Thus, four channels at 50 percent of full load plus eight channels at full load are equivalent in terms of watt-minutes to 10 channels at 100 percent heavy load.

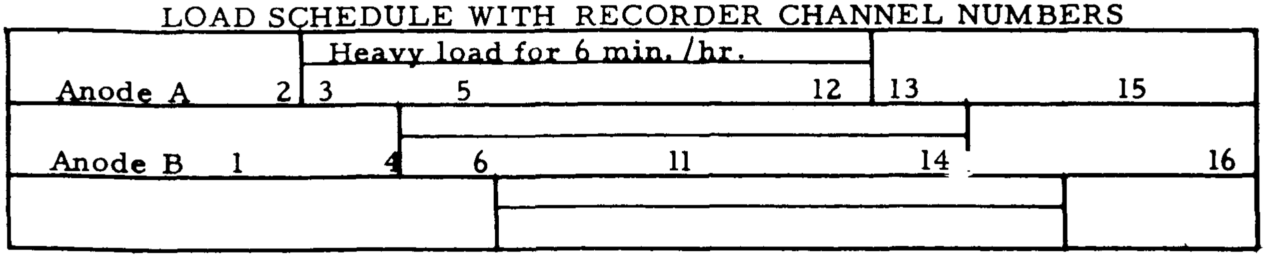
In general, the performance of the two anodes was much the same. As expected, the potential dropped as the load was increased and then recovered as the load was decreased. The effect of increased current density on the cathode is shown by channels 3 vs 5.

Further data reported on this cell is presented in 2.6.6.1.

SCHEMATIC OF CELL P-134




LOAD SCHEDULE WITH RECORDER CHANNEL NUMBERS




FORM FM-100

Figure 7

# TABLE XIII

## PERIODIC CELL VOLTAGES

### Cell No. P-134

Refer to Figure

| Anode: | B | A | A | B | A | B | B | A | A | B | A | B |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Channel No. | 1 | 2 | 3 | 4 | 5 | 6 | 11 | 12 | 13 | 14 | 15 | 16 |
| Hours | | | | | | | | | | | | |
| 1 | 1.87 | 1.87 | 1.75 | 1.82 | 1.70 | 1.68 | 1.72 | 1.73 | 1.83 | 1.78 | 1.88 | 1.90 |
| 12 | 1.91 | 1.91 | 1.80 | 1.87 | 1.77 | 1.76 | 1.72 | 1.68 | 1.83 | 1.67 | 1.87 | 1.86 |
| 24 | 1.91 | 1.90 | 1.79 | 1.87 | 1.74 | 1.74 | 1.70 | 1.61 | 1.83 | 1.65 | 1.86 | 1.86 |
| 36 | 1.89 | 1.89 | 1.77 | 1.84 | 1.69 | 1.70 | 1.58 | 1.58 | 1.79 | 1.60 | 1.84 | 1.85 |
| 48 | 1.82 | 1.81 | 1.69 | 1.78 | 1.57 | 1.62 | 1.48 | 1.51 | 1.75 | 1.53 | 1.78 | 1.79 |
| 60 | 1.90 | 1.90 | 1.77 | 1.86 | 1.71 | 1.70 | 1.62 | 1.65 | 1.82 | 1.59 | 1.86 | 1.86 |
| 72 | 1.84 | 1.84 | 1.61 | 1.77 | 1.51 | 1.53 | 1.43 | 1.46 | 1.75 | 1.46 | 1.80 | 1.82 |
| 84 | 1.82 | 1.81 | 1.59 | 1.74 | 1.51 | 1.50 | 1.42 | 1.48 | 1.72 | 1.45 | 1.77 | 1.78 |
| 96 | 1.77 | 1.76 | 1.53 | 1.69 | 1.42 | 1.45 | 1.35 | 1.31 | 1.62 | 1.36 | 1.71 | 1.73 |
| 108 | 1.73 | 1.73 | 1.51 | 1.64 | 1.43 | 1.45 | 1.42 | 1.39 | 1.57 | 1.46 | 1.66 | 1.69 |
| 114 | 1.65 | 1.64 | 1.39 | 1.52 | 1.27 | 1.25 | 1.20 | 1.19 | 1.44 | 1.26 | 1.55 | 1.58 |
| | Lt. load 54 min/hr. | | ← | | Heavy load 6 min. /hr. | | | | | → | Lt. load 54 min. /hr | |
| | | | ← 50% → | | ← | 100% | | → | ← 50% → | | | |

## 2.6.6. Cell Resistance and Capacitance

A Kelvin ac bridge with a phase-sensitive null indicator was constructed and used to measure the subject characteristics of cells during discharge.[2] A diagram of the circuitry is shown in Figure 8. In order to avoid interruption of continuous cell discharge, the bridge was connected in parallel with the cell circuit. The computation of the resistance of Cell No. B-59 from the bridge measurements is presented as an example.

Heavy load resistor, $R_l = 2.7\Omega$

Standard resistor, $R_s = 1.35\Omega$

Standard capacitor $C_s = 24950$ microfarads, with $0.0695\Omega$ equivalent series resistance as measured by the bridge in calibration procedures.

$R_t = 0.311\Omega$ (total calculated from bridge readings)

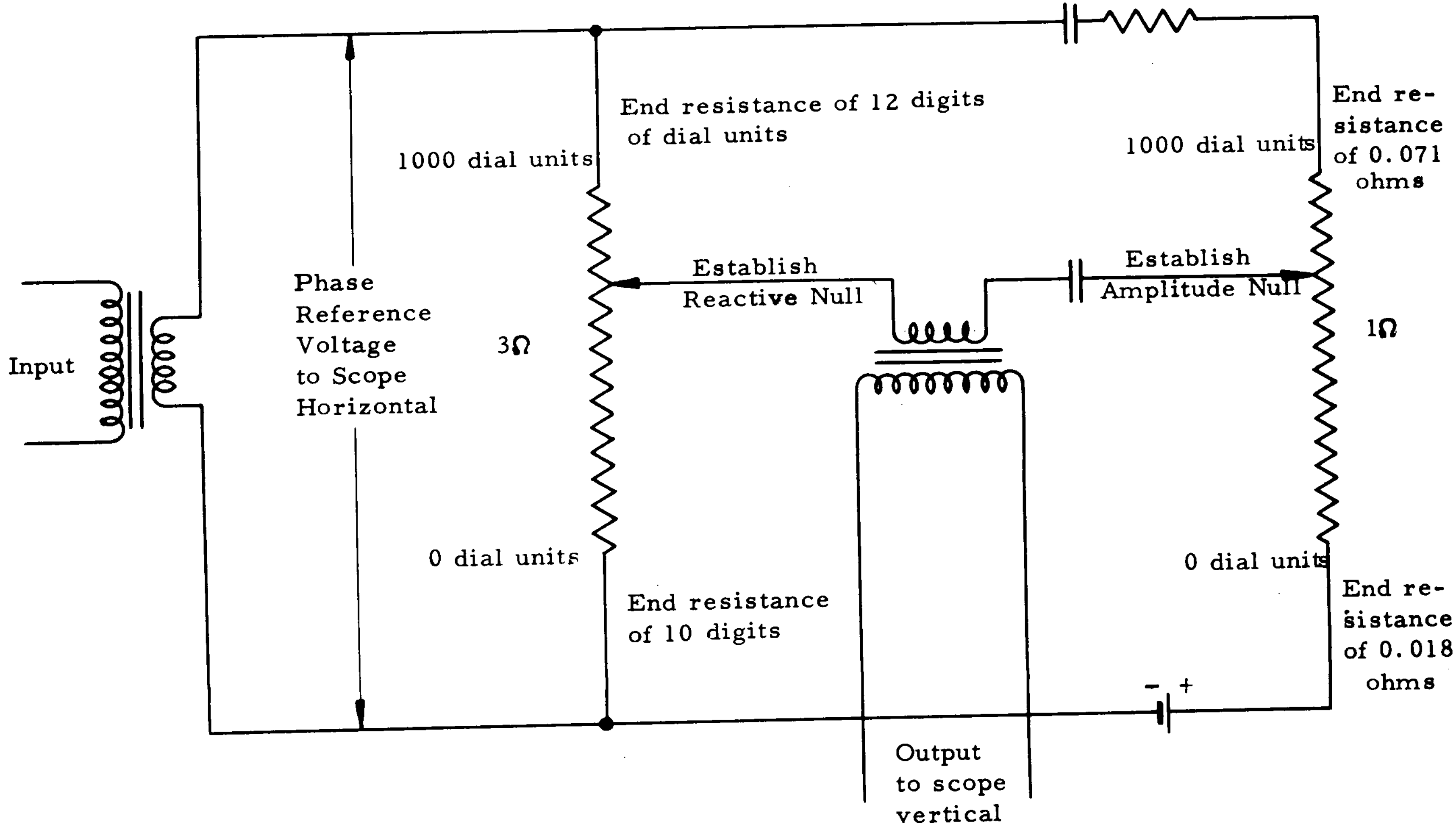
$R_u$ = unknown cell resistance, calculated from the formula for parallel resistances, as follows:

$$1/R_t = 1/R_u + 1/R_l;\ 1/0.311 = 1/R_u + 1/2.7;\ R_u = 0.351\Omega$$

For the purpose of these studies, the difference of $0.04\Omega$ is negligible for comparative purposes. In the case of the $13.5\Omega$ light load resistor, the correction is insignificant.

The resistance and capacitance values under light and heavy loads are plotted against the current and extrapolated to zero current.

[2]"Storage Batteries," Vinal, 4th Edition, Pages 318 - 331, John Wiley & Sons, Inc., New York, 1955.




FORM FM-101

Kelvin- ac Bridge with Phase Sensitive Null Indicator

Figure 8

### 2.6.6.1. Resistance and Capacitance of Prismatic Cell

Cell No. P-134, which had one cathode and two separately loaded anodes, is described in Section 2.6.5. and illustrated in Figure 7. The data in Table XIV seem to indicate that the origin of the capacitance values in the system, Mg/ KSCN:$NH_3$/S, is in the anode.

TABLE XIV

Resistance and Capacitance of Prismatic Cell No. P-134

| | Elapsed Time | Anode A to cathode | | Anode B to cathode | | Anode to anode | |
|---|---|---|---|---|---|---|---|
| | hours | mF | ohms | mF | ohms | mF | ohms |
| Light load | 4 | 16.8 | 0.68 | 17.8 | 0.40 | 9.2 | 0.98 |
| Heavy load | 4 | 13.4 | 0.74 | 15.4 | 0.76 | 7.7 | 1.12 |
| X* | 4 | (a) 17.9 | 0.66 | (a)19.5 | 0.36 | (a)10.4 | 0.92 |
| Light load | 24 | 17.8 | 0.78 | 19.0 | 1.35 | 9.9 | 1.38 |
| Heavy load | 24 | 20.0 | 0.75 | 19.0 | 0.81 | 9.9 | 1.26 |
| X* | 24 | 17.0 | 0.79 | 19.0 | 1.54 | 9.9 | 1.70 |
| Light load | 47 | 13.9 | 0.82 | 13.8 | 1.58 | 7.3 | 1.39 |
| Heavy load | 47 | 13.1 | 0.99 | 13.8 | 0.85 | 6.3 | 1.43 |
| X* | 47 | 14.0 | 0.78 | 13.8 | 1.78 | 7.4 | 1.38 |

*X = values obtained by extrapolation to zero current.

Capacitance in millifarads (mF)

[a] The 60 cycle ac impedance of the cells results largely from the anode to electrolyte capacitance, cell resistance, and cathode capacitance in series. The measured value of cell capacitance appears to be limited by the anode active area since the cathode capacitance is quite high.

Verification:

$$1/C_a + 1/C_c = 1/C$$

Where $C_a$ = Anode A to cathode, capacitance value
$C_c$ = Anode B to cathode, capacitance value
$C$ = Anode A to anode B, capacitance value

$$1/16.5 + 1/19.5 = 1/9.0$$

Therefore, cathode capacitive reactance is negligible, particularly during the first day of discharge.

## 2.6.6.2. Effects of Mercuric Sulfate in Bobbin Cells

The addition of of small amounts of $HgSO_4$ to the cell system of the preceeding paragraph appears to increase the effective anode area substantially, and the capacitance values observed after the required life had been exceeded may indicate cathode polarization. The data are presented in Table XV.

TABLE XV

Resistance and Capacitance of Bobbin Cells Containing $HgSO_4$

| Cell No. | Elapsed Time hours | Cell life to 1.3V | Cell Size | Light load mF | Light load ohms | Heavy load mF | Heavy load ohms | X* mF | X* ohms |
|---|---|---|---|---|---|---|---|---|---|
| B-57 | 16 | 84 | 1/2 | 32 | 0.17 | 28 | 0.18 | 25 | 0.20 |
| | 92 | | | 5 | 1.46 | 7.5 | 1.14 | 12 | 1.64 |
| B-58 | 16 | 106 | 1/2 | 45 | 0.55 | 50 | 0.52 | 55 | 0.50 |
| | 93 | | | 19 | 0.54 | 21 | 0.51 | 23 | 0.55 |
| B-59 | 17 | 111 | full | 41 | 0.38 | 40 | 0.31 | 42 | 0.33 |
| | 40 | | | 82 | 0.23 | 50 | 0.24 | 47 | 0.25 |
| | 64 | | | 39 | 0.33 | 41 | 0.33 | 46 | 0.33 |
| | 138 | | | 28 | 0.85 | 22 | 0.81 | 20 | 0.80 |

*X = values obtained by extrapolation to zero current
Capacitance in millifarads (mF).

Cathode Composition:

| | B-57 % | B-58 % | B-59 % |
|---|---|---|---|
| $HgSO_4$ | ** | 9.5 | 9.5 |
| Sulfur | 50 | 45 | 45.2 |
| Graphite | 40 | 36 | 36.3 |
| Acetylene Black | 10 | 9.5 | 9.0 |

**Electrolyte saturated with $HgSO_4$ (about 0.1%)

## 2.6.6.3 Resistance and Capacitance of Bobbin Cells

A summary of the measurements taken on 15 cells is shown in Table XVI. While the object of this tudy was to build a background of valid resistance readings in the face of series capacitive reactance, it was found that capacitance was more significant than resistance (as long as R was reasonable). Capacitance values decrease markedly near end of cell life. While the cells of Table XVI include many construction and test variations, the general trend of decreasing capacitance with continued discharge is quite evident.

The last column of Table XVI summarizes the resistance data and shows that the internal cell resistances are generally of the order of 10 percent of the value of the heavy load resistor prior to cut-off.

## TABLE XVI

### Resistance and Capacitance of Bobbin Cells

Cells Identified in Table II of Appendix A

| Cell No. B- | Cell life to 1.3V | Temp. °C | Cell Size | Elapsed Time hours | mF* | ohms* |
|---|---|---|---|---|---|---|
| 50 | 61 | -90 | full | 23 | 125 | 0.15 |
| | | | | 46 | 52 | 0.30 |
| 51 | 69 | -90 | full | 23 | 87 | 0.25 |
| | | | | 45 | 57 | 0.35 |
| 52 | 68 | -90 | full | 24 | 25 | 0.27 |
| | | | | 45 | 24 | 0.57 |
| 53 | 59 | -90 | full | 22 | 98 | 0.25 |
| | | | | 45 | 38 | 0.37 |
| 54 | 113 | -90 | 1/2 | 18 | 57 | 0.55 |
| | | | | 41 | 28 | 0.67 |
| | | | | 118 | 47 | 0.63 |
| 55 | 72 | -90 | full | 72 | 45 | 0.62 |
| 56 | 76 | -63 | 1/2 | 69 | 247 | 0.37 |
| | | | | 89 | 168 | 0.45 |
| 57 | 84 | -90 | 1/2 | 16 | 25 | 0.20 |
| | | | | 92 | 12 | 1.64 |
| 58 | 106 | -90 | 1/2 | 16 | 55 | 0.50 |
| | | | | 93 | 23 | 0.55 |
| 59 | 111 | -90 | full | 17 | 42 | 0.33 |
| | | | | 40 | 47 | 0.25 |
| | | | | 64 | 46 | 0.33 |
| | | | | 138 | 20 | 0.80 |
| 60 | 127 | -40 | 1/2 | 12 | 78 | 0.28 |
| | | | | 40 | 43 | 0.25 |
| | | | | 64 | 60 | 0.35 |
| | | | | 138 | 7 | 0.35 |
| 61 | 176 | -63 | 1/2 | 16 | 160 | 0.33 |
| | | | | 186 | 7 | 1.60 |
| 62 | 82 | -90 | 1/2 | 16 | 147 | 0.35 |
| | | | | 40 | 60 | 0.47 |
| | | | | 114 | 5 | 1.83 |
| 63 | 101 | -73 | full | 16 | ≈1F | 0.37 |
| | | | | 89 | 252 | 0.35 |
| | | | | 111 | 125 | 0.47 |
| 64 | 97 | -73 | full | 16 | 475 | 0.26 |
| | | | | 40 | 475 | 0.14 |
| | | | | 112 | 90 | 0.10 |

* Values obtained by extrapolation to zero current.
Capacitance in millifarads (mF): Resistance in ohms.

## 3. BOBBIN CELL DESIGN, CONSTRUCTION AND TESTING

Since cylindrical cells offer many advantages over prismatic cells in simplicity and ease of construction, the development of bobbin cells was started in the second quarter. The knowledge gained in contract NAS 3-6009 and from the prismatic cell studies was used as a basis where applicable. A general description of the method of construction, cross-sectional sketches and drawings may be found in Appendix B.

### 3.1. Preliminary Designs for Task I

Nos. B-1, 2, and 3 were of simple construction with central rod anode and annular ring cathode. Since all three seemed short of life because of insufficient anode area, the rod anodes were replaced by cylindrical coils made of AZ31B Mg Exmet. This modification was beneficial and yielded longer cell life. The improvement was approximately proportional to the increase in apparent anode area in cells B-4 through B-7. This relationship was held for B-7 even though much of the additional area was provided by the use of external anodes in conjunction with the central coil. It is surprising that the proportionality between Nos. B-6 and 7 remained a direct ratio since the change in geometry permitted discharge in two directions from the cathode rather than the single-sided discharge of all of the preceding bobbin cells.

Following these cells, five designs (Nos. B-8 t0 B-12) were constructed and placed on discharge at -90°C. Unfortunately, the refrigerator malfunctioned badly and permitted the temperature to rise as high as -66°C, with an average of about -81°C. Consequently, the test results are of little value, except that they indicate that center bobbins (B-10 and 11) seem to function poorly. Cell No. B-8, which had a center coil of Mg Exmet surrounded by an annular ring cathode and a double Exmet anode on the outside of the cathode, provided the longest life.

Because of the poor temperature regulation, it was necessary to build similar cells, B-13 through 16. The central bobbin cathode with outside anodes (B-14) gave the poorest results; a central star-shaped anode with ten longitudinal fins and the cathode mix between the separator and the case (B-15) provided the longest life, 62 hours to 1.3 volts. In this type of cell, the cathode was in the form of a thin-walled cylinder, and the conductive case served as the collector. Since the B-15 configuration seemed to be the best, it was adopted for all subsequent tests in this phase of the program. Any modifications to this basic design will be explained in the later sections.

## 3.2. Electrolyte Studies at -90°C

During the discharge of the Mg/KSCN/S type cells the $K^+$ ion is converted to an equivalent of $Mg^{++}$ ion. The spent electrolyte [$(\frac{1}{2}Mg(SCN)_2)$] should by theory, be superior to the initial electrolyte since the couple $Mg/Mg^{++}$ is now defined. Spent electrolyte was used alone and in combination with virgin $KSCN/NH_3$ solutions. Some cells were activated with 34% KSCN; others, with 25% KSCN. The composition of the cathode was varied also. The test results are summarized in Table XVII.

TABLE XVII

Electrolyte Studies

| Cell No. B- | S % | C % | Acet. Blk. % | Electrolyte (Wt. % as KSCN) Virgin | Spent | 50% Virgin 50% Spent | Hours to* 1.5V | 1.3V |
|---|---|---|---|---|---|---|---|---|
| 15 | 70 | 30 | 0 | 34 | | | 54 | 62 |
| 17 | 70 | 30 | 0 | | 25 | | 36 | 63 |
| 19 | 50 | 45 | 5 | | 25 | | 80 | 91 |
| 23 | 50 | 45 | 5 | 34 | | | 66 | 73 |
| 24 | 50 | 45 | 5 | | | 25 | 71 | 84 |
| 26** | 50 | 45 | 5 | 34 | | | 56 | 67 |
| 27** | 50 | 45 | 5 | 25 | | | 40 | 47 |
| 30 | 50 | 40 | 10 | 34 | | | 68 | 76 |
| 31 | 50 | 40 | 10 | 25 | | | 43 | 53 |

* Under heavy load.
** Ball-milled.

The change to spent electrolyte in B-17 was not beneficial. In B-19, the following changes were made:

a. Spent electrolyte was used.

b. The proportion of graphite to sulfur was increased.

c. 5% acetylene black was added.

d. The total cathode weight was decreased from 120 to 89 grams.

The combination proved to be good by increasing the cell life to 91 hours to the

1.3 volt cut-off. The fact that B-23 with virgin electrolyte ran only 73 hours indicates that the spent electrolyte was responsible for part of the gain. The voltage under heavy load of B-23 ran from 0.2 to 0.1 volt above that of B-19 during the first 55 hours, after which it decreased rapidly to the 1.3 volt cut-off at 73 hours. The use of half-spent electrolyte in B-24 again demonstrated its contribution by extending the cell life from 73 hours to 84 hours.

The more concentrated electrolyte (34% vs 25%) was shown to be much superior, as may be seen by a comparison of B-26 with 27 and 30 with 31. It seems probable that a cell such as B-19 could be improved through the use of a 34% spent electrolyte.

Attempts were made to synthesize $Mg(SCN)_2$ by the reaction of magnesium with a solution of $NH_4SCN$ in liquid ammonia but there is some doubt about the composition of the reaction products. This electrolyte was used in cells B-20 and 21, and a mixture of 1 part of this to 9 parts of virgin KSCN solution was used in B-29. None of these cells discharged well. Other methods of preparing $Mg(SCN)_2$ are being considered.

## 3.3. Ball-Milling of Cathode Mix

The cathode ingredients were mixed as a slurry in heptane in a ball mill in order to obtain a more intimate mixture and, consequently, improved cell performance. After milling for 24 hours, the slurry was removed from the jar, and the heptane was removed by evaporation. The resultant soft cake was pulverized manually and packed into the cathode space of the cell B-26 in the usual manner.

A comparison of the life of this cell with No. B-23 (Table XVII) shows a reduction from 73 hours to 67 hours under the same discharge conditions. Although nothing was gained by this extra milling procedure over the usual manual method, some advantage might be gained by a study of the effects of other mechanical devices.

## 3.4. Variations in Proportions of Graphite (C), Acetylene Black and Sulfur

In the following table, the effects of changes in cathode composition are shown. All cells were activated with 34 weight percent KSCN in ammonia and were discharged at -90°C.

TABLE XVIII

Cathode Composition Variations

| Cell No. B- | S % | C % | Acet. Blk. % | Cath. Wt. Total gms. | Cathode Density g/in.$^3$ | Hours to* 1.5V | Hours to* 1.3V | F/mol Sulfur |
|---|---|---|---|---|---|---|---|---|
| Half-sized Cells: | | | | | | | | |
| 15 | 70 | 30 | 0 | 120 | 11.8 | 54 | 62 | 0.08 |
| 25 | 50 | 50 | 0 | 89 | 8.7 | 51 | 51 | 0.12** |
| 23 | 50 | 45 | 5 | 89 | 8.7 | 66 | 73 | 0.17 |
| 30 | 50 | 40 | 10 | 96 | 9.4 | 68 | 76 | 0.17 |
| 32 | 50 | 0 | 50 | 70 | 6.9 | 67 | 75 | 0.22 |
| Full-sized Cells: | | | | | | | | |
| 50 | 50 | 40 | 10 | 192 | 9.4 | 56 | 61 | 0.13 |
| 51 | 50 | 40 | 10 | 192 | 9.4 | 62 | 69 | 0.15 |
| 52 | 40 | 50 | 10 | 192 | 9.4 | 61 | 68 | 0.18 |
| 28 | 50 | 30 | 20 | 192 | 7.9 | 53 | 57 | 0.14 |
| 52 | 40 | 40 | 20 | 192 | 7.9 | 59 | 59 | 0.19 |

*Under heavy load.
**Between the 51st and 53rd hours, the discharge curve dropped 0.45 volts under heavy load-reason unknown.

It is apparent that acetylene black improved the efficiency of sulfur utilization and the cell life of the half-sized cells. About the same number of hours were obtained with 5, 10 and 50 percent acetylene black, and all of these cells performed better than the cathodes containing 50 percent acetylene black, yielded the highest efficiency and a 75-hour life to 1.3 volts. However on that cell, the powders were very difficult to mix and pack in the dry state; so they were mixed in heptane, the slurry was poured into the case and then the anode in its separator cup was forced down into position through the slurry. Finally, the cell was dried in a vacuum chamber for two days before activation. The cathode of B-30, with 10 percent acetylene black, seemed to be about the best based on handling qualities of the mix and coulombic output of the cell. The optimum composition and degree of compaction cannot be determined with such a limited number of experiments.

## 3.5. Task I. B., Construction of the Five (5) Ammonia Cells Most Likely to Operate at -90°C for 72 Hours

The specifications for the construction and testing of the subject cells were submitted to and approved by the Project Manager. These are given in Table XIX and Figures 9 and 10.

TABLE XIX

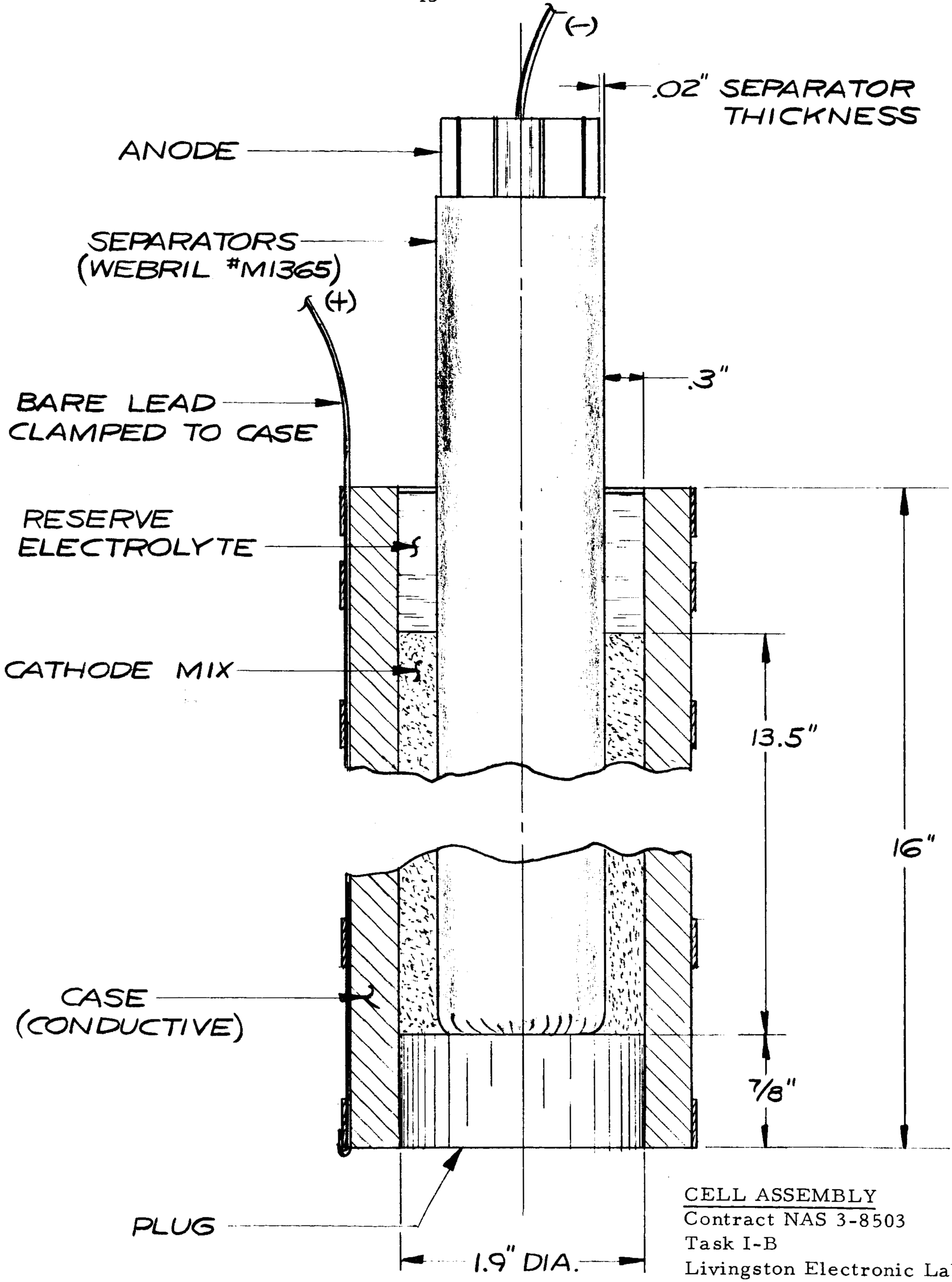
Task I. B., Construction/Load Specifications

| | | |
|---|---|---|
| CATHODE: | Sulfur (grams/%) | 96/50 |
| | Carbon (grams/%) | 77/40 |
| | Acetylene black (grams/%) | 19/10 |
| | Total cathode wt., grams | 192 |
| | Thickness of annular ring (in.) | 0.30 |
| | Length (in.) | 13.5 |
| | Collector | CAB-XL Case |
| ANODE: | AZ31B Mg Sheet | 10 longitudinal fins |
| | Apparent Area ($cm^2$) | 354 |
| ELECTROLYTE (liquid $NH_3$ solvent): | | |
| | KSCN (weight %) | 34 |
| | Volume (cc) | 575 |
| NET CELL VOLUME ($in.^3$) | | 43 |
| LOAD ($\Omega$): | | 2.7 for 6 mins.<br>13.5 for 54 mins. |

The first set of five (5) cells (Nos. B-33 to 37) tested under this requirement provided an average life of 61 hours, with a maximum of 70 hours and a minimum of 53 hours under heavy load to the 1.3 volt cut-off. The cathodes were packed by tamping with a rod, an unsatisfactory method for a full-sized cell. As a result, only 170 grams were used, rather than the 192 grams desired.

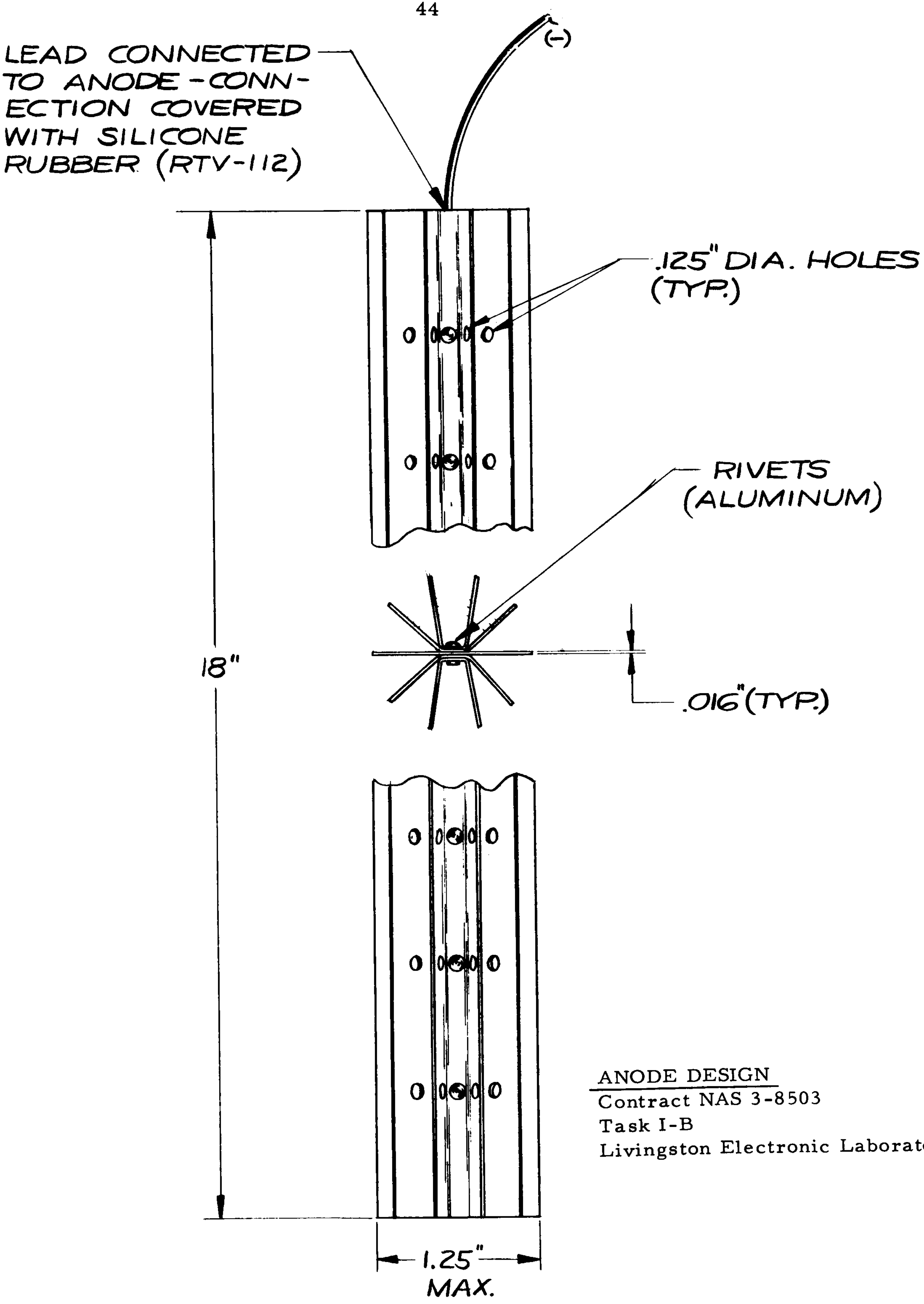
To simplify and improve the packing, an annular sleeve piston was fabricated to press the cathode mix into place. In building B-42, 24 ten gram (240g total) increments of the mixture were added. To each addition, the maximum manual pressure was applied, and it was found that the depth of each increment was very constant at 9/16 inch, for a total of 13.5 inches. A run time of only 61 hours indicated that this cathode was too dense. The large quantity of oxidant yielded only 0.10 faraday per mol.

Therefore, in the second set of five (5) cells (B-43 to 47), 192 grams of the cathode mix were used. Each of ten 19.2 gram portions was added and pressed with the piston to 1/10th of the total depth of 13.5 inches. When discharged, an average life of 64 hours was achieved, with a maximum of 77 hours and a minimum of 58 hours.




CELL ASSEMBLY
Contract NAS 3-8503
Task I-B
Livingston Electronic Lab

Figure 9




ANODE DESIGN
Contract NAS 3-8503
Task I-B
Livingston Electronic Laboratory

Figure 10

### 3.5.1. External Resistance

Resistance measurements indicated the need to employ double lead wires between the cells and the loads and more collector clamps on the cases. These modifications were adopted in subsequent cells as shown in Table II of the Appendix. A comparison of cells B-50 and 51 with B-43 to 47 shows a modest improvement, particularly in the maximum voltage under heavy load. The average increased from 1.72 to 1.79 volts.

## 3.6. Mercuric Sulfate/Sulfur Cells

In an attempt to extend the cell life beyond that achieved in Nos. B-43 to B-47 and to exceed, if possible, the goal of 72 hour operation, experiments were conducted with $HgSO_4$ as an additive to the S/C cathode. A number of such cells were tested in the current configuration which uses an outer annular cathode and a finned anode in the center. The results are given in Table XX along with those of two cells T-60 and T-119 built under Contract NAS 3-6009. The latter cells had center bobbin cathodes surrounded by cylindrical sheet anodes.

TABLE XX

Mercuric Sulfate/Sulfur Cells

| Cell No. | $HgSO_4$ g | S g | Graphite g | Acet. blk. g | Cath. wt. g | Wt. % KSCN | Temp. °C | Hours to* 1.5V | Hours to* 1.3V |
|---|---|---|---|---|---|---|---|---|---|
| B-56 | 53 | 10 | 45 | 5 | 113 | 25 | -63 | 68 | 76[c] |
| T-60 | 106 | 20 | 60 | 0 | 186 | 25 | -63 | 106 | 119 |
| B-55 | 106 | 20 | 90 | 10 | 226 | 34 | -90 | 59 | 72 |
| T-119 | 106 | 20 | 60 | 0 | 186 | 34 | -90 | 21 | 27 |
| B-54 | 10 | 48 | 38 | 10 | 106 | 34 | -90 | 101 | 113[c] |
| B-58 | 10 | 48 | 38 | 10 | 106 | 34 | -90 | 96 | 106[c] |
| B-59 | 20 | 96 | 77 | 19 | 212 | 34 | -90 | 95 | 111 |
| B-57 | a | 48 | 38 | 10 | 96 | 34 | -90 | 64 | 84[c] |
| B-62 | b | 48 | 38.5 | 9.5 | 96 | 34 | -90 | 71 | 82[c] |
| B-61 | 10 | 48 | 38.5 | 9.5 | 106 | 34 | -63 | 158 | 176[c] |
| B-60 | 10 | 48 | 38.5 | 9.5 | 106 | 34 | -40 | 97 | 127[c] |

*Under heavy load.
[a]The electrolyte was saturated with $HgSO_4$ (about 0.1%)
[b]Seven (7) grams of $HgSO_4$ were wrapped and sealed in a cylindrical capsule of Webril separator paper and placed in the anode compartment.
[c]Half-sized cells: the resistive loads were adjusted accordingly.

Cell No. B-56, containing the same ratio of $HgSO_4$ to S as T-60, was tested at -63°C to compare the performance in the two configurations. Additional graphite and acetylene black were added to extend the cathode length and thereby utilize comparable anode areas. B-56 was definitely inferior to T-60 and did not meet the 72 hour requirement to the 1.5 volt cut-off. On the contrary, the use of the current configuration in B-55 at -90°C yielded results that were far superior to those obtained from cell No. T-119.

9.5 percent $HgSO_4$ was added to the S/C cathode of cell No. B-54. The performance of this cell represents an outstanding improvement in life at -90°C; 101 hours to 1.5 volts and 113 hours to 1.3 volts. Excellent replication was achieved with B-58, another half-size cell, and with B-59, a similar full-sized cell. Nos. B-57 and 62 which had $HgSO_4$ in the anode compartment did not run as long as those having it in the cathode, but they were much better than the two preceeding groups of five (B-33 to 37 and 43 to 47) which did not contain any $HgSO_4$.

Nos. B-61 and 60 were discharged at -63°C and at -40°C, respectively, to determine the performance characteristics of the $HgSO_4$/S cathode at higher temperatures. The results were beyond all expectations; 158 hours at -63° and 97 hours at -40° to an end voltage of 1.5. Sulfur/carbon cathodes, without $HgSO_4$, ran at -63° for 53 hours to 1.5 volts (B-38 and 39) and at -40° for 91 hours to the same end voltage (B-40 and 41).

## 3.7. Task II, Design

A self-contained ammonia cell, excluding activator, was designed for the purpose of fabricating a number of such cells for test or delivery to NASA. The advantages and disadvantages of the various features, as depicted in numerous preliminary sketches, were discussed with LEC personnel and the Project Manager. The cell which met with the approval of all concerned is illustrated by drawings B-1227, B-1228, A-1238, and A-1239 and is further defined by the Parts and Materials List; all of which may be found in Appendix B, together with a general description of the method of construction. It was designed to accommodate electrodes of the type used in cell B-59 and to perform in accordance with the contract specifications.

## 3.8. Task III, Test and Redesign

Two mockup cells, B-63 and 64, were constructed, based on the approved design from Task II. Since the assembly procedures were satisfactory, it was decided to evaluate the units by activation and discharge at -73°C. The results were most gratifying: Cell B-63 ran 81 hours to 1.5V, 101 hours at 1.3V; Cell B-64 ran 87 hours to 1.5V, 97 hours to 1.3V. Additional data on these cells may be found in Table II of Appendix A.

## 4. FUTURE WORK

Task III-A will be completed next month by building and testing five cells. The design will be based on the approved design drawings from Task II. In this first set of five cells, the anode must be fabricated from sheet and rod stock. As soon as the extruded anodes become available, the second group of five cells will be constructed and tested to satisfy the requirements of Task III-B. The delivery date of the anodes was estimated by the manufacturer to be October 19, 1966.

In addition, the cathode formulation will be improved if possible by testing a series of cells covering a broad range of $HgSO_4$ content.

In other cells, substitutes for the "star" or finned anode will be tested. One will be a simple 1/2 inch diameter rod; another will be a 1-1/4 inch diameter cylinder with numerous holes for electrolyte passage.

# APPENDIX A

## NOTES TO TABLES

a. Loads shown as A/B represent cyclic loads of A Ω for 6 minutes and B Ω for 54 minutes.

b. Cumulative hours based on heavy load. Hours shown as A/B represent A hours to 1.5 volts and B hours to 1.3 volts.

c. Based on lighter load.

d. Based on heavier load.

e. Based on "apparent" anode area.

f. Mg rod, 1/2" dia., finned and fluted.

g. Mg rod, 1/2" dia., four 1/8" x 1/8" vertical flutes.

## MATERIALS IDENTIFICATION

j. $HgSO_4$. A. R. Grade; Mallinckrodt Chemical Works, St. Louis, Mo.

k. Sulfur. Sublimed, Merck & Co., Inc., Rahway, N. J.

kk. Sulfur. N. F. Sublimed powder, Matheson, Coleman & Bell, Norwood, Ohio

l. Carbon. Air spun graphite, Type 200-44; Jos. Dixon Crucible Co., Jersey City, N. J.

m. Binder. Polystyrene dissolved in toluene; (1.0g/100 ml).

n. KSCN; Reagent; B & A. Code 2144; Allied Chemical Co., New York, N. Y. LEC Lot No. 8.

nn. KSCN; Reagent; B & A. Code 2144; Allied Chemical Co., New York, N. Y. LEC Lot No. 9.

o. KSCN; Reagent; Fisher P-317, Lot No. 743879, Fisher Scientific Co., Pittsburgh, Pa. LEC Lot No. 7.

p. Pure Mg sheet. Dow Chemical Co., Midland, Michigan.

q. AZ31B Mg sheet. Dow Chemical Co., Midland, Michigan.

r. Silver-plated copper Exmet. Exmet Corp., Bridgeport, Conn.

Manufacturer's Designation: 20 Cu 30-2/0

| | |
|---|---|
| Original metal thickness, 20 mils | Strand width, 30 mils |
| Metal symbol, Cu (copper) | Mesh designation, 2/0 |

s. Copper Exmet. Exmet Corporation, Bridgeport, Conn.

Manufacturer's Designation: 20 Cu 30-2/0

| | |
|---|---|
| Original metal thickness, 20 mils | Strand width, 30 mils |
| Metal symbol, Cu (copper) | Mesh designation, 2/0 |

## NOTES TO TABLES

### MATERIALS IDENTIFICATION

t. SM-91 Polypropylene non-woven fabric; .005" thickness per layer. The Kendall Co., Walpole, Mass.

u. M-1365 non-woven acetate & cotton; 0.004"/layer. The Kendall Co., Walpole, Mass.

v. MPR-Microporous rubber; .030"/layer. American Hard Rubber Co., Butler, N.J.

w. Copper Exmet, silver-plated after having been cut to size.

Manufacturer's Designation: 20 Cu 30-2/0

| | |
|---|---|
| Original metal thickness, 20 mils | Strand width, 30 mils |
| Metal symbol, Cu (copper) | Mesh designation, 2/0 |

ww. Copper Exmet, gold-plated after having been cut to size.

Manufacturer's Designation: 20 Cu 30-2/0

| | |
|---|---|
| Original metal thickness, 20 mils | Strand width, 30 mils |
| Metal symbol, Cu (copper) | Mesh designation, 2/0 |

x. Pure Silver Exmet.

Manufacturer's Designation: 5 Ag 8-1/0

| | |
|---|---|
| Original metal thickness, 5 mils | Strand width, 8 mils |
| Metal symbol, Ag (silver) | Mesh designation, 1/0 |

xx. Lead Exmet.

Manufacturer's Designation: 25 Pb 25-1/0

| | |
|---|---|
| Original metal thickness, 25 mils | Strand width, 25 mils |
| Metal symbol, Pb (lead) | Mesh designation, 1/0 |

y. AZ31B Mg Exmet.

Manufacturer's Designation: 16 Mg 30-2/0E

| | |
|---|---|
| Original metal thickness, 16 mils | Strand width, 30 mils |
| Metal symbol, Mg (magnesium) | Mesh designation, 2/0E |

yy. Aluminum collector, 0.020" thick, Lincaine perforations, Item 33, Reynolds Aluminum Company.

z. Porous polyethylene tube, Bel-Art Products, Pequannock, N.J. 100 micron pore size, 1.0" O.D. x 5/8" I.D.

zz. Aluminum Exmet.

Manufacturer's Designation: 20 Al 40-1/0

| | |
|---|---|
| Original metal thickness, 20 mils | Strand width, 40 mils |
| Metal symbol, Al (aluminum) | Mesh designation, 1/0 |

# TABLE I

## ELECTROCHEMICAL CELL TESTS

Discharge Temperature: -90°C
Pasted Plate Configuration
Polyethylene Bag Vehicles
Cathode Collector: Silver-plated Exmet

Cathode Binder[m]: 0.2g Polystyrene in 20 cc Toluene for Std. 36g Cathodes
Electrolyte: 34 Wt.% KSCN[n] in liquid ammonia

| Cell No. P- | 46 | 47 | 51 | 54 |
|---|---|---|---|---|
| Major Variables | Thin Cathodes | | Same as P-52 No MPR | Thick Cathode |
| Hours to End Voltage[b] (1.5/1.3V) | 37/49 | 31/48 | 61/70 | 20/30 |
| Cathode: $HgSO_4$[j] (g) | 5 | 5 | 20 | 100 |
| Cathode: Sulfur[k] (g) | 1 | 1 | 4 | 20 |
| Cathode: Carbon[l] (g) | 3 | 3 | 12 | 60 |
| Cathode: Paper Pulp (g) | --- | --- | --- | 1.8 |
| Separator Thickness (in.), M1365[u] | 0.020 | 0.020 | 0.020 | 0.020 |
| Separator Thickness (in.), MPR[v] | --- | --- | --- | --- |
| Anode Area ($cm^2$) AZ31B Mg | 210[q] | 210[q] | 210[q] | 210[q] |
| Anode Reference AZ31B Mg | --- | --- | --- | --- |
| Cathode Collector Area ($cm^2$) | 210[w] | 210[w] | 210[w] | 210[w] |
| Volume Electrolyte (cc) | 100 | 100 | 100 + 50 | 350 |
| Net Cell Volume ($in.^3$) | 7.5 | 7.5 | 7.5 | 27 |
| Load[a] (ohms) | 48/240 | 48/240 | 13.5/68 | 2.7/13.5 |
| Initial Closed Circuit Voltage[c] | 2.24 | 2.23 | 2.24 | 2.14 |
| Peak Closed Circuit Voltage[c] | 2.24 | 2.23 | 2.25 | 2.21 |
| End Voltage (heavy load) | 1.30 | 1.30 | 1.30 | 1.30 |
| End Voltage (light load) | 1.65 | 1.62 | 1.61 | 2.04 |
| Peak Current Density[d] ($mA/cm^2$) | 0.22 | 0.22 | 0.76 | 3.42 |
| Obs. Coulombs/g Total Oxidants | 304 | 298 | 393 | 165 |
| Observed F/mol Total Oxidants | 0.39 | 0.38 | 0.51 | 0.21 |
| Observed F/mol Sulfur | 0.60 | 0.59 | 0.78 | 0.33 |
| Observed F/mol $HgSO_4$ | 1.13 | 1.10 | 1.45 | 0.61 |
| Watt Hours/$in.^3$ Net Cell | 0.12 | 0.12 | 0.62 | 0.36 |
| Terminal O.C.V. (at hours/V) | 119/0.95 | 119/1.05 | 140/0.95 | 74/2.28 |

Prismatic Configuration

CODE

c) Based on lighter load
d) Based on heavier load
q) Solid sheet

v) Microporous Rubber
w) Ag-plated Copper Exme
x) Pure Silver Exmet
y) Exmet

| 55 | | 56 | 57 | 58 |
|---|---|---|---|---|
| Added extra anodes along two edges | | MPR sealed at edges | 5-electrode research cell. See text. | Wt. ratio S:C = 5.7 |
| Edge Anodes Loaded | Regular Anodes Loaded | | | |
| 0/1 | 10/13 | 34/40 | 25/57 | 53/89 |
| 20 | | 20 | 20 | 0 |
| 4 | | 4 | 4 | 21 |
| 12 | | 12 | 12 | 3.7 |
| --- | | --- | --- | --- |
| 0.020 | | --- | 0.020 | 0.020 |
| --- | | 0.060 | --- | --- |
| 16[q] | 210[q] | 210[q] | 105[q] | 210[q] |
| regular[q] | edge[q] | --- | 1[q], 1[y] | --- |
| 210[w] | 210[w] | 210[w] | 105[w] | 210[w] |
| 100 | | 150 | 250 | 100 |
| 7.5 | | 10 | 17 | 7.5 |
| 13.5/68 | | 13.5/68 | 13.5/68 | 13.5/68 |
| 2.09 | 2.12 | 2.25 | 2.21 | 1.95 |
| 2.09 | 2.24 | 2.27 | 2.24 | 1.98 |
| 1.30 | 1.30 | 1.30 | 1.30 | 1.30 |
| 2.05 | 2.04 | 1.52 | 1.67 | 1.82 |
| 6.32 | 0.75 | 0.78 | 1.46 | 0.62 |
| --- | 72 | 226 | 318 | 526 |
| --- | 0.09 | 0.29 | 0.41 | 0.17 |
| --- | 0.14 | 0.45 | 0.63 | 0.17 |
| --- | 0.27 | 0.83 | 1.18 | --- |
| --- | 0.11 | 0.27 | 0.22 | 0.67 |
| --- | 145/2.15 | 73/0.89 | --- | 140/1.94 |

# TABLE I

## ELECTROCHEMICAL CELL TESTS

Discharge Temperature: -90°C
Pasted Plate Configuration

Polyethylene Bag Vehicles
Cathode Collector: Silver-plated Exmet

Cathode Binder[m]: 0.2g Polystyrene in 20 cc Toluene for Std. 36g Cathodes
Electrolyte: 34 Wt.% KSCN[n] in liquid ammonia

| Cell No. P- | 59 | 60 | 61 | 62 |
|---|---|---|---|---|
| Major Variables | Separation 7 layers | | Thin Cathode | Separation 2 layers |
| Hours to End Voltage[b] (1.5/1.3V) | 24/26 | 55/56 | 73/82 | 40/64 |
| Cathode: $HgSO_4$[j] (g) | 20 | 20 | 5.95 | 0 |
| Cathode: Sulfur[k] (g) | 4 | 4 | 1.19 | 11.0 |
| Cathode: Carbon[l] (g) | 12 | 12 | 3.57 | 11.0 |
| Cathode: Paper Pulp (g) | --- | --- | --- | --- |
| Separator Thickness (in.), M1365[u] | 0.028 | 0.028 | 0.020 | 0.008 |
| Separator Thickness (in.), MPR[v] | --- | --- | 0.030 | --- |
| Anode Area ($cm^2$) AZ31B Mg | 210[q] | 210[q] | 210[q] | 210[q] |
| Anode Reference AZ31B Mg | --- | --- | --- | --- |
| Cathode Collector Area ($cm^2$) | 210[w] | 210[w] | 210[w] | 210[w] |
| Volume Electrolyte (cc) | 100 | 100 | 100 | 100 |
| Net Cell Volume ($in.^3$) | 7.5 | 7.5 | 7.5 | 7.5 |
| Load[a] (ohms) | 13.5/68 | 13.5/68 | 48/240 | 13.5/68 |
| Initial Closed Circuit Voltage[c] | 2.22 | 2.22 | 2.20 | 1.94 |
| Peak Closed Circuit Voltage[c] | 2.24 | 2.24 | 2.20 | 2.00 |
| End Voltage (heavy load) | 1.30 | 1.30 | 1.30 | 1.30 |
| End Voltage (light load) | 2.08 | 2.01 | 1.50 | 1.80 |
| Peak Current Density[d] ($mA/cm^2$) | 0.75 | 0.75 | 0.22 | 0.64 |
| Obs. Coulombs/g Total Oxidants | 145 | 312 | 431 | 726 |
| Observed F/mol Total Oxidants | 0.19 | 0.40 | 0.56 | 0.24 |
| Observed F/mol Sulfur | 0.29 | 0.62 | 0.86 | 0.24 |
| Observed F/mol $HgSO_4$ | 0.54 | 1.15 | 1.59 | --- |
| Watt Hours/$in.^3$ Net Cell | 0.23 | 0.49 | 0.20 | 0.49 |
| Terminal O.C.V. (at hours/V) | 92/2.22 | 92/2.25 | 102/1.30 | 102/1.64 |

Prismatic Configuration

CODE

c) Based on lighter load
d) Based on heavier load
q) Solid sheet

v) Microporous Rubber
w) Ag-plated Copper Exmet
x) Pure Silver Exmet
y) Exmet

| 63 | 65 | 66 | 69 | | 70 |
|---|---|---|---|---|---|
| | Paste on one side of grid | | 3-Electrode Cell | | |
| Ag Exmet Collector (x) | Paste facing anode | Grid facing anode | Sulfur electrode | Carbon[1] electrode | Single anode discharge |
| 54/66 | 42/47 | 67/69 | 81/202 | 25 | 54/85 |
| 20 | 20 | 20 | 0 | 0 | 0 |
| 4 | 4 | 4 | 21 | 0 | 21 |
| 12 | 12 | 12 | 3.7 | 16 | 3.7 |
| --- | --- | --- | --- | --- | --- |
| 0.020 | 0.020 | 0.020 | 0.020 | 0.020 | 0.020 |
| --- | --- | --- | --- | --- | --- |
| 210[q] | 105[y] | 105[y] | 105[q] | 105[q] | 105[q] |
| --- | (q) | (q) | --- | --- | --- |
| 210[x] | 105[w] | 105[w] | 105[w] | 105[w] | 105[w] |
| 150 | 150 | 150 | 150 | 150 | 150 |
| 10 | 10 | 10 | 10 | 10 | 10 |
| 13.5/68 | 13.5/68 | 13.5/68 | 13.5/O. C. | 68 | 13.5/68 |
| 2.21 | 2.22 | 2.22 | 1.61[d] | 1.41 | 1.85 |
| 2.22 | 2.22 | 2.24 | 1.65[d] | 1.41 | 1.91 |
| 1.30 | 1.30 | 1.30 | 1.30 | --- | 1.30 |
| 1.49 | 1.59 | 1.47 | 2.05 O. C. | 0.65 | 1.77 |
| 0.77 | 1.51 | 1.52 | 1.16 | --- | 1.14 |
| 366 | 260 | 385 | 377 | 64 | 490 |
| 0.47 | 0.34 | 0.50 | 0.13 | --- | 0.16 |
| 0.73 | 0.52 | 0.77 | 0.13 | --- | 0.16 |
| 1.35 | 0.96 | 1.42 | --- | --- | --- |
| 0.43 | 0.30 | 0.45 | 0.32 | --- | 0.46 |
| 73/1.73 | 74/1.47 | 74/1.47 | 311/2.03 | 311/1.82 | 237/1.19 |

# TABLE I

## ELECTROCHEMICAL CELL TESTS

Discharge Temperature: -90°C
Pasted Plate Configuration

Polyethylene Bag Vehicles
Cathode Collector: Silver-plated Exmet

Cathode Binder[m]: 0.2g Polystyrene in 20 cc Toluene for Std. 36g Cathodes
Electrolyte: 34 Wt. % KSCN[n] in liquid ammonia

| Cell No. P- | 71 | 72 | 73 | 74 |
|---|---|---|---|---|
| Major Variables | 1/4" Cathode Single Anode Discharge | | 5-electrode research cell. 3 cathodes. | Single Anode Ag Exmet collector (x) |
| Hours to End Voltage[b] (1.5/1.3V) | 11/13 | 17/19 | See text | 4/27 |
| Cathode: $HgSO_4$[j] (g) | 40 | 40 | 0 | 0 |
| Cathode: Sulfur[k] (g) | 8 | 8 | 63 | 21 |
| Cathode: Carbon[l] (g) | 24 | 24 | 11.1 | 3.7 |
| Cathode: Paper Pulp (g) | --- | 0.72 | --- | --- |
| Separator Thickness (in.), M1365[u] | 0.020 | 0.020 | 0.020 | 0.020 |
| Separator Thickness (in.), MPR[v] | --- | --- | --- | --- |
| Anode Area ($cm^2$) AZ31B Mg | 105[q] | 105[q] | 105[q] | 105[q] |
| Anode Reference AZ31B Mg | (q) | (q) | (y) | --- |
| Cathode Collector Area ($cm^2$) | 105[w] | 105[w] | 315[w] | 105[x] |
| Volume Electrolyte (cc) | 150 | 150 | 200 | 130 |
| Net Cell Volume ($in.^3$) | 10 | 10 | 21 | 9 |
| Load[a] (ohms) | 6.75/34 | 6.75/34 | 4.5/22.7 | 13.5/68 |
| Initial Closed Circuit Voltage[c] | 1.97 | 2.13 | 1.78 | 1.68 |
| Peak Closed Circuit Voltage[c] | 2.00 | 2.18 | 1.90 | 1.83 |
| End Voltage (heavy load) | 1.30 | 1.30 | 0.68 | 1.30 |
| End Voltage (light load) | 1.90 | 1.78 | 1.61 | 1.76 |
| Peak Current Density[d] ($mA/cm^2$) | 2.67 | 3.02 | 3.02 | 1.15 |
| Obs. Coulombs/g Total Oxidants | 68 | 104 | --- | 153 |
| Observed F/mol Total Oxidants | 0.09 | 0.14 | --- | 0.05 |
| Observed F/mol Sulfur | 0.13 | 0.21 | --- | 0.05 |
| Observed F/mol $HgSO_4$ | 0.25 | 0.39 | --- | --- |
| Watt Hours/$in.^3$ Net Cell | 0.15 | 0.24 | --- | 0.16 |
| Terminal O.C.V. (at hours/V) | 163/1.89 | 1.63/1.05 | 213/2.01 | 93/2.00 |

Prismatic Configuration

c) Based on lighter load
d) Based on heavier load
q) Solid sheet

CODE

v) Microporous Rubber
w) Ag-plated Copper Exmet
x) Pure Silver Exmet
y) Exmet

| 75 | 76 | 77 | 78 | 79 |
|---|---|---|---|---|
| 2-Anodes Ag Exmet collector (x) | Sulfur: Carbon Weight Ratio: | | | |
| | 2.33 | 2.33 | 1.50 | 1.50 |
| 0/56 | 99/141 | 100/120 | 93/103 | 94/106 |
| 0 | 0 | 0 | 0 | 0 |
| 21 | 17 | 17 | 14 | 14 |
| 3.7 | 7.3 | 7.3 | 9.3 | 9.3 |
| --- | --- | --- | --- | --- |
| 0.020 | 0.020 | 0.020 | 0.020 | 0.020 |
| --- | --- | --- | --- | --- |
| 210[q] | 210[q] | 210[q] | 210[q] | 210[q] |
| --- | --- | --- | --- | --- |
| 210[x] | 210[w] | 210[w] | 210[w] | 210[w] |
| 130 | 125 | 125 | 125 | 125 |
| 9 | 9 | 9 | 9 | 9 |
| 13.5/68 | 13.5/68 | 13.5/68 | 13.5/68 | 13.5/68 |
| 1.63 | 1.97 | 1.97 | 1.98 | 1.97 |
| 1.80 | 1.99 | 1.99 | 2.00 | 2.00 |
| 1.30 | 1.30 | 1.30 | 1.30 | 1.30 |
| 1.77 | 1.52 | 1.73 | 1.68 | 1.67 |
| 0.49 | 0.70 | 0.70 | 0.70 | 0.70 |
| 312 | 1035 | 882 | 918 | 945 |
| 0.10 | 0.34 | 0.29 | 0.30 | 0.31 |
| 0.10 | 0.34 | 0.29 | 0.30 | 0.31 |
| --- | --- | --- | --- | --- |
| 0.31 | 0.90 | 0.77 | 0.65 | 0.67 |
| 93/1.98 | 165/1.54 | 165/1.55 | 165/1.06 | 165/1.10 |

TABLE I

ELECTROCHEMICAL CELL TESTS

Discharge Temperature: -90°C
Pasted Plate Configuration
Cathode Binder[m]: 0.2g polystyrene in 20 cc toluene
M-1365 Separator: 5 layers at 0.004" per layer
Electrolyte: 34 Wt. % KSCN[n] in liquid ammonia

Cathode Collector: Silver-plated Exmet[w]
Polyethylene Bag Vehicles

| Cell No. P- | 80 | 81 | 82 | 83 | 84 |
|---|---|---|---|---|---|
| Major Variables | Research Cell 3 Cath. 4 Anodes See Text. | Acetylene Black 15% Carbon | | Acetylene Black 30% Carbon | |
| Hours to End Voltage[b] (1.5/1.3V) | 36/47 | 85/118 | 82/121 | 80/87 | 83/108 |
| Cathode: Sulfur[k] (g) | 63 | 21 | 21 | 17 | 17 |
| Cathode: Carbon[l] (g) | 11.1 | 3.3 | 2.9 | 6.6 | 5.9 |
| Cathode: Acetylene Black (g) | | 0.4 | 0.8 | 0.7 | 1.4 |
| Cathode: Paper Pulp (g) | | | | | |
| Anode Material: AZ31B Mg Sheet[q] Exmet[y] | 1 [q] 3 [y] | 2 [q] | 2 [q] | 2 [q] | 2 [q] |
| Anode Area ($cm^2$) | 420 | 210 | 210 | 210 | 210 |
| Cathode Collector[w] Area ($cm^2$) | 315 | 210 | 210 | 210 | 210 |
| Volume Electrolyte (cc) | 300 | 125 | 125 | 125 | 125 |
| Net Cell Volume ($in.^3$) | 21 | 9 | 9 | 9 | 9 |
| Load[a] (ohms) | 4.5/22.7 | 13.5/68 | 13.5/68 | 13.5/68 | 13.5/68 |
| Initial Closed Circuit Voltage[c] | 1.93 | 1.99 | 1.94 | 1.98 | 2.04 |
| Peak Closed Circuit Voltage[c] | 1.95 | 2.09 | 2.08 | 2.03 | 2.09 |
| End Voltage (Heavy Load) | 1.30 | 1.30 | 1.30 | 1.30 | 1.30 |
| End Voltage (Light Load) | 1.82 | 1.77 | 1.71 | 1.70 | 1.62 |
| Peak Current Density[d] ($mA/cm^2$) | 0.93 | 0.67 | 0.67 | 0.66 | 0.68 |
| Observed Coulombs/g Sulfur | 276 | 721 | 738 | 643 | 818 |
| Observed F/mol Sulfur | 0.09 | 0.24 | 0.24 | 0.21 | 0.27 |
| Watt Hours/$in.^3$ Net Cell | 0.38 | 0.80 | 0.81 | 0.56 | 0.73 |
| Terminal O.C.V. (at Hours/V) | 167/1.85 | 146/1.82 | 146/1.70 | 146/1.50 | 146/1.55 |
| **Temperature °C Maximum** | -89.1 | -74.5 | -74.5 | -74.5 | -74.5 |
| **Temperature °C Minimum** | -90.2 | -89.8 | -89.8 | -89.8 | -89.8 |
| **Temperature °C (Time Weighted) Ave.** | -89.7 | -87.0 | -87.0 | -85.5 | -88.8 |

Prismatic Configuration

| 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 |
|---|---|---|---|---|---|---|---|
| Paper Pulp | | | | Acetylene Black | | | |
| 30% Carbon | | 15% Carbon | | 15% Carbon | | 30% Carbon | |
| 75/89 | 72/109 | 68/100 | 45/69 | 44/72 | 76/85 | 52/80 | 81/86 |
| 17 | 17 | 21 | 21 | 21 | 21 | 17 | 17 |
| 7.3 | 7.3 | 3.7 | 3.7 | 3.3 | 2.9 | 6.6 | 5.9 |
| | | | | 0.4 | 0.8 | 0.7 | 1.4 |
| 0.25 | 0.75 | 0.25 | 0.75 | | | | |
| 2 q | 2 q | 2 q | 2 q | 2 q | 2 q | 2 q | 2 q |
| 210 | 210 | 210 | 210 | 210 | 210 | 210 | 210 |
| 210 | 210 | 210 | 210 | 210 | 210 | 210 | 210 |
| 100 | 120 | 110 | 130 | 100 | 100 | 100 | 100 |
| 7.5 | 8.5 | 8 | 9 | 7.5 | 7.5 | 7.5 | 7.5 |
| 13.5/68 | 13.5/68 | 13.5/68 | 13.5/68 | 13.5/68 | 13.5/68 | 13.5/68 | 13.5/68 |
| 1.95 | 1.94 | 1.92 | 1.91 | 1.90 | 1.94 | 1.94 | 1.99 |
| 2.01 | 1.99 | 1.97 | 1.95 | 1.96 | 1.96 | 1.98 | 1.99 |
| 1.30 | 1.30 | 1.30 | 1.30 | 1.30 | 1.30 | 1.30 | 1.30 |
| 1.80 | 1.73 | 1.73 | 1.72 | 1.85 | 1.87 | 1.89 | 1.86 |
| 0.63 | 0.64 | 0.62 | 0.60 | 0.60 | 0.62 | 0.62 | 0.65 |
| 657 | 800 | 590 | 405 | 422 | 499 | 584 | 631 |
| 0.22 | 0.27 | 0.20 | 0.13 | 0.14 | 0.17 | 0.19 | 0.21 |
| 0.69 | 0.73 | 0.71 | 0.43 | 0.54 | 0.63 | 0.60 | 0.66 |
| 136/1.80 | 136/1.72 | 136/1.80 | 136/1.69 | 119/2.02 | 119/2.04 | 119/1.98 | 119/1.96 |
| -88.6 | -88.6 | -88.6 | -88.6 | -89.1 | -89.1 | -89.1 | -89.1 |
| -90.9 | -90.9 | -90.9 | -90.0 | -90.8 | -90.8 | -90.8 | -90.8 |
| -89.6 | -89.7 | -89.6 | -89.2 | -90.1 | -90.1 | -90.1 | -90.1 |

## TABLE I

## ELECTROCHEMICAL CELL TESTS- Prismatic Configuration

Discharge Temperature: -90°C
Pasted Plate Configuration
Cathode Binder[m]: 0.2g polystyrene in 20 cc toluene
M-1365 Separator: 5 layers at 0.004" per layer
Electrolyte: 34 Wt. % KSCN[n] in liquid ammonia

Cathode Collector: Silver-plated Exmet[w]
Polyethylene Bag Vehicles

| Cell No. P- | 93 | 94 | 95 | 96 | 97 |
|---|---|---|---|---|---|
| Major Variables | Research Cell<br>3 Cath.<br>6 Anodes<br>See Text. | Single Anode Discharge<br>5-1/4" Holes in Anode | Single Anode Discharge | Replicates of Cells P-76 & 77 | |
| Hours to End Voltage[b] (1.5/1.3V) | 42/58 | 54/58 | 43/55 | 73/105 | 67/80 |
| Cathode: Sulfur[k] (g) | 63 | 17 | 17 | 17 | 17 |
| Cathode: Carbon[l] (g) | 11.1 | 7.3 | 7.3 | 7.3 | 7.3 |
| Cathode: Acetylene Black (g) | | | | | |
| Cathode: Paper Pulp (g) | | | | | |
| Anode Material: AZ31B Mg Sheet[q]<br>Exmet[y] | 1 [q]<br>5 [y] | 1 [q] | 1 [q] | 2 [q] | 2 [q] |
| Anode Area ($cm^2$) | 630 | 105 | 105 | 210 | 210 |
| Cathode Collector[w] Area ($cm^2$) | 315 | 105 | 105 | 210 | 210 |
| Volume Electrolyte (cc) | 300 | 100 | 100 | 100 | 100 |
| Net Cell Volume ($in.^3$) | 21 | 7.5 | 7.5 | 7.5 | 7.5 |
| Load[a] (ohms) | 4.5/22.7 | 13.5/68 | 13.5/68 | 13.5/68 | 13.5/68 |
| Initial Closed Circuit Voltage[c] | 1.93 | 1.99 | 1.96 | 2.03 | 1.97 |
| Peak Closed Circuit Voltage[c] | 1.96 | 2.02 | 2.01 | 2.06 | 2.00 |
| End Voltage (Heavy Load) | 1.30 | 1.30 | 1.30 | 1.30 | 1.30 |
| End Voltage (Light Load) | 1.79 | 1.84 | 1.81 | 1.77 | 1.78 |
| Peak Current Density[d] ($mA/cm^2$) | 0.62 | 1.30 | 1.30 | 0.67 | 0.66 |
| Observed Coulombs/g Sulfur | 340 | 428 | 405 | 785 | 587 |
| Observed F/mol Sulfur | 0.11 | 0.14 | 0.13 | 0.26 | 0.19 |
| Watt Hours/$in.^3$ Net Cell | 0.46 | 0.45 | 0.42 | 0.83 | 0.61 |
| Terminal O. C. V. (at Hours/V) | | 119/1.74 | 119/1.79 | 119/1.86 | 119/1.76 |
| **Temperature °C Maximum** | -87.3 | -79.8 | -79.8 | -79.8 | -79.8 |
| **Temperature °C Minimum** | -88.7 | -88.5 | -88.5 | -88.5 | -88.5 |
| **Temperature °C (Time Weighted) Ave.** | -88.0 | -84.5 | -84.8 | -84.4 | -84.4 |

TABLE I

ELECTROCHEMICAL CELL TESTS-

Cathode Binder[m]: 0.2g polystyrene in 20 cc toluene    Polyethylene Bag Vehicles
M-1365 Separator[u]: 5 layers at 0.004" per layer
Electrolyte: 34 wt. % KSCN[n] in liquid ammonia - 125 cc per cell
Anodes: AZ31B Mg Sheet[q]-2 per cell    Area = 210 $cm^2$
Cathode Collector Area = 210 $cm^2$    Net Cell Volume = 9 $in.^3$    Load[a] (Ω) = 13.5/68
Nine 1/4" holes were drilled in the anodes of all cells, except P-100 and 101.

| Cell No. P- | 99 | 100 | 101 | |
|---|---|---|---|---|
| Major Variables | -63° | -63° | -63° | |
| | | No holes in anodes | | |
| | Silver-plated copper Exmet collectors[w] | | | |
| Hours to End Voltage[b] (1.5/1.3V) | 51/75 | 42/50 | 44/54 | |
| Cathode: Sulfur[k] (g/%) | 21/85 | 17/70 | 17/70 | |
| Cathode: Carbon[l] (g/%) | 3.7/15 | 7.3/30 | 7.3/30 | |
| Initial Closed Circuit Voltage[c] | 2.07 | 2.06 | 2.03 | |
| Peak Closed Circuit Voltage[c] | 2.08 | 2.06 | 2.03 | |
| End Voltage (Heavy Load) | 1.30 | 1.30 | 1.30 | |
| End Voltage (Light Load) | 1.64 | 1.64 | 1.64 | |
| Peak Current Density[d] ($mA/cm^2$) | 0.70 | 0.70 | 0.69 | |
| Observed Coulombs/g Sulfur | 456 | 374 | 401 | |
| Observed F/mol Sulfur | 0.15 | 0.12 | 0.13 | |
| Watt Hours/$in.^3$ Net Cell | 0.50 | 0.33 | 0.35 | |
| Terminal O. C. V. (at Hours/V) | 116/1.54 | 89/1.52 | 89/1.56 | |
| Temperature, °C (Maximum) | -64.0 | -64.0 | -64.0 | |
| Temperature, °C (Minimum) | -66.2 | -65.2 | -65.2 | |
| Temperature, °C (Time weighted Ave.) | -65.1 | -64.6 | -64.6 | |
| Residual Electrolyte Volume, % | 90 | 90 | 50 | |
| Corrosion of Collector | Severe | Severe | Moderate | |
| Elapsed Time, Hours | 119 | 118 | 118 | |

Prismatic Configuration

| 102 | 103 | 104 | 105 | 106 | 107 | 108 | 109 |
|---|---|---|---|---|---|---|---|
| -63° | -63° | -63° | -63° | -63° | -63° | -63° | -40° |
| Silver-plated copper Exmet collectors[w] | | | | Pb Exmet Collector[xx] | | Perforated Al Collectors[yy] | |
| 66/75 | 38/48 | 28/49 | 49/75 | 42/54 | 37/56 | 0/0 | 0/0 |
| 17/70 | 17/70 | 17/70 | 21/85 | 17/70 | 17/70 | 21/85 | 21/85 |
| 7.3/30 | 7.3/30 | 7.3/30 | 3.7/15 | 7.3/30 | 7.3/30 | 3.7/15 | 3.7/15 |
| 2.11 | 2.08 | 2.06 | 2.06 | 1.75 | 1.79 | 1.21 | 1.43 |
| 2.12 | 2.08 | 2.07 | 2.06 | 1.75 | 1.79 | 1.21 | 1.56 |
| 1.30 | 1.30 | 1.30 | 1.30 | 1.30 | 1.30 | 0.81 | 1.07 |
| 1.58 | 1.66 | 1.75 | 1.64 | 1.69 | 1.68 | --- | 1.46 |
| 0.71 | 0.71 | 0.70 | 0.70 | 0.60 | 0.61 | --- | --- |
| 571 | 361 | 367 | 454 | 367 | 386 | --- | --- |
| 0.19 | 0.12 | 0.12 | 0.15 | 0.12 | 0.13 | --- | --- |
| 0.51 | 0.32 | 0.33 | 0.50 | 0.30 | 0.31 | --- | --- |
| 89/1.60 | 116/1.55 | 116/1.58 | 116/1.53 | 91/1.71 | 91/1.77 | 17/2.00 | 66/1.78 |
| -64.0 | -64.0 | -64.0 | -64.0 | -64.0 | -64.0 | -63.0 | --- |
| -65.2 | -65.3 | -65.3 | -66.2 | -65.3 | -65.3 | -65.3 | --- |
| -64.7 | -64.9 | -64.8 | -65.1 | -64.8 | -64.8 | -64.5 | -40 |
| 40 | 40 | 60 | 90 | 75 | 75 | 50 | Wet, only |
| Moderate | Severe | Severe | Severe | Destroyed | Destroyed | None | Nil |
| 118 | 120 | 120 | 119 | 95 | 95 | 48 | 94 |

TABLE I

ELECTROCHEMICAL CELL TESTS-

Cathode Binder[m]: 0.2g polystyrene in 20 cc toluene    Polyethylene Bag Vehicles
M-1365 Separator[u]: 5 layers at 0.004" per layer
Electrolyte: 34 wt. % KSCN[n] in liquid ammonia - 125 cc per cell
Anodes: AZ31B Mg Sheet[q]-2 per cell    Area = 210 $cm^2$
Cathode Collector Area = 210 $cm^2$    Net Cell Volume = 9 $in.^3$    Load[a] (Ω) = 13.5/68
Nine 1/4" holes were drilled in the anodes of all cells, except P-100 and 101.

| Cell No. P- | 110 | 111 |
|---|---|---|
| Major Variables | -63° | -40° |
| | Perforated Aluminum Collectors[yy] | |
| Hours to End Voltage[b] (1.5/1.3V) | 15/44 | 13/37 |
| Cathode: Sulfur[k] (g/%) | 17/70 | 17/70 |
| Cathode: Carbon[l] (g/%) | 7.3/30 | 7.3/30 |
| Initial Closed Circuit Voltage[c] | 1.87 | 2.06 |
| Peak Closed Circuit Voltage[c] | 1.89 | 2.09 |
| End Voltage (Heavy Load) | 1.30 | 1.30 |
| End Voltage (Light Load) | 1.75 | 1.77 |
| Peak Current Density[d] ($mA/cm^2$) | 0.57 | 0.61 |
| Observed Coulombs/g Sulfur | 313 | 280 |
| Observed F/mol Sulfur | 0.10 | 0.09 |
| Watt Hours/$in.^3$ Net Cell | 0.26 | 0.25 |
| Terminal O.C.V. (at Hours/V) | 47/1.96 | 66/1.83 |
| Temperature, °C (Maximum) | -63.0 | --- |
| Temperature, °C (Minimum) | -65.3 | --- |
| Temperature, °C (Time weighted Ave.) | -64.5 | -40 |
| Residual Electrolyte Volume, % | 60 | Wet, only |
| Corrosion of Collector | None | Nil |
| Elapsed Time, Hours | 48 | 94 |

Continued

Prismatic Configuration

| | | | | | |
|---|---|---|---|---|---|
| 112 | 113 | 114 | 115 | 116 | 117 |
| -63° | -63° | -40° | -40° | -40° | -40° |
| Gold-plated Copper Exmet Collectors[ww] | | | | Ag-plated Cu Collectors[w] | |
| 64/75 | 65/73 | 38/52 | 34/39 | 8/11 | 30/35 |
| 17/70 | 17/70 | 17/70 | 17/70 | 17/70 | 17/70 |
| 7.3/30 | 7.3/30 | 7.3/30 | 7.3/30 | 7.3/30 | 7.3/30 |
| 2.06 | 2.05 | 2.15 | 2.14 | 2.05 | 2.10 |
| 2.07 | 2.07 | 2.15 | 2.14 | 2.05 | 2.11 |
| 1.30 | 1.30 | 1.30 | 1.30 | 1.30 | 1.30 |
| 1.55 | 1.83 | 1.82 | 1.72 | 1.46 | 1.57 |
| 0.67 | 0.67 | 0.73 | 0.72 | 0.69 | 0.72 |
| 567 | 552 | 400 | 2.98 | 82 | 274 |
| 0.19 | 0.18 | 0.13 | 0.10 | 0.03 | 0.09 |
| 0.51 | 0.49 | 0.36 | 0.27 | 0.07 | 0.25 |
| 87/1.86 | 87/1.94 | 66/2.05 | 66/2.00 | 66/1.57 | 66/1.60 |
| -64.5 | -64.5 | --- | --- | --- | --- |
| -65.7 | -65.7 | --- | --- | --- | --- |
| -64.8 | -64.8 | -40 | -40 | -40 | -40 |
| 80 | 75 | 20 | 20 | 80 | 80 |
| Nil | Nil | Nil | Mild | Severe | Severe |
| 114 | 114 | 95 | 95 | 96 | 96 |

TABLE I

ELECTROCHEMICAL CELL TESTS-

Polyethylene Bag Vehicles
Anode Area (2 sides): 210 $cm^2$ Thickness: 0.016" AZ31B Mg Sheet[q]
Cathode Collector Area (2 sides): 210 $cm^2$
Cathode Binder[m]: 0.2g polystyrene in 20 cc toluene
M-1365 Separator[u]: 5 layers at 0.004" per layer Load[a] ($\Omega$) = 13.5/68

| Cell No. P- | | 118 | 119 | 120 | 121 |
|---|---|---|---|---|---|
| Nominal Discharge Temp. (°C) | | -63 | -63 | -40 | -40 |
| Major Variables | | Temperature Cathode Compos. | | Temperature Cathode Compos. | |
| Hours to End Voltage[b] (1.5/1.3V) | | 32/38 | 35/39 | 35/51 | 29/38 |
| Cathode: | $HgSO_4$[j] (g/%) | 20/55.6 | 20/55.6 | 20/55.6 | 20/55.6 |
| | Sulfur[k] (g/%) | 4/11.1 | 4/11.1 | 4/11.1 | 4/11.1 |
| | Carbon[l] (g/%) | 12/33.3 | 12/33.3 | 12/33.3 | 12/33.3 |
| | Collector | w | w | w | w |
| Electrolyte: | KSCN[nn] (% as KSCN) | 34 | 34 | 34 | 34 |
| | $Mg(SCN)_2$ (% as KSCN) | | | | |
| | "Spent" (% as KSCN) | | | | |
| | Volume (cc) | 125 | 125 | 125 | 125 |
| Net Cell Volume ($in.^3$) | | 9 | 9 | 9 | 9 |
| Initial Closed Circuit Voltage[c] | | 2.13 | 2.24 | 2.27 | 2.25 |
| Peak Closed Circuit Voltage[c] | | 2.13 | 2.24 | 2.32 | 2.31 |
| End Voltage (Heavy Load) | | 1.30 | 1.30 | 1.30 | 1.30 |
| End Voltage (Light Load) | | 1.52 | 1.40 | 1.47 | 1.39 |
| Peak Current Density[d] ($mA/cm^2$) | | 0.73 | 0.77 | 0.80 | 0.80 |
| Observed Coulombs/g Total Oxidants | | 206 | 218 | 291 | 217 |
| Observed F/mol Total Oxidants | | 0.27 | 0.28 | 0.38 | 0.28 |
| Observed F/mol Sulfur | | 0.41 | 0.43 | 0.58 | 0.43 |
| Observed F/mol $HgSO_4$ | | 0.76 | 0.80 | 1.08 | 0.80 |
| Watt Hours/$in.^3$ Net Cell | | 0.26 | 0.29 | 0.39 | 0.29 |
| Terminal O.C.V. (at Hrs./V) | | 67/1.07 | 67/0.75 | 67/1.41 | 67/1.03 |

Prismatic Configuration

| | | | | | |
|---|---|---|---|---|---|
| 125 | 126 | 127 | 128 | 129 | 130 |
| -63 | -90 | -90 | -90 | -90 | -63 |
| Note [1] | Virgin Electrolyte Cathode Compos. | | "Spent" Electrolyte Cathode Compos. | | Temperature Conc. of Electrolyte |
| 41/43 | 0/95 | 17/89 | 25/110 | 90/113 | 25/30 |
| 20/55.6 | 0 | 0 | 0 | 0 | 20/55.6 |
| 4/11.1 | 21/85 | 21/85 | 17/70 | 17/70 | 4/11.1 |
| 12/33.3 | 3.7/15 | 3.7/15 | 7.3/30 | 7.3/30 | 12/33.3 |
| zz | w | w | w | w | w |
| 25 | 25 | 25 | | | 25 |
| | | | 25 | 25 | |
| 125 | 200 | 200 | 200 | 200 | 125 |
| 9 | 13 | 13 | 13 | 13 | 9 |
| 2.23 | 1.78 | 1.81 | 1.83 | 1.76 | 1.98 |
| 2.24 | 1.84 | 1.86 | 1.89 | 1.86 | 1.98 |
| 1.30 | 1.30 | 1.30 | 1.30 | 1.30 | 1.30 |
| 1.54 | 1.74 | 1.76 | 1.71 | 1.71 | 1.50 |
| 0.77 | 0.53 | 0.57 | 0.55 | 0.54 | 0.67 |
| 240 | 538 | 506 | 782 | 794 | 155 |
| 0.31 | 0.18 | 0.17 | 0.26 | 0.26 | 0.20 |
| 0.48 | 0.18 | 0.17 | 0.26 | 0.26 | 0.31 |
| 0.89 | --- | --- | --- | --- | 0.57 |
| 0.32 | 0.38 | 0.36 | 0.45 | 0.46 | 0.19 |
| 65/0.85 | 137/1.82 | 137/1.78 | 210/1.35 | 210/1.34 | 65/1.08 |

[1] Electrolyte Concentration, Aluminum Exmet Collector.

TABLE I (Continued)

ELECTROCHEMICAL CELL TESTS - Prismatic Configuration

Polyethylene Bag Vehicles
Anode Area (2 sides): 210 $cm^2$ Thickness: 0.016" AZ31B Mg Sheet[q]
Cathode Collector Area (2 sides): 210 $cm^2$
Cathode Binder[m]: 0.2g polystyrene in 20 cc toluene
M-1365 Separator[u]: 5 layers at 0.004" per layer Load[a] (Ω) = 13.5/68

| Cell No. P- | 131 | 132 | 133 | 134 | |
|---|---|---|---|---|---|
| Nominal Discharge Temp. °C | -63 | -63 | -90 | -90 | |
| Major Variables | Electrolyte Conc. Al Exmet collector. | | $Mg(SCN)_2$ Electrolyte – S treatment. | Each anode loaded separately with 1/2 usual load. | |
| | | | | Anode A | Anode B |
| Hours to End Voltage[b] (1.5/1.3V) | 45/82 | 57/83 | 0/12 | 69/110 | 71/113 |
| Cathode: $HgSO_4$[j] (g/%) | 0 | 0 | 0 | 0 | |
| Sulfur[k] (g/%) | 17/70 | 17/70 | 17/70 | 17/70 | |
| Carbon[l] (g/%) | 7.3/30 | 7.3/30 | 7.3/30 | 7.3/30 | |
| Collector | zz | zz | w | w | |
| Electrolyte: KSCN[nn] (% as KSCN) | 25 | 25 | --- | 34 | |
| $Mg(SCN)_2$ (% as KSCN) | --- | --- | 34 | --- | |
| "Spent" (% as KSCN) | --- | --- | --- | --- | |
| Volume (cc) | 125 | 125 | 125 | 125 | |
| Net Cell Volume (in.$^3$) | 9 | 9 | 9 | 9 | |
| Initial Closed Circuit Voltage[c] | 2.05 | 2.05 | 1.64 | 1.87 | 1.82 |
| Peak Closed Circuit Voltage[c] | 2.05 | 2.05 | 1.71 | 1.91 | 1.88 |
| End Voltage (heavy load) | 1.30 | 1.30 | 1.30 | 1.30 | 1.30 |
| End Voltage (light load) | 1.75 | 1.79 | 1.65 | 1.69 | 1.53 |
| Peak Current Density[d] (mA/$cm^2$) | 0.64 | 0.65 | 0.48 | 0.62 | 0.63 |
| Observed Coulombs/g Total Oxidants | 612 | 620 | 80 | 392 | 399 |
| Observed F/mol Total Oxidants | 0.20 | 0.20 | 0.03 | 0.13 | 0.13 |
| Observed F/mol Sulfur | 0.20 | 0.20 | 0.03 | 0.13 | 0.13 |
| Observed F/mol $HgSO_4$ | --- | --- | --- | --- | --- |
| Watt Hours/in.$^3$ Net Cell | 0.54 | 0.55 | 0.06 | 0.33 | 0.33 |
| Terminal OCV (at hrs./V) | 162/1.70 | 162/1.73 | 257/0.62 | --- | --- |

TABLE II

ELECTROCHEMICAL CELL TESTS-

y) AZ31B Mg Exmet
u) M-1365 Separator - 5 layers at 0.004" per layer = 0.020" thick
Electrolyte: 34 Wt. %KSCN[n] in liquid ammonia

| Cell No. B- | 1 | 2 | 3 |
|---|---|---|---|
| Major Variables | Inverse Bobbins | | |
| | Porous polyethylene Separators[z] | | M-1365[u] Separation |
| | Central rod anodes | | |
| Hours to End Voltage[b] (1.5/1.3V) | 2/4 | 0/0 | 0/0 |
| Cathode: $HgSO_4$[j] (grams/%) | 100/55.6 | 0 | 0 |
| Cathode: Sulfur[k] (grams/%) | 20/11.1 | 102/85 | 42.5/70 |
| Cathode: Carbon[l] (grams/%) | 60/33.3 | 18/15 | 18.2/30 |
| Cathode: Acetylene Black | --- | --- | --- |
| Cathode Thickness (in.) | 0.45 | 0.45 | 0.35 |
| Cathode Length (in.) | 5.5 | 4.5 | 5.0 |
| Cathode Collector, Ag Wire (W) or Case (C) | 2W | 2W | 1W, 1C |
| Anode, Central (Cylindrical) | Mg rod[f] | Mg rod[f] | Mg rod[g] |
| Apparent Area ($cm^2$) | 56 | 46 | 51 |
| Anode, Outer (Cylindrical) | --- | --- | --- |
| Apparent Area ($cm^2$) | --- | --- | --- |
| Net Cell Volume ($in.^3$) | 16 | 16 | 12 |
| Load[a] (ohms) | 2.7/13.5 | 2.7/13.5 | 5.4/27 |
| Initial Closed Circuit Voltage[c] | 2.10 | 0.70 | 1.52 |
| Peak Closed Circuit Voltage[c] | 2.11 | 0.73 | 1.52 |
| End Voltage (Heavy Load) | 1.30 | --- | --- |
| End Voltage (Light Load) | 2.08 | --- | --- |
| Peak Anode Current Density ($mA/cm^2$)[d, e] | 10.8 | Nil | 2.3 |
| Obs. Coulombs/g Total Oxidants | Nil | --- | Nil |
| Observed F/mol Total Oxidants | Nil | --- | --- |
| Observed F/mol Sulfur | --- | --- | --- |
| Observed F/mol $HgSO_4$ | --- | --- | --- |
| Watt Hours/$in.^3$ Net Cell | --- | --- | --- |
| Terminal OCV (at Hours/V) | 116/2.30 | 116/2.10 | 78/2.18 |
| Temperature (°C) Maximum | -89.0 | -89.0 | --- |
| Temperature (°C) Minimum | -90.9 | -90.9 | --- |
| Temperature (Time Weighted) Average | -90.0 | -90.0 | -89.8 |

Bobbin Configurations - Nominal Minus 90°C

| | | | |
|---|---|---|---|
| 4 | 5 | 6 | 7 |
| Inverse Bobbins | | | Holes in Anodes |
| M-1365 Separation [u] | | | |
| Coiled Central Exmet Anodes | | | |
| Acetylene Black | MPR[v] spacer in anode coil | Larger Diam. anode | Added outer anodes |
| 22/28 | 20/31 | 32/35 | 50/70 |
| 0 | 0 | 0 | 0 |
| 42.5/70 | 85.0/70 | 70.8/70 | 47.6/70 |
| 12.1/20 | 36.4/30 | 30.3/30 | 20.4/30 |
| 6.1/10 | --- | --- | --- |
| 0.32 | 0.37 | 0.27 | 0.24 |
| 6.0 | 5.0 | 5.0 | 5.3 |
| 1C | 1C | 1C | 4W |
| Coil [y] | Coil [y] | Coil [y] | Coil [y] |
| 99 | 114 | 133 | 108 |
| --- | --- | --- | 3 sheets [y] |
| --- | --- | --- | 167 |
| 17 | 25 | 25 | 27 |
| 5.4/27 | 5.4/27 | 5.4/27 | 5.4/27 |
| 2.03 | 1.99 | 2.03 | 2.02 |
| 2.03 | 1.99 | 2.05 | 2.02 |
| 1.30 | 1.30 | 1.30 | 1.30 |
| 1.85 | 1.87 | 1.87 | 1.80 |
| 3.25 | 2.65 | 2.50 | 1.21 |
| 208 | 114 | 157 | 461 |
| 0.07 | 0.04 | 0.05 | 0.15 |
| 0.07 | 0.04 | 0.05 | 0.15 |
| --- | --- | --- | --- |
| 0.24 | 0.18 | 0.21 | 0.38 |
| 145/2.10 | --- | 150/2.06 | 70/2.09 |
| -89.2 | -87.8 | -87.8 | -79.5 |
| -90.7 | -88.6 | -89.0 | -86.3 |
| -89.7 | -88.5 | -88.2 | -84.1 |

# TABLE II

## ELECTROCHEMICAL CELL TESTS

Bobbin Configurations - Nominal -90°C

q) AZ31B Mg Sheet. u) M-1365 Separator, 5 layers at 0.004" per layer = 0.020" thick.
y) AZ31B Mg Exmet. Electrolyte: 34 Wt. % KSCN[n] in liquid ammonia

| Cell No. B- | 8[1] | 9[1] |
|---|---|---|
| Major Variables | Annular Ring Cathodes | |
| | Exmet Anodes | Sheet Anodes |
| Hours to End Voltage[b] (1.5/1.3V) | 18/42 | 10/21 |
| Cathode: Sulfur[k] (grams/%) | 47.6/70 | 47.6/70 |
| Carbon[l] (grams/%) | 20.4/30 | 20.4/30 |
| Cathode Thickness (in.) | 0.24 | 0.25 |
| Cathode Length (in.) | 7 | 5.5 |
| Cathode Collector: Ag Wire (W) or Case (C) | 4W | 4W |
| Anode: Central (Cylindrical) | Coil[y] | Coil[q] |
| Apparent Area ($cm^2$) | 144 | 120 |
| Anode: Outer (Cylindrical) | 2 sheets[y] | 2 sheets[q] |
| Apparent Area ($cm^2$) | 226 | 188 |
| Net Cell Volume ($in.^3$) | 27 | 23 |
| Load[a] ($\Omega$) | 5.4/27 | 5.4/27 |
| Initial Closed Circuit Voltage[c] | 1.76 | 1.75 |
| Peak Closed Circuit Voltage[c] | 1.82 | 1.84 |
| End Voltage (heavy load) | 1.30 | 1.30 |
| End Voltage (light load) | 1.67 | 1.70 |
| Peak Anode Current Density ($mA/cm^2$)[d, e] | 0.77 | 0.92 |
| Observed Coulombs/g Sulfur | 260 | 130 |
| Observed F/mol Sulfur | 0.09 | 0.04 |
| Watt Hours/$in.^3$ Net Cell | 0.20 | 0.12 |
| Terminal OCV (at hours/V) | 65/2.02 | 65/2.02 |
| Temperature (°C) Maximum | -66.0 | -66.0 |
| Temperature (°C) Minimum | -90.0 | -90.0 |
| Temperature (Time Weighted) Average | -81.5 | -81.0 |

[1] Design similar to B-7, except both central and outside anode layers were separated
[2] Two (2) outer anodes separated by MPR[v] strips. 1/4" holes in anodes.
[3] Ln. = Longitudinal

| 10[2] | 11[2] | 12 |
|---|---|---|
| Central Bobbin Cathodes | | Central Anode 6 Ln.[3] Fins |
| Exmet Anodes | Sheet Anodes | Annular Ring Cathode |
| 1/18 | 0/0 | 19/26 |
| 84/70 | 84/70 | 84/70 |
| 36/30 | 36/30 | 36/30 |
| 1.16 | 1.16 | 0.37 |
| 7.3 | 7.5 | 5.5 |
| 2W | 2W | 1C |
| --- | --- | Fins[q] |
| --- | --- | 186 |
| 2 sheets[y] | 2 sheets[q] | --- |
| 175 | 181 | --- |
| 27 | 27 | 23 |
| 2.7/13.5 | 2.7/13.5 | 5.4/27 |
| 1.64 | 1.69 | 1.73 |
| 1.68 | 1.70 | 1.90 |
| 1.30 | 1.29 | 1.30 |
| 1.64 | 1.65 | 1.70 |
| 2.79 | 2.66 | 1.59 |
| 121 | --- | 94 |
| 0.04 | --- | 0.03 |
| 0.16 | --- | 0.15 |
| 65/2.00 | 65/2.03 | 65/2.00 |
| -66.0 | --- | -66.0 |
| -90.0 | --- | -90.0 |
| -81.0 | -90.0 | -81.8 |

by MPR[v] strips. 1/4" holes in anodes.

TABLE II

ELECTROCHEMICAL CELL TESTS-

Nominal Discharge Temperature: -90°C (Except B-22)
AZ31B Mg Sheet[q] AZ31B Mg Exmet[y]
M-1365 Separator[u]: 5 layers at 0.004" per layer

| Cell No. B- | 13 | 14 |
|---|---|---|
| Major Variables | Central & outside anodes. Annular ring cathode. | 2 outside anodes central bob[illegible] cathode. |
| Hours to End Voltage[b] (1.5/1.3V) | 23/56 | 0/22 |
| Cathode: $HgSO_4$[j] (grams/%) | 0 | 0 |
| Sulfur[k] (grams/%) | 63/70 | 98/70 |
| Carbon[l] (grams/%) | 27/30 | 42/30 |
| Acetylene Black (grams/%) | 0 | 0 |
| Thickness (in.) | 0.24 | 1.16 |
| Length (in.) | 6.75 | 10 |
| Collector: Ag Wire (W) or Case (C) | 4W | 2W |
| Anode: Central (Cylindrical) | Coil[y] | --- |
| Apparent Area ($cm^2$) | 139 | --- |
| Outer (Cylindrical) | 2 sheets[y] | 2 sheets[y] |
| Apparent Area ($cm^2$) | 218 | 242 |
| Electrolyte: KSCN[nn] (Wt. % as KSCN) | 34 | 34 |
| $Mg(SCN)_2$ (Wt. % as KSCN) | --- | --- |
| "Spent" (Wt. % as KSCN) | --- | --- |
| Volume (cc) | 400 | 500 |
| Net Cell Volume ($in.^3$) | 27 | 35 |
| Load[a] ($\Omega$) | 5.4/27 | 2.7/13.5 |
| Initial Closed Circuit Voltage[c] | 1.84 | 1.77 |
| Peak Closed Circuit Voltage[c] | 1.84 | 1.80 |
| End Voltage (Heavy Load) | 1.30 | 1.30 |
| End Voltage (Light Load) | 1.78 | 1.71 |
| Peak Current Density ($mA/cm^2$)[d, e] | 0.79 | 2.14 |
| Observed Coulombs/g Sulfur | 264 | 132 |
| Observed F/mol Sulfur | 0.09 | 0.04 |
| Watt Hours/$in.^3$ Net Cell | 0.27 | 0.15 |
| Terminal O. C. V. (at Hours/V) | 67/2.08 | 45/1.96 |

Bobbin Configurations

| 15 | 16 | 17 | 19 | 20 | 21 |
|---|---|---|---|---|---|
| Central anode. 10 Longitudinal fins. | Central Exmet coil + 3 outer anodes. | "Spent" Electrolyte | "Spent" Electrolyte Acet. Black | Mg(SCN)$_2$ Electrolyte S:C | HgSO$_4$:C |
| 54/62 | 25/42 | 36/63 | 80/91 | 2/6 | 1/3 |
| 0 | 0 | 0 | 0 | 0 | 110/55.6 |
| 84/70 | 61.6/70 | 84/70 | 44.4/50 | 44.4/50 | 22/11.1 |
| 36/30 | 26.4/30 | 36/30 | 40.0/45 | 40.0/45 | 66/33.3 |
| 0 | 0 | 0 | 4.4/5 | 4.4/5 | 0 |
| 0.30 | 0.25 | 0.30 | 0.30 | 0.30 | 0.30 |
| 6.75 | 5.25 | 6.75 | 6.75 | 6.75 | 6.50 |
| 1C | 4W | 1C | 1C | 1C | 1C |
| 10 Fins[q] | Coil[y] | 10 Fins[q] | 10 Fins[q] | 10 Fins[q] | 10 Fins[q] |
| 171 | 108 | 171 | 171 | 171 | 165 |
| --- | 3 sheets[y] | --- | --- | --- | --- |
| --- | 167 | --- | --- | --- | --- |
| 34 | 34 | --- | --- | --- | --- |
| --- | --- | --- | --- | 24.5 | 24.5 |
| --- | --- | 25 | 25 | --- | --- |
| 400 | 350 | 400 | 350 | 400 | 300 |
| 31 | 27 | 31 | 28 | 31 | 25 |
| 5.4/27 | 5.4/27 | 5.4/27 | 5.4/27 | 5.4/27 | 5.4/27 |
| 1.93 | 1.91 | 1.91 | 1.92 | 1.94 | 2.01 |
| 1.94 | 1.91 | 1.91 | 1.92 | 1.94 | 2.01 |
| 1.30 | 1.30 | 1.30 | 1.30 | 1.30 | 1.30 |
| 1.82 | 1.84 | 1.83 | 1.79 | 1.76 | 1.95 |
| 1.78 | 1.06 | 1.79 | 1.83 | 1.74 | 1.81 |
| 226 | 209 | 228 | 624 | 41 | --- |
| 0.08 | 0.07 | 0.08 | 0.21 | 0.01 | --- |
| 0.28 | 0.21 | 0.28 | 0.44 | 0.03 | --- |
| 67/2.13 | 47/2.13 | 89/2.08 | 93/2.06 | 18/2.08 | 17/2.12 |

TABLE II

ELECTROCHEMICAL CELL TESTS-

Nominal Discharge Temperature: -90°C (Except B-22)
AZ31B Mg Sheet[q] AZ31B Mg Exmet[y]
M-1365 Separator[u]: 5 layers at 0.004" per layer

| Cell No. B- | 22 | |
|---|---|---|
| Major Variables | 1/2 Virgin + 1/2 "Spent electrolyte<br>-40°C (+) | -63°C<br>Cumulative Hours |
| Hours to End Voltage[b] (1.5/1.3V) | 26/30 | 59/72 |
| Cathode: $HgSO_4$[j] (grams/%) | 0 | |
| Sulfur[k] (grams/%) | 44.4/50 | |
| Carbon[l] (grams/%) | 40.0/45 | |
| Acetylene Black (grams/%) | 4.4/5 | |
| Thickness (in.) | 0.30 | |
| Length (in.) | 6.25 | |
| Collector: Ag Wire (W) or Case (C) | 1C | |
| Anode: Central (Cylindrical) | 10 Fins[q] | |
| Apparent Area ($cm^2$) | 158 | |
| Outer (Cylindrical) | --- | |
| Apparent Area ($cm^2$) | --- | |
| Electrolyte: KSCN[nn] (Wt. % as KSCN) | 25 | |
| $Mg(SCN)_2$ (Wt. % as KSCN) | --- | |
| "Spent" (Wt. % as KSCN) | 25 | |
| Volume (cc) | 450 | |
| Net Cell Volume ($in.^3$) | 33 | |
| Load[a] (Ω) | 5.4/27 | |
| Initial Closed Circuit Voltage[c] | 2.15 | 2.02 |
| Peak Closed Circuit Voltage[c] | 2.16 | 2.02 |
| End Voltage (Heavy Load) | 1.30 | 1.30 |
| End Voltage (Light Load) | 1.84 | 1.89 |
| Peak Current Density ($mA/cm^2$)[d, e] | 2.37 | 1.93 |
| Observed Coulombs/g Sulfur | 221 | 297 |
| Observed F/mol Sulfur | 0.07 | 0.10 |
| Watt Hours/$in.^3$ Net Cell | 0.14 | 0.18 |
| Terminal O.C.V. (at Hours/V) | 155/2.13 | |

Bobbin Configuration

| 23 | 24 | 25 | 26 | 27 |
|---|---|---|---|---|
| Electrolyte conc. & kind Acet. Black | 1/2 Virgin + 1/2 "Spent" electrolyte | S:C ratio No Acet. Black | Ball-milled in heptane | Ball-milled in heptane Electrolyte concentration |
| 66/73 | 71/84 | 51/51 | 56/67 | 40/47 |
| 0 | 0 | 0 | 0 | 0 |
| 44.4/50 | 44.4/50 | 44.4/50 | 45.0/50 | 45.0/50 |
| 40.0/45 | 40.0/45 | 44.4/50 | 40.5/45 | 40.5/45 |
| 4.4/5 | 4.4/5 | 0 | 4.5/5 | 4.5/5 |
| 0.30 | 0.30 | 0.30 | 0.30 | 0.30 |
| 6.75 | 6.75 | 6.75 | 6.75 | 6.75 |
| 1C | 1C | 1C | 1C | 1C |
| 10 Fins[q] | 10 Fins[q] | 10 Fins[q] | 10 Fins[q] | 10 Fins[q] |
| 171 | 171 | 171 | 171 | 171 |
| --- | --- | --- | --- | --- |
| --- | --- | --- | --- | --- |
| 34 | 25 | 34 | 34 | 25 |
| --- | --- | --- | --- | --- |
| --- | 25 | --- | --- | --- |
| 400 | 400 | 400 | 400 | 400 |
| 31 | 31 | 31 | 31 | 31 |
| 5.4/27 | 5.4/27 | 5.4/27 | 5.4/27 | 5.4/27 |
| 1.95 | 1.91 | 1.95 | 1.91 | 1.99 |
| 1.95 | 1.99 | 1.95 | 1.94 | 1.99 |
| 1.30 | 1.30 | 1.30 | 1.30 | 1.30 |
| 1.78 | 1.81 | 1.88 | 1.71 | 1.82 |
| 1.86 | 1.81 | 1.82 | 1.83 | 1.84 |
| 507 | 590 | 354 | 456 | 326 |
| 0.17 | 0.20 | 0.12 | 0.15 | 0.11 |
| 0.33 | 0.39 | 0.23 | 0.30 | 0.22 |
| 117/2.09 | 225/1.85 | 117/2.01 | 136/1.96 | 87/2.09 |

TABLE II

ELECTROCHEMICAL CELL TESTS-

Nominal Discharge Temperature: -90°C (Except B-22)
AZ31B Mg Sheet[q] AZ31B Mg Exmet[y]
M-1365 Separator[u]: 5 layers at 0.004" per layer

| Cell No. B- | | | 28 | 29 |
|---|---|---|---|---|
| Major Variables | | | Full sized cell. / 20% Acet. Black | 90% KSCN + 10% $Mg(SCN)_2$ / 20% Acet. Black |
| Hours to End Voltage[b] (1.5/1.3V) | | | 53/57 | 30/41 |
| Cathode: | $HgSO_4$[j] | (grams/%) | 0 | 0 |
| | Sulfur[k] | (grams/%) | 81.0/50 | 50/50 |
| | Carbon[l] | (grams/%) | 48.5/30 | 30/30 |
| | Acetylene Black | (grams/%) | 32.5/20 | 20/20 |
| | Thickness (in.) | | 0.30 | 0.30 |
| | Length (in.) | | 13.5 | 6.75 |
| | Collector: Ag Wire (W) or Case (C) | | 1C | 1C |
| Anode: | Central (Cylindrical) | | 10 Fins[q] | 10 Fins[q] |
| | Apparent Area ($cm^2$) | | 342 | 171 |
| | Outer (Cylindrical) | | --- | --- |
| | Apparent Area ($cm^2$) | | --- | --- |
| Electrolyte: | KSCN[m] | (Wt. % as KSCN) | 34 | 25 |
| | $Mg(SCN)_2$ | (Wt. % as KSCN) | --- | 25 |
| | "Spent" | (Wt. % as KSCN) | --- | --- |
| | Volume | (cc) | 575 | 450 |
| Net Cell Volume ($in.^3$) | | | 48 | 34 |
| Load[a] ($\Omega$) | | | 2.7/13.5 | 5.4/27 |
| Initial Closed Circuit Voltage[c] | | | 1.94 | 2.01 |
| Peak Closed Circuit Voltage[c] | | | 1.95 | 2.01 |
| End Voltage (Heavy Load) | | | 1.30 | 1.30 |
| End Voltage (Light Load) | | | 1.82 | 1.82 |
| Peak Current Density ($mA/cm^2$)[d, e] | | | 1.85 | 1.89 |
| Observed Coulombs/g Sulfur | | | 431 | 257 |
| Observed F/mol Sulfur | | | 0.14 | 0.09 |
| Watt Hours/$in.^3$ Net Cell | | | 0.33 | 0.17 |
| Terminal O.C.V. (at Hours/V) | | | 112/2.09 | 42/2.11 |

Bobbin Configuration

| | | |
|---|---|---|
| 30 | 31 | 32 |
| 10% Acet. Black | Electrolyte concentration | 50% Acet. Black<br>No graphite<br>Mixed in heptane and dried |
| 68/76 | 43/53 | 67/75 |
| 0 | 0 | 0 |
| 48/50[kk] | 48/50[kk] | 35/50[kk] |
| 38/40 | 38/40 | 0 |
| 10/10 | 10/10 | 35/50 |
| 0.30 | 0.30 | 0.30 |
| 6.75 | 6.75 | 6.75 |
| 1C | 1C | 1C |
| 10 Fins[q] | 10 Fins[q] | 10 Fins[q] |
| 171 | 171 | 171 |
| --- | --- | --- |
| --- | --- | --- |
| 34 | 25 | 34 |
| --- | --- | --- |
| --- | --- | --- |
| 350 | 400 | 400 |
| 28 | 31 | 31 |
| 5.4/27 | 5.4/27 | 5.4/27 |
| 2.01 | 2.06 | 2.01 |
| 2.01 | 2.06 | 2.01 |
| 1.30 | 1.30 | 1.30 |
| 1.79 | 1.82 | 1.75 |
| 1.93 | 1.99 | 1.88 |
| 498 | 352 | 674 |
| 0.17 | 0.12 | 0.22 |
| 0.39 | 0.25 | 0.35 |
| 87/2.05 | 87/2.08 | 117/1.79 |

TABLE II

ELECTROCHEMICAL CELL TESTS - Bobbin Configurations

Nominal Discharge Temp.: -90°C (except B-38, -39, -40, -41, -48, -49, -56)
M-1365 Separator[u]: 5 layers at 0.004" per layer
Case served as cathode collector. Electrolyte: 34 Wt. % KSCN[nn], except B-56)
Central finned anode (10 fins[q]), AZ31B Mg Sheet.

| Cell No. B- | 33 | 34 | 35 | 36 | 37 |
|---|---|---|---|---|---|
| Major Variables | Cells B-33 to B-40 were packed with a rod, as usual. | | | | |
| Hours to End Voltage[b] (1.5/1.3V) | 56/63 | 61/70 | 48/53 | 51/56 | 54/63 |
| Cathode: Sulfur[kk] (grams/%) | 85/50 | Replicates of Cell B-33. | | | |
| Carbon[l] (grams/%) | 68/40 | | | | |
| Acetylene Black (g/%) | 17/10 | | | | |
| Total Weight (grams) | 170 | | | | |
| Cathode Thickness (inches) | 0.30 | | | | |
| Cathode Length (inches) | 13.5 | | | | |
| Anode:[q] Apparent Area ($cm^2$) | 342 | | | | |
| Electrolyte Volume (cc) | 660 | 660 | 660 | 660 | 660 |
| Net Cell Volume ($inches^3$) | 53 | 53 | 53 | 53 | 53 |
| Load[a] (ohms) | 2.7/13.5 | 2.7/13.5 | 2.7/13.5 | 2.7/13.5 | 2.7/13.5 |
| Initial Closed Circuit Voltage[c] | 1.94 | 1.96 | 1.95 | 1.93 | 1.95 |
| Peak Closed Circuit Voltage[c] | 1.97 | 1.99 | 1.97 | 1.95 | 1.96 |
| End Voltage (Heavy Load) | 1.30 | 1.30 | 1.30 | 1.30 | 1.30 |
| End Voltage (Light Load) | 1.81 | 1.80 | 1.78 | 1.76 | 1.80 |
| Peak Current Density ($mA/cm^2$)[d, e] | 1.86 | 1.90 | 1.87 | 1.87 | 1.88 |
| Observed Coulombs/g Sulfur | 459 | 514 | 387 | 407 | 459 |
| Observed F/mol Sulfur | 0.15 | 0.17 | 0.13 | 0.14 | 0.15 |
| Watt Hours/$inches^3$ Net Cell | 0.34 | 0.38 | 0.28 | 0.29 | 0.34 |
| Terminal O.C.V. (at Hours/V) | 71/2.12 | 71/2.10 | 71/2.12 | 71/2.09 | 71/2.11 |

| | | | | |
|---|---|---|---|---|
| 38 | 39 | 40 | 41 | 42 |
| -63° | -63° | -40° | -40° | |
| Cells B-33 to B-40 were packed with a rod, as usual. | | | Cells B-41 to B-64 were packed with an annular sleeve piston | |
| 59/73 | 47/61 | 83/100 | 99/108 | 49/61 |
| 42.5/50 | 48/50 | 48/50 | 48/50 | 120/50 |
| 34.0/40 | 38.5/40 | 38.5/40 | 38.5/40 | 96/40 |
| 8.5/10 | 9.5/10 | 9.5/10 | 9.5/10 | 24/10 |
| 85 | 96 | 96 | 96 | 240 |
| 0.30 | 0.30 | 0.30 | 0.30 | 0.30 |
| 6.75 | 6.75 | 6.75 | 6.75 | 13.5 |
| 171 | 171 | 171 | 171 | 342 |
| 450 | 450 | 440 | 460 | 690 |
| 34 | 34 | 34 | 34 | 55 |
| 5.4/27 | 5.4/27 | 5.4/27 | 5.4/27 | 2.7/13.5 |
| 2.08 | 2.09 | 2.16 | 2.16 | 1.97 |
| 2.10 | 2.10 | 2.16 | 2.15 | 1.97 |
| 1.30 | 1.30 | 1.30 | 1.30 | 1.30 |
| 1.82 | 1.57 | 1.97 | 1.95 | 1.80 |
| 2.04 | 2.06 | 2.19 | 2.18 | 1.88 |
| 551 | 408 | 681 | 736 | 314 |
| 0.18 | 0.14 | 0.23 | 0.24 | 0.10 |
| 0.33 | 0.27 | 0.46 | 0.50 | 0.30 |
| 140/1.76 | 140/1.56 | 115/2.06 | 115/2.04 | 68/2.08 |

TABLE II

## ELECTROCHEMICAL CELL TESTS - BOBBIN CONFIGURATIONS

Nominal Discharge Temp.: -90°C (except B-38, -39, -40, -41, -48,
M-1365 Separator[u]: 5 layers at 0.004" per layer
Case served as cathode collector. Electrolyte: 34 Wt.% KSCN[nn],
Central finned anode (10 fins[q]), AZ31B Mg Sheet.

| Cell No. B- | 43 | 44 | 45 | 46 | 47 |
|---|---|---|---|---|---|
| Major Variables | Cells B-41 to B-64 were packed with an annular sleeve piston | | | | |
| Hours to End Voltage[b] (1.5/1.3V) | 55/77 | 52/58 | 57/65 | 52/58 | 55/63 |
| Cathode: Sulfur[kk] (grams/%) | 96/50 | Replicates of Cell B-43 | | | |
| Carbon[l] (grams/%) | 77/40 | | | | |
| Acetylene Black (g/%) | 19/10 | | | | |
| Total Weight (grams) | 192 | | | | |
| Cathode Thickness (inches) | 0.30 | | | | |
| Cathode Length (inches) | 13.5 | | | | |
| Anode:[q] Apparent Area ($cm^2$) | 342 | | | | |
| Electrolyte Volume (cc) | 690 | 690 | 670 | 710 | 690 |
| Net Cell Volume ($inches^3$) | 55 | 55 | 55 | 55 | 55 |
| Load[a] (ohms) | 2.7/13.5 | 2.7/13.5 | 2.7/13.5 | 2.7/13.5 | 2.7/13.5 |
| Initial Closed Circuit Voltage[c] | 1.96 | 1.96 | 1.95 | 1.96 | 1.94 |
| Peak Closed Circuit Voltage[c] | 1.96 | 1.98 | 1.96 | 1.97 | 1.94 |
| End Voltage (Heavy Load) | 1.30 | 1.30 | 1.30 | 1.30 | 1.30 |
| End Voltage (Light Load) | 1.80 | 1.79 | 1.77 | 1.77 | 1.77 |
| Peak Current Density ($mA/cm^2$)[d, e] | 1.89 | 1.85 | 1.85 | 1.86 | 1.86 |
| Observed Coulombs/g Sulfur | 495 | 375 | 419 | 375 | 403 |
| Observed F/mol Sulfur | 0.16 | 0.12 | 0.14 | 0.12 | 0.13 |
| Watt Hours/$inches^3$ Net Cell | 0.39 | 0.30 | 0.33 | 0.30 | 0.32 |
| Terminal O.C.V. (at Hours/V) | 89/2.10 | 113/2.07 | 113/2.07 | 113/1.94 | 113/2.03 |
| No. of Hose Clamps | 6 | 4 | 4 | 4 | 4 |

-49, -56)

except B-56)

| 48 | 49 | 50 | 51 | 52 |
|---|---|---|---|---|
| 7 collector clamps on case. Temp. Note 1 | Cu Exmet sleeve on case secured by 14 clamps. Temp. Note 2 | Replicates of B-49 Temp. correct at -90°C | | S:C Ratio |
| 67/116 | 47/127 | 56/61 | 62/69 | 61/68 |
| Replicates of Cell B-43, except for means of collection from case. | | | | 77/40 |
| | | | | 96/50 |
| | | | | 19/10 |
| | | | | 192 |
| | | | | 0.30 |
| | | | | 13.5 |
| | | | | 342 |
| 675 | 700 | 650 | 650 | 650 |
| 55 | 55 | 55 | 55 | 55 |
| 2.7/13.5 | 2.7/13.5 | 2.7/13.5 | 2.7/13.5 | 2.7/13.5 |
| 1.95 | 1.94 | 1.99 | 1.98 | 1.98 |
| 2.08 | 2.14 | 1.99 | 1.98 | 1.98 |
| 1.30 | 1.30 | 1.30 | 1.30 | 1.30 |
| 1.85 | 1.85 | 1.79 | 1.80 | 1.81 |
| 2.06 | 2.18 | 1.96 | 1.91 | 1.91 |
| 772 | 862 | 397 | 449 | 548 |
| 0.26 | 0.29 | 0.13 | 0.15 | 0.18 |
| 0.63 | 0.72 | 0.32 | 0.36 | 0.35 |
| 142/2.06 | 138/2.01 | 119/2.00 | 118/2.07 | 118/2.05 |
| 4 + 3 | 14 | 15 | 18 | 16 |
| | Copper Exmet sleeve between case and clamps | | | |

Double lead wires from cells to loads used on Cells B-49 to B-56, except B-54

Note 1 - Temp.: 24 hours at -90°; 20 hours from -90° to -55°; balance of test at -65°C.

Note 2 - Temp.: 18 hours from -90° to -51°; balance at -65°C.

TABLE II

ELECTROCHEMICAL CELL TESTS - BOBBIN CONFIGURATIONS

Nominal Discharge Temp.: -90°C (except B-38, -39, -40, -41, -48, -49, -56
M-1365 Separator[u]: 5 layers at 0.004" per layer
Case served as cathode collector. Electrolyte: 34 Wt.% KSCN[nn], except B-56)
Central finned anode (10 fins[q]), AZ31B Mg sheet.

| Cell No. B- | 53 | 54 | 55 | 56 |
|---|---|---|---|---|
| Major Variables | Increased acetylene black. | $HgSO_4$: 10g/9.5% | $HgSO_4$: 106g/47% | $HgSO_4$: 53g/47% (-63°C) 25 Wt.%KSCN |
| Hours to End Voltage[b] (1.5/1.3V) | 52/59 | 101/113 | 59/72 | 68/76 |
| Cathode: Sulfur[kk] (g/%) | 65/40 | 48/45 | 20/9 | 10/9 |
| Carbon[l] (g/%) | 65/40 | 38/36 | 90/40 | 45/40 |
| Acetylene Black (g/%) | 32/20 | 10/9.5 | 10/4 | 5/4 |
| Total Weight (grams) | 162 | 106 | 226 | 113 |
| Cathode Thickness (inches) | 0.30 | 0.30 | 0.30 | 0.30 |
| Cathode Length (inches) | 13.5 | 6.75 | 13.5 | 6.75 |
| Anode:[q] Apparent Area ($cm^2$) | 342 | 171 | 342 | 171 |
| Electrolyte Volume (cc) | 650 | 425 | 660 | 625 |
| Net Cell Volume ($inches^3$) | 55 | 28 | 55 | 28 |
| Load[a] (ohms) | 2.7/13.5 | 5.4/27 | 2.7/13.5 | 5.4/27 |
| Initial Closed Circuit Voltage[c] | 1.98 | 2.09 | 2.15 | 2.20 |
| Peak Closed Circuit Voltage[c] | 1.98 | 2.12 | 2.17 | 2.25 |
| End Voltage (heavy load) | 1.30 | 1.30 | 1.30 | 1.30 |
| End Voltage (light load) | 1.78 | 1.77 | 1.56 | 1.43 |
| Peak Current Density ($mA/cm^2$)[d, e] | 1.90 | 2.09 | 2.21 | 2.32 |
| Observed Coulombs/g Sulfur | 563 | 631* | 372* | 406* |
| Observed F/mol Sulfur | 0.19 | 0.25* | 0.50* | 0.54* |
| Watt Hours/$inches^3$ Net Cell | 0.30 | 0.62 | 0.42 | 0.45 |
| Terminal O.C.V. (at hours/V) | 118/1.99 | 120/1.92 | 89/1.91 | 90/1.33 |
| No. of Hose Clamps | 14 | 4 | 18 | 8 |
| | Copper Exmet sleeve between case and clamps | | Copper Exmet sleeve between case and clamps. | |

Double lead wires from cells to loads used on Cells B-49 to B-56, except B-54.

* Based on total oxidants.

and B-60 and -61)

Copper Exmet sleeve between case and clamps.

| 57 | 58 | 59 | 60 | 61 | 62 |
|---|---|---|---|---|---|
| Electrolyte saturated with $HgSO_4^j$ | $HgSO_4^j$: 10g/9.5% | $HgSO_4^j$: 20g/9.5% Full size | $HgSO_4^j$: 10g/9.5% -40°C | $HgSO_4^j$: 10g/9.5% -63°C | H[illegible]$SO_4^j$ in W[illegible]bril capsule in anode space. |
| 64/84 | 96/106 | 95/111 | 97/127 | 158/176 | 71/82 |
| 48/50 | 48/45 | 96/45.2 | 48/45.2 | 48/45.2 | 48/50 |
| 38/40 | 38/36 | 77/36.3 | 38.5/36.3 | 38.5/36.3 | 38.5/40 |
| 10/10 | 10/9.5 | 19/9.0 | 9.5/9.0 | 9.5/9.0 | 9.5/10 |
| 96 | 106 | 212 | 106 | 106 | 96 |
| 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 |
| 6.75 | 6.75 | 13.5 | 6.75 | 6.75 | 6.75 |
| 171 | 171 | 342 | 171 | 171 | 171 |
| 425 | 425 | 740 | 620 | 560 | 450 |
| 28 | 28 | 55 | 28 | 28 | 28 |
| 5.4/27 | 5.4/27 | 2.7/13.5 | 5.4/27 | 5.4/27 | 5.4/27 |
| 1.99 | 2.12 | 2.06 | 2.17 | 2.20 | 1.95 |
| 1.99 | 2.13 | 2.09 | 2.19 | 2.22 | 1.95 |
| 1.30 | 1.30 | 1.30 | 1.30 | 1.30 | 1.30 |
| 1.81 | 1.80 | 1.79 | 1.90 | 1.78 | 1.76 |
| 1.92 | 2.17 | 2.10 | 2.26 | 2.26 | 1.92 |
| 546 | 592* | 615* | 724* | 1010* | 526 |
| 0.18 | 0.23* | 0.24* | 0.28* | 0.40* | 0.17 |
| 0.43 | 0.58 | 0.61 | 0.73 | 1.02 | 0.41 |
| 119/2.01 | 119/1.96 | 140/2.07 | 140/2.00 | 188/1.88 | 116/2.02 |
| 8 | 8 | 21 | 9 | 8 | 8 |

# TABLE II

## ELECTROCHEMICAL CELL TESTS - BOBBIN CONFIGURATION

### Task III - "Mockup" Cells in full hardware

Nominal Discharge Temp.: -73°C    Case served as cathode collector.
M-1365 Separator[u]: 5 layers at 0.004" per layer. Electrolyte: 34 Wt. % KSCN[nn]
Central finned anode (10 fins[q]), AZ31B Mg Sheet.
Refer to Drawings: B-1227, B-1228, A-1238, and A-1239, Appendix B
Refer to Parts and Materials List, Appendix B

| Cell No. B- | 63 | 64 |
|---|---|---|
| Major Variables | $HgSO_4$[j] 20g/9.5% | $HgSO_4$[j] 20g/9.5% |
| Hours to End Voltage[b] (1.5/1.3V) | 81/101 | 87/97 |
| Cathode: Sulfur[kk] (g/%) | 96/45.2 | 96/45.2 |
| Carbon[l] (g/%) | 77/36.3 | 77/36.3 |
| Acetylene Black (g/%) | 19/9.0 | 19/9.0 |
| Total Weight (grams) | 212 | 212 |
| Cathode Thickness (inches) | 0.30 | 0.30 |
| Cathode Length (inches) | 13.5 | 13.5 |
| Anode:[q] Apparent Area ($cm^2$) | 342 | 342 |
| Electrolyte Volume (cc) | 500 | 500 |
| Net Cell Volume ($inches^3$) | 39 | 39 |
| Load[a] (ohms) | 2.7/13.5 | 2.7/13.5 |
| Initial Closed Circuit Voltage[c] | 2.15 | 2.18 |
| Peak Closed Circuit Voltage[c] | 2.18 | 2.19 |
| End Voltage (heavy load) | 1.50 | 1.50 |
| End Voltage (light load) | 1.99 | 1.97 |
| Peak Current Density ($mA/cm^2$)[d, e] | 2.17 | 2.21 |
| Observed Coulombs/g Total Oxidants | 486 | 521 |
| Observed F/mol Total Oxidants | 0.19 | 0.20 |
| Watt Hours/$inches^3$ Net Cell | 0.74 | 0.79 |
| Terminal O.C.V. (at hours/V) | 112/2.10 | 113/2.15 |
| No. of Hose Clamps | 7 | 7 |

No copper Exmet; double lead wires

TABLE III-A (Prismatic Cells)

PERIODIC CELL VOLTAGES

| Test | High Load Voltage after: (hours) | | | | | | Low Load Voltage after: (hours) | | | | | | Hours to:[d] | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | 12 | 24 | 36 | 48 | 60 | 72 | 12 | 24 | 36 | 48 | 60 | 72 | 1.5V | 1.3V |
| P-54 | 1.74 | 1.33 | 0.85 | --- | --- | --- | 2.15 | 2.02 | 1.70 | --- | --- | --- | 20 | 30 |
| P-56 | 2.19 | 1.80 | 1.43 | 0.98 | --- | --- | 2.25 | 1.93 | 1.66 | 1.17 | --- | --- | 34 | 40 |
| P-58 | 1.68 | 1.65 | 1.59 | 1.58 | 1.46 | 1.38 | 1.97 | 1.94 | 1.92 | 1.91 | 1.88 | 1.84 | 53 | 89 |
| P-59 | 2.06 | 1.85 | 1.12 | .93 | --- | --- | 2.24 | 2.12 | 2.12 | --- | --- | --- | 24 | 26 |
| P-60 | 2.08 | 2.04 | 1.86 | 1.52 | .73 | --- | 2.24 | 2.23 | 2.20 | 2.12 | 1.46 | --- | 55 | 56 |
| P-61 | 1.90 | 1.90 | 1.89 | 1.58 | 1.69 | 1.51 | 1.95 | 1.94 | 1.95 | 1.84 | 1.88 | 1.80 | 73 | 83 |
| P-62 | 1.65 | 1.57 | 1.56 | 1.43 | 1.28 | --- | 2.01 | 1.97 | 1.95 | 1.89 | 1.81 | --- | 40 | 60 |
| P-63 | 2.05 | 2.12 | 1.60 | 1.55 | 1.30 | --- | 2.17 | 2.20 | 1.80 | 1.73 | 1.75 | --- | 54 | 66 |
| P-65 | 2.15 | 1.95 | 1.60 | 1.27 | --- | --- | 2.22 | 2.17 | 1.80 | 1.53 | --- | --- | 42 | 57 |
| P-66 | 2.14 | 2.15 | 1.95 | 1.62 | 1.62 | --- | 2.23 | 2.23 | 2.17 | 1.88 | 1.88 | --- | 67 | 69 |
| P-69 | 1.57 | 1.54 | 1.60 | 1.54 | 1.50 | 1.50 | 2.00 | 2.02 | 2.10 | 2.09 | 2.10 | 2.10 | 81 | 202 |
| P-70 | 1.55 | 1.53 | 1.55 | 1.51 | 1.45 | 1.40 | 1.90 | 1.89 | 1.89 | 1.85 | 1.84 | 1.82 | 54 | 85 |
| P-71 | 1.80 | .70 | --- | --- | --- | --- | 1.90 | 1.54 | --- | --- | --- | --- | 13 | 13 |
| P-72 | 1.72 | 1.06 | --- | --- | --- | --- | 2.22 | 1.85 | --- | --- | --- | --- | 17 | 20 |
| P-74 | 1.33 | 1.30 | 1.26 | --- | --- | --- | 1.81 | 1.75 | 1.76 | --- | --- | --- | 4 | 27 |
| P-75 | 1.34 | 1.38 | 1.35 | 1.32 | 1.30 | --- | 1.79 | 1.79 | 1.80 | 1.77 | 1.77 | --- | 0 | 56 |
| P-76 | 1.80 | 1.80 | 1.76 | 1.76 | 1.68 | 1.68 | 1.98 | 2.00 | 1.98 | 1.98 | 1.96 | 1.95 | 99 | 141 |
| P-77 | 1.80 | 1.82 | 1.78 | 1.77 | 1.68 | 1.65 | 1.99 | 2.01 | 1.98 | 1.99 | 1.96 | 1.95 | 100 | 120 |
| P-78 | 1.82 | 1.85 | 1.81 | 1.81 | 1.70 | 1.71 | 2.00 | 2.02 | 2.00 | 2.01 | 1.98 | 1.95 | 93 | 103 |
| P-79 | 1.90 | 1.82 | 1.80 | 1.78 | 1.70 | 1.71 | 2.00 | 2.00 | 1.99 | 1.99 | 1.97 | 1.95 | 94 | 106 |
| P-80 | 1.70 | 1.62 | 1.50 | 1.28 | --- | --- | 1.95 | 1.94 | 1.90 | 1.81 | 1.78 | 1.72 | 36 | 47 |

TABLE III-A (Prismatic Cells)

PERIODIC CELL VOLTAGES

| Test | High Load Voltage after: (hours) | | | | | | Low Load Voltage after: (hours) | | | | | | Hours to:[d] | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | 12 | 24 | 36 | 48 | 60 | 72 | 12 | 24 | 36 | 48 | 60 | 72 | 1.5V | 1.3V |
| P- 81 | 1.82 | 1.81 | 1.82 | 1.81 | 1.85 | 1.81 | 1.99 | 1.99 | 1.99 | 2.00 | 2.06 | 2.06 | 85 | 118 |
| P- 82 | 1.81 | 1.78 | 1.77 | 1.74 | 1.84 | 1.78 | 2.00 | 1.98 | 1.97 | 1.97 | 2.05 | 2.03 | 82 | 121 |
| P- 83 | 1.86 | 1.85 | 1.83 | 1.77 | 1.80 | 1.70 | 2.02 | 2.01 | 2.00 | 1.98 | 2.00 | 1.97 | 80 | 87 |
| P- 84 | 1.87 | 1.88 | 1.91 | 1.87 | 1.93 | 1.80 | 2.05 | 2.07 | 2.08 | 2.07 | 2.09 | 2.02 | 83 | 108 |
| P- 85 | 1.77 | 1.75 | 1.65 | 1.63 | 1.60 | 1.52 | 2.01 | 2.00 | 1.95 | 1.94 | 1.92 | 1.88 | 75 | 89 |
| P- 86 | 1.79 | 1.71 | 1.63 | 1.57 | 1.58 | 1.48 | 1.99 | 1.97 | 1.94 | 1.92 | 1.90 | 1.85 | 72 | 109 |
| P- 87 | 1.71 | 1.65 | 1.59 | 1.56 | 1.51 | 1.45 | 1.96 | 1.95 | 1.90 | 1.88 | 1.84 | 1.80 | 68 | 100 |
| P- 88 | 1.65 | 1.60 | 1.52 | 1.45 | 1.35 | 1.21 | 1.94 | 1.89 | 1.82 | 1.79 | 1.76 | 1.70 | 45 | 69 |
| P- 89 | 1.60 | 1.58 | 1.53 | 1.46 | 1.35 | 1.29 | 1.93 | 1.90 | 1.88 | 1.87 | 1.85 | 1.85 | 44 | 72 |
| P- 90 | 1.68 | 1.65 | 1.63 | 1.60 | 1.55 | 1.53 | 1.95 | 1.93 | 1.92 | 1.92 | 1.90 | 1.90 | 76 | 85 |
| P- 91 | 1.70 | 1.67 | 1.60 | 1.51 | 1.46 | 1.47 | 1.95 | 1.95 | 1.93 | 1.92 | 1.93 | 1.92 | 52 | 80 |
| P- 92 | 1.70 | 1.68 | 1.62 | 1.60 | 1.52 | 1.60 | 1.95 | 1.95 | 1.94 | 1.92 | 1.92 | 1.92 | 81 | 86 |
| P- 93 | 1.73 | 1.65 | 1.56 | 1.40 | 1.24 | --- | 1.97 | 1.95 | 1.90 | 1.83 | 1.78 | --- | 42 | 58 |
| P- 94 | 1.80 | 1.81 | 1.72 | 1.58 | 1.19 | --- | 2.00 | 2.02 | 1.98 | 1.95 | 1.80 | --- | 54 | 58 |
| P- 95 | 1.79 | 1.72 | 1.57 | 1.44 | --- | --- | 2.00 | 2.01 | 1.93 | 1.89 | 1.61 | --- | 43 | 55 |
| P- 96 | 1.85 | 1.85 | 1.81 | 1.81 | 1.68 | 1.50 | 2.01 | 2.04 | 2.04 | 2.06 | 2.01 | 1.93 | 73 | 105 |
| P- 97 | 1.85 | 1.85 | 1.75 | 1.73 | 1.57 | 1.45 | 1.99 | 2.00 | 1.96 | 1.97 | 1.90 | 1.86 | 67 | 81 |
| P- 99 | 1.87 | 1.76 | 1.67 | 1.55 | 1.45 | 1.34 | 2.00 | 1.96 | 1.92 | 1.87 | 1.76 | 1.68 | 51 | 75 |
| P-100 | 1.85 | 1.72 | 1.60 | 1.35 | --- | --- | 1.98 | 1.92 | 1.84 | 1.68 | --- | --- | 42 | 50 |
| P-101 | 1.81 | 1.69 | 1.57 | 1.44 | --- | --- | 1.89 | 1.83 | 1.76 | 1.69 | --- | --- | 44 | 54 |
| P-102 | 1.95 | 1.88 | 1.82 | 1.74 | 1.55 | 1.35 | 2.05 | 2.03 | 2.00 | 1.97 | 1.82 | 1.65 | 66 | 75 |
| P-103 | 1.75 | 1.65 | 1.52 | 1.29 | --- | --- | 1.90 | 1.87 | 1.78 | 1.67 | --- | --- | 38 | 48 |
| P-104 | 1.83 | 1.73 | 1.46 | 1.32 | --- | --- | 1.90 | 1.89 | 1.73 | 1.80 | --- | --- | 28 | 49 |
| P-105 | 1.85 | 1.79 | 1.65 | 1.50 | 1.38 | 1.32 | 1.97 | 1.98 | 1.90 | 1.81 | 1.71 | 1.65 | 49 | 75 |

TABLE III-A (Prismatic Cells)

PERIODIC CELL VOLTAGES

| Test | High Load Voltage after: (hours) | | | | | | Low Load Voltage after: (hours) | | | | | | Hours to:[d] | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | 12 | 24 | 36 | 48 | 60 | 72 | 12 | 24 | 36 | 48 | 60 | 72 | 1.5V | 1.3V |
| P-106 | 1.65 | 1.62 | 1.56 | 1.40 | 1.17 | --- | 1.71 | 1.72 | 1.70 | 1.70 | 1.63 | --- | 42 | 54 |
| P-107 | 1.63 | 1.60 | 1.50 | 1.38 | 1.21 | --- | 1.70 | 1.73 | 1.70 | 1.71 | 1.66 | --- | 37 | 56 |
| P-110 | 1.52 | 1.40 | 1.33 | --- | --- | --- | 1.87 | 1.82 | 1.78 | --- | --- | --- | 15 | 44 |
| P-111 | 1.50 | 1.38 | 1.30 | 1.25 | --- | --- | 1.95 | 1.85 | 1.77 | 1.78 | --- | --- | 13 | 37 |
| P-112 | 1.91 | 1.91 | 1.90 | 1.72 | 1.54 | 1.33[1] | 2.07 | 2.07 | 2.07 | 2.02 | 1.93 | 1.62[1] | 64[1] | 75[1] |
| P-113 | 1.90 | 1.89 | 1.85 | 1.75 | 1.59 | 1.32[1] | 2.07 | 2.06 | 2.06 | 2.02 | 1.95 | 1.79[1] | 65[1] | 73[1] |
| P-114 | 2.03 | 1.93 | 1.58 | 1.33 | --- | --- | 2.12 | 2.06 | 1.91 | 1.79 | --- | --- | 38 | 52 |
| P-115 | 2.01 | 1.85 | 1.42 | 1.20 | --- | --- | 2.10 | 2.03 | 1.80 | 1.20 | --- | --- | 34 | 39 |
| P-116 | 1.23 | .70 | --- | --- | --- | --- | 1.45 | .92 | --- | --- | --- | --- | 8 | 11 |
| P-117 | 1.73 | 1.62 | 1.25 | --- | --- | --- | 2.00 | 1.78 | 1.55 | --- | --- | --- | 30 | 35 |
| P-118 | 1.95 | 1.86 | 1.35 | --- | --- | --- | 2.02 | 1.96 | 1.58 | --- | --- | --- | 32 | 38 |
| P-119 | 2.18 | 1.98 | 1.43 | --- | --- | --- | 2.23 | 2.10 | 1.57 | --- | --- | --- | 35 | 39 |
| P-120 | 2.22 | 1.99 | 1.48 | 1.35 | --- | --- | 2.29 | 2.09 | 1.61 | 1.52 | --- | --- | 35 | 51 |
| P-121 | 2.20 | 1.85 | 1.33 | --- | --- | --- | 2.19 | 1.96 | 1.45 | --- | --- | --- | 29 | 38 |
| P-125 | 2.17 | 1.93 | 1.70 | 1.03 | --- | --- | 2.23 | 2.02 | 1.91 | 1.18 | --- | --- | 41 | 43 |
| P-126 | 1.49 | 1.40 | 1.40 | 1.48 | 1.45 | 1.43 | 1.85 | 1.80 | 1.80 | 1.83 | 1.83 | 1.80 | 0 | 95 |
| P-127 | 1.60 | 1.49 | 1.35 | 1.45 | 1.40 | 1.35 | 1.86 | 1.80 | 1.80 | 1.82 | 1.82 | 1.79 | 12 | 89 |
| P-128 | 1.51 | 1.51 | 1.50 | 1.45 | 1.45 | 1.42 | 1.88 | 1.88 | 1.90 | 1.80 | 1.83 | 1.81 | 25 | 110 |
| P-129 | 1.49 | 1.59 | 1.58 | 1.53 | 1.57 | 1.53 | 1.85 | 1.88 | 1.87 | 1.87 | 1.87 | 1.86 | 90 | 113 |
| P-130 | 1.85 | 1.56 | 1.20 | --- | --- | --- | 1.90 | 1.75 | 1.35 | --- | --- | --- | 25 | 30 |
| P-131 | 1.70 | 1.63 | 1.54 | 1.48 | 1.40 | 1.35 | 2.00 | 1.98 | 1.94 | 1.87 | 1.81 | 1.78 | 45 | 82 |
| P-132 | 1.74 | 1.67 | 1.61 | 1.55 | 1.46 | 1.40 | 2.03 | 2.00 | 1.98 | 1.92 | 1.87 | 1.84 | 57 | 83 |
| P-133 | 1.27 | 1.24 | --- | --- | --- | --- | 1.65 | 1.65 | --- | --- | --- | --- | 0 | <12 |

[1] Recorder failure; voltage estimated.

TABLE III-B (Bobbin Cells)

PERIODIC CELL VOLTAGES

| Test No. | High Load Voltage after: (hours) 12 | 24 | 36 | 48 | 60 | 72 | Low Load Voltage after: (hours) 12 | 24 | 36 | 48 | 60 | 72 | Hours to:[d] 1.5V | 1.3V |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B- 4 | 1.63 | 1.40 | --- | --- | --- | --- | 1.99 | 1.92 | --- | --- | --- | --- | 22 | 28 |
| B- 5 | 1.59 | 1.40 | 1.19 | --- | --- | --- | 1.97 | 1.93 | 1.85 | --- | --- | --- | 20 | 31 |
| B- 6 | 1.78 | 1.65 | 1.25 | --- | --- | --- | 2.04 | 2.01 | 1.88 | --- | --- | --- | 31 | 35 |
| B- 7 | 1.71 | 1.62 | 1.58 | 1.51 | 1.35 | --- | 2.00 | 1.96 | 1.95 | 1.89 | 1.85 | --- | 50 | 70 |
| B- 8 | 1.52 | 1.37 | 1.32 | 1.28[2] | --- | --- | 1.75 | 1.66 | 1.66 | 1.68 | --- | --- | 18 | 42[2] |
| B- 9 | 1.45 | 1.21 | 1.26 | 1.31 | --- | --- | 1.78 | 1.65 | 1.69 | 1.75 | --- | --- | 10 | 21 |
| B-10 | 1.33 | .95 | --- | --- | --- | --- | 1.65 | 1.51 | --- | --- | --- | --- | 1 | 18 |
| B-12 | 1.63 | 1.31 | 1.40 | 1.50 | --- | --- | 1.89 | 1.70 | 1.75 | --- | --- | --- | 19 | 26 |
| B-13 | 1.50 | 1.46 | 1.47 | 1.40 | 1.20 | --- | 1.82 | 1.76 | 1.81 | 1.70 | 1.77 | --- | 23 | 56 |
| B-14 | 1.35 | 1.20 | 1.06 | --- | --- | --- | 1.77 | 1.68 | 1.63 | --- | --- | --- | 0 | 22 |
| B-15 | 1.65 | 1.56 | 1.60 | 1.53 | 1.33 | --- | 1.93 | 1.82 | 1.93 | 1.92 | 1.84 | --- | 54 | 62 |
| B-16 | 1.50 | 1.55 | 1.40 | --- | --- | --- | 1.85 | 1.85 | 1.87 | --- | --- | --- | 25 | 42 |
| B-17 | 1.52 | 1.52 | 1.49 | 1.40 | 1.33 | --- | 1.87 | 1.86 | 1.87 | 1.86 | 1.85 | --- | 36 | 63 |
| B-19 | 1.49 | 1.51 | 1.55 | 1.52 | 1.55 | 1.52 | 1.88 | 1.90 | 1.90 | 1.85 | 1.86 | 1.85 | 80 | 91 |
| B-22 | 1.92 | 1.60 | 1.26 | --- | (at -40°C) | | 2.11 | 1.98 | 1.52 | --- | --- | --- | 26 | 30 |
| B-22 | 1.55 | 1.53 | 1.38 | 1.10 | (at -63°C) | | 1.93 | 1.92 | 1.80 | --- | --- | --- | 59 | 72 |
| B-23 | 1.69 | 1.67 | 1.69 | 1.66 | 1.60 | 1.30 | 1.93 | 1.91 | 1.92 | 1.91 | 1.90 | 1.79 | 66 | 73 |
| B-24 | 1.57 | 1.55 | 1.60 | 1.53 | 1.55 | 1.48 | 1.88 | 1.94 | 1.93 | 1.91 | 1.90 | 1.86 | 71 | 84 |
| B-25 | 1.65 | 1.58 | 1.61 | 1.56 | 1.25 | --- | 1.94 | 1.91 | 1.91 | 1.89 | 1.75 | --- | 51 | 51 |

[2] Temperature increase; voltage estimated.

TABLE III-B (Bobbin Cells)

PERIODIC CELL VOLTAGES

| Test No. | High Load Voltage after: (hours) 12 | 24 | 36 | 48 | 60 | 72 | Low Load Voltage after: (hours) 12 | 24 | 36 | 48 | 60 | 72 | Hours to:[d] 1.5V | 1.3V |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B-26 | 1.66 | 1.65 | 1.65 | 1.59 | 1.43 | 1.16 | 1.93 | 1.90 | 1.88 | 1.85 | 1.76 | 1.62 | 56 | 67 |
| B-27 | 1.56 | 1.59 | 1.56 | 1.25 | --- | --- | 1.91 | 1.93 | 1.91 | 1.81 | --- | --- | 40 | 47 |
| B-28 | 1.69 | 1.67 | 1.66 | 1.58 | 1.22 | --- | 1.92 | 1.91 | 1.90 | 1.90 | 1.77 | --- | 53 | 57 |
| B-29 | 1.60 | 1.59 | 1.42 | 1.15 | --- | --- | 1.96 | 1.95 | 1.87 | 1.73 | --- | --- | 30 | 41 |
| B-30 | 1.70 | 1.70 | 1.70 | 1.67 | 1.61 | 1.38 | 1.91 | 1.92 | 1.91 | 1.90 | 1.88 | 1.83 | 68 | 76 |
| B-31 | 1.65 | 1.67 | 1.60 | 1.36 | --- | --- | 1.96 | 1.98 | 1.95 | 1.85 | --- | --- | 43 | 53 |
| B-32 | 1.70 | 1.67 | 1.67 | 1.64 | 1.59 | 1.35 | 1.97 | 1.95 | 1.95 | 1.92 | 1.89 | 1.81 | 67 | 75 |
| B-33 | 1.70 | 1.66 | 1.65 | 1.60 | 1.36 | --- | 1.96 | 1.95 | 1.93 | 1.90 | 1.85 | --- | 56 | 63 |
| B-34 | 1.72 | 1.72 | 1.75 | 1.67 | 1.52 | 1.17 | 1.97 | 1.97 | 1.94 | 1.90 | 1.86 | 1.78 | 61 | 70 |
| B-35 | 1.70 | 1.66 | 1.72 | 1.48 | --- | --- | 1.95 | 1.94 | 1.95 | 1.86 | --- | --- | 48 | 53 |
| B-36 | 1.69 | 1.64 | 1.70 | 1.55 | 1.12 | --- | 1.95 | 1.93 | 1.92 | 1.86 | 1.70 | --- | 51 | 56 |
| B-37 | 1.72 | 1.66 | 1.70 | 1.56 | 1.35 | --- | 1.95 | 1.94 | 1.94 | 1.88 | 1.83 | --- | 54 | 63 |
| B-38 | 1.85 | 1.76 | 1.71 | 1.56 | 1.49 | 1.30 | 2.08 | 1.95 | 1.93 | 1.88 | 1.90 | 1.83 | 59 | 73 |
| B-39 | 1.81 | 1.72 | 1.65 | 1.43 | 1.35 | --- | 1.97 | 1.89 | 1.81 | 1.71 | 1.60 | --- | 47 | 61 |
| B-40 | 2.00 | 1.93 | 1.85 | 1.83 | 1.70 | 1.66 | 2.13 | 2.09 | 2.07 | 2.08 | 2.05 | 2.05 | 83 | 100 |
| B-41 | 1.98 | 1.94 | 1.86 | 1.80 | 1.74 | 1.78 | 2.12 | 2.09 | 2.08 | 2.07 | 2.05 | 2.05 | 99 | 108 |
| B-42 | 1.70 | 1.69 | 1.67 | 1.54 | 1.33 | --- | 1.95 | 1.92 | 1.90 | 1.85 | 1.80 | --- | 49 | 61 |
| B-43 | 1.74 | 1.70 | 1.70 | 1.62 | 1.45 | 1.38 | 1.95 | 1.91 | 1.92 | 1.90 | 1.85 | 1.84 | 55 | 77 |
| B-44 | 1.69 | 1.64 | 1.63 | 1.55 | 1.25 | --- | 1.97 | 1.95 | 1.91 | 1.87 | 1.77 | --- | 52 | 58 |
| B-45 | 1.66 | 1.67 | 1.65 | 1.58 | 1.44 | --- | 1.95 | 1.92 | 1.90 | 1.86 | 1.83 | --- | 57 | 65 |
| B-46 | 1.70 | 1.70 | 1.65 | 1.54 | 1.24 | --- | 1.95 | 1.92 | 1.90 | 1.86 | 1.75 | --- | 52 | 58 |
| B-47 | 1.70 | 1.67 | 1.65 | 1.54 | 1.43 | --- | 1.94 | 1.90 | 1.89 | 1.84 | 1.80 | --- | 55 | 63 |
| B-48 | 1.72 | 1.72 | 1.88 | 1.81 | 1.64 | 1.47 | 1.96 | 1.95 | 2.05 | 2.05 | 1.91 | 1.86 | 67 | 116 |

TABLE III-B (Bobbin Cells)

PERIODIC CELL VOLTAGES

| Test | High Load Voltage after: (hours) | | | | | | Low Load Voltage After: (hours) | | | | | | Hours to:[d] | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | 12 | 24 | 36 | 48 | 60 | 72 | 12 | 24 | 36 | 48 | 60 | 72 | 1.5V | 1.3V |
| B-49 | 1.96 | 1.95 | 1.70 | 1.47 | 1.39 | 1.40 | 2.10 | 2.10 | 1.91 | 1.85 | 1.83 | 1.85 | 47 | 127 |
| B-50 | 1.76 | 1.78 | 1.75 | 1.62 | 1.36 | --- | 1.95 | 1.95 | 1.91 | 1.85 | 1.82 | --- | 56 | 61 |
| B-51 | 1.74 | 1.74 | 1.74 | 1.67 | 1.57 | 1.23 | 1.92 | 1.91 | 1.91 | 1.88 | 1.86 | 1.76 | 62 | 69 |
| B-52 | 1.71 | 1.73 | 1.70 | 1.63 | 1.50 | 1.22 | 1.93 | 1.91 | 1.90 | 1.88 | 1.85 | 1.80 | 61 | 68 |
| B-53 | 1.73 | 1.74 | 1.71 | 1.58 | 1.29 | --- | 1.93 | 1.92 | 1.90 | 1.85 | 1.77 | --- | 52 | 59 |
| B-54 | 1.87 | 1.64 | 1.64 | 1.61 | 1.65 | 1.60 | 2.10 | 1.89 | 1.87 | 1.85 | 1.89 | 1.86 | 101 | 113 |
| B-55 | 1.97 | 1.96 | 1.88 | 2.03 | 1.46 | 1.26 | 2.17 | 2.12 | 2.15 | 2.17 | 1.85 | 1.56 | 59 | 72 |
| B-56 | 2.14 | 2.10 | 2.05 | 1.83 | 1.80 | 1.37 | 2.22 | 2.20 | 2.17 | 2.05 | 1.94 | 1.51 | 68 | 76 |
| B-57 | 1.76 | 1.74 | 1.74 | 1.72 | 1.55 | 1.37 | 1.95 | 1.93 | 1.92 | 1.92 | 1.87 | 1.82 | 64 | 84 |
| B-58 | 1.93 | 1.66 | 1.70 | 1.73 | 1.71 | 1.69 | 2.12 | 1.92 | 1.91 | 1.92 | 1.91 | 1.90 | 96 | 106 |
| B-59 | 1.92 | 1.71 | 1.72 | 1.68 | 1.67 | 1.64 | 2.10 | 1.90 | 1.87 | 1.88 | 1.87 | 1.87 | 95 | 111 |
| B-60 | 2.05 | 1.97 | 1.80 | 1.82 | 1.81 | 1.69 | 2.13 | 2.11 | 2.11 | 2.09 | 2.07 | 2.08 | 97 | 127 |
| B-61 | 2.05 | 1.98 | 1.97 | 1.95 | 1.95 | 1.88 | 2.20 | 2.11 | 2.12 | 2.10 | 2.10 | 2.08 | 158 | 176 |
| B-62 | 1.76 | 1.75 | 1.73 | 1.70 | 1.60 | 1.45 | 1.95 | 1.95 | 1.92 | 1.90 | 1.88 | 1.84 | 71 | 82 |
| B-63 | 1.84 | 1.87 | 1.85 | 1.84 | 1.73 | 1.65 | 2.08 | 2.09 | 2.08 | 2.07 | 2.05 | 2.03 | 81 | 101 |
| B-64 | 1.85 | 1.89 | 1.89 | 1.87 | 1.80 | 1.74 | 2.05 | 2.08 | 2.08 | 2.07 | 2.06 | 2.05 | 87 | 97 |

# APPENDIX B

## 1. Prismatic Cell Construction

Figure 1 illustrates a prismatic cell comprising a pasted-plate cathode enclosed and sealed within a separator, two magnesium anodes and a plastic envelope case. A silver-plated copper Exmet (expanded metal) grid serves as the carrier for the paste and as a cathode collector. The lead wire is soldered to the Exmet, and the joint is coated with Krylon or rubber cement.

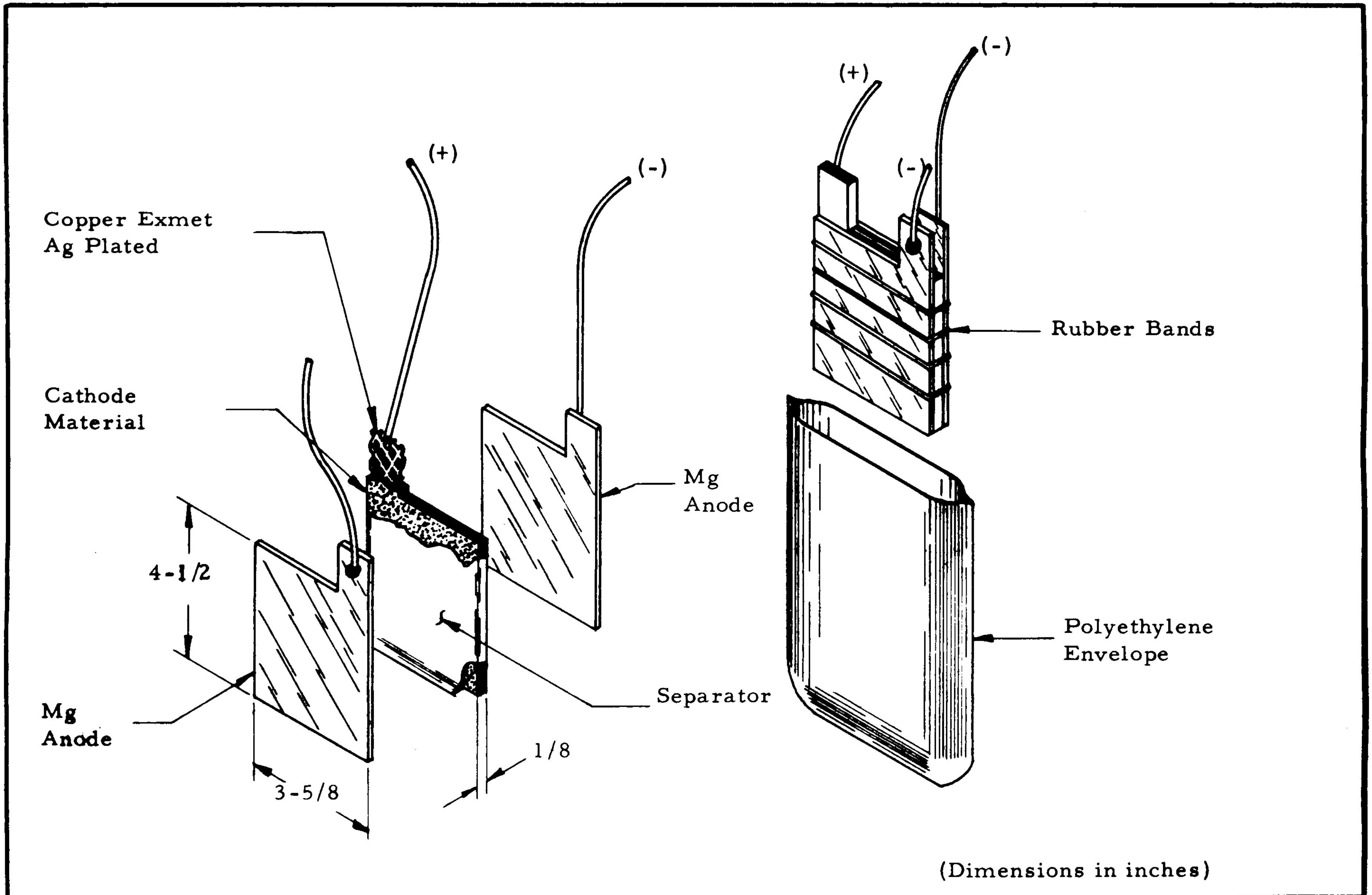
The oxidant(s) and graphite in the desired proportions are dry blended and are then mixed with a binder (1% solution of polystyrene in toluene) into a workable paste. The paste is spread evenly on both sides of the grid with a spatula. During this procedure, the surface may be moistened with toluene as necessary to counteract evaporation. The finished plate is air-dried overnight, or until the odor of toluene has disappeared. Forced drying is not applied in order to avoid shrinking and cracking of the paste.

A suitable separator is then wrapped around the dried plate and sealed at the seams.

A magnesium sheet anode is applied to each face of the cathode on the outside of the separator, and the two anodes are held in place with rubber bands which permit swelling of the cathode during activation and discharge. The anode lead wires are attached with aluminum rivets, and the connections are protected with Krylon or rubber cement.

The entire cell assembly is encased in a polyethylene envelope which may be used for discharge at any temperature below the boiling point of liquid ammonia.

The general design may be varied at will to meet the requirements of special tests.

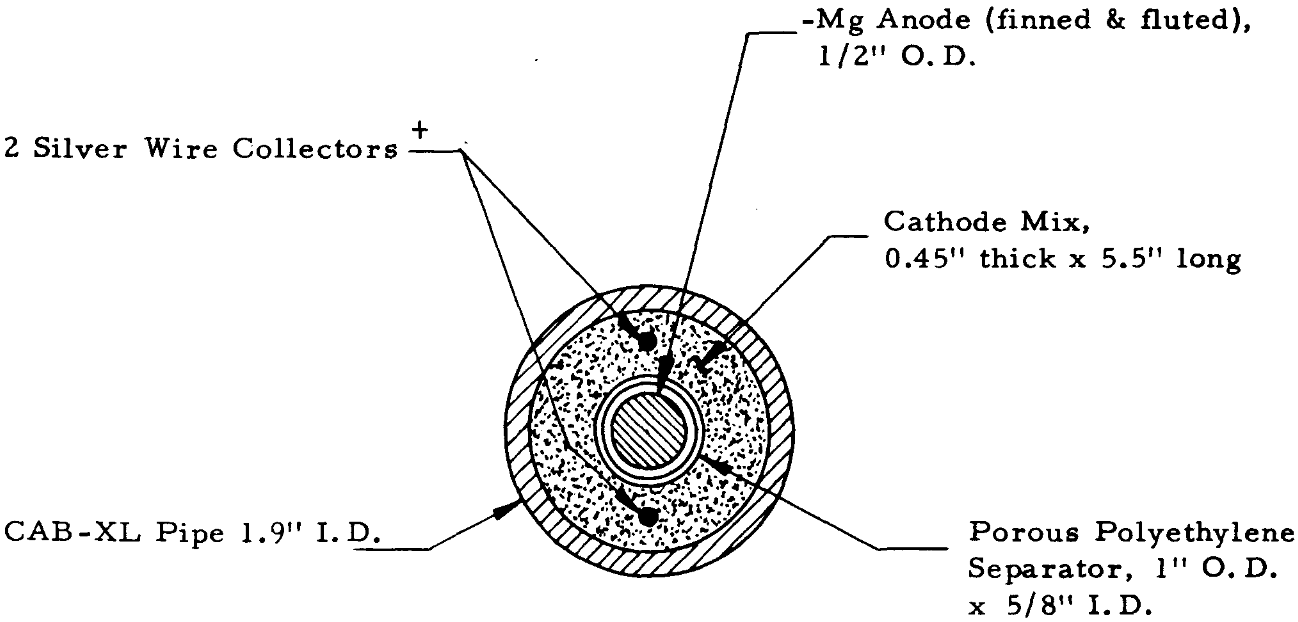



FORM FM-101

TYPICAL PRISMATIC CELL

Figure 1

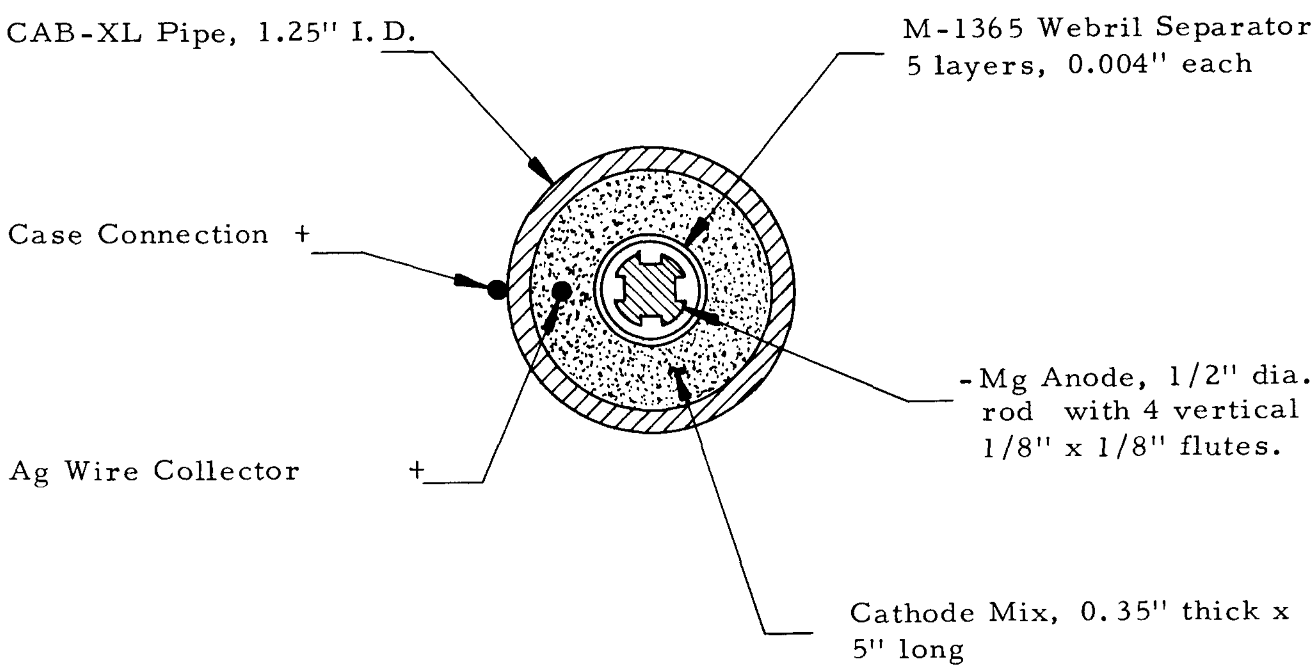
BOBBIN CELLS NOS. B-1 and B-2




FORM FM-100

Figure 2

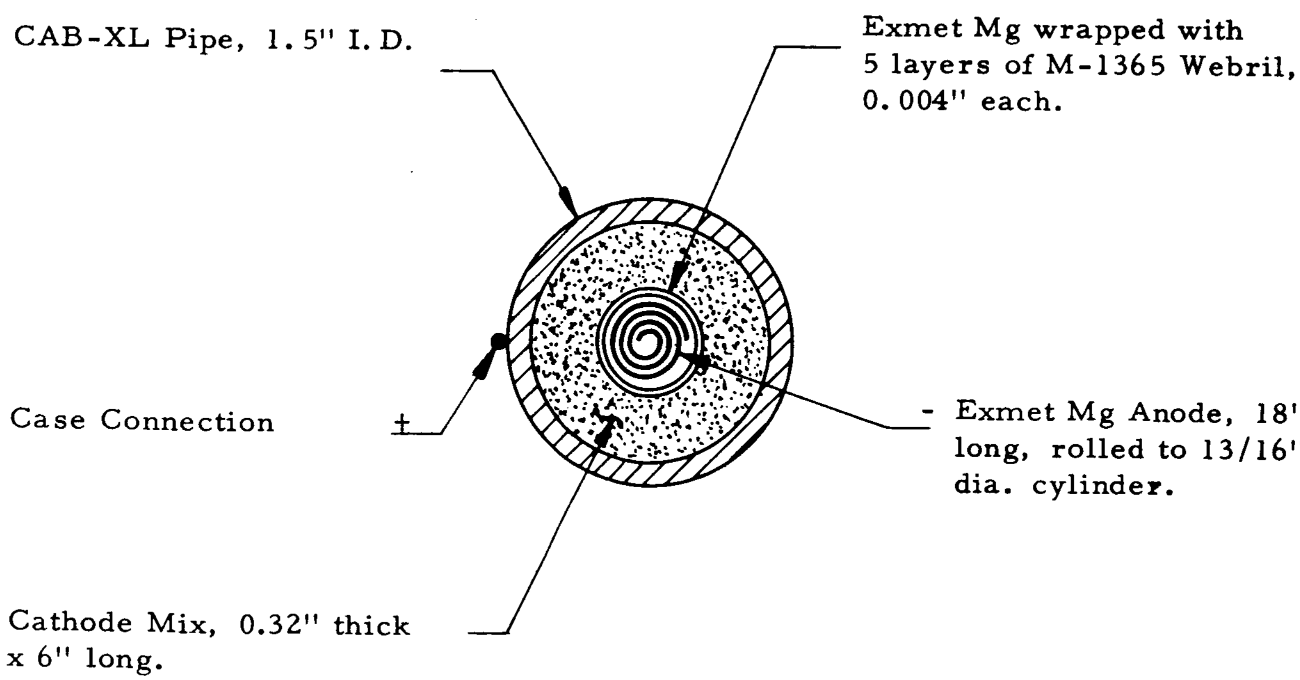
BOBBIN CELL NO. B-3




FORM FM-100

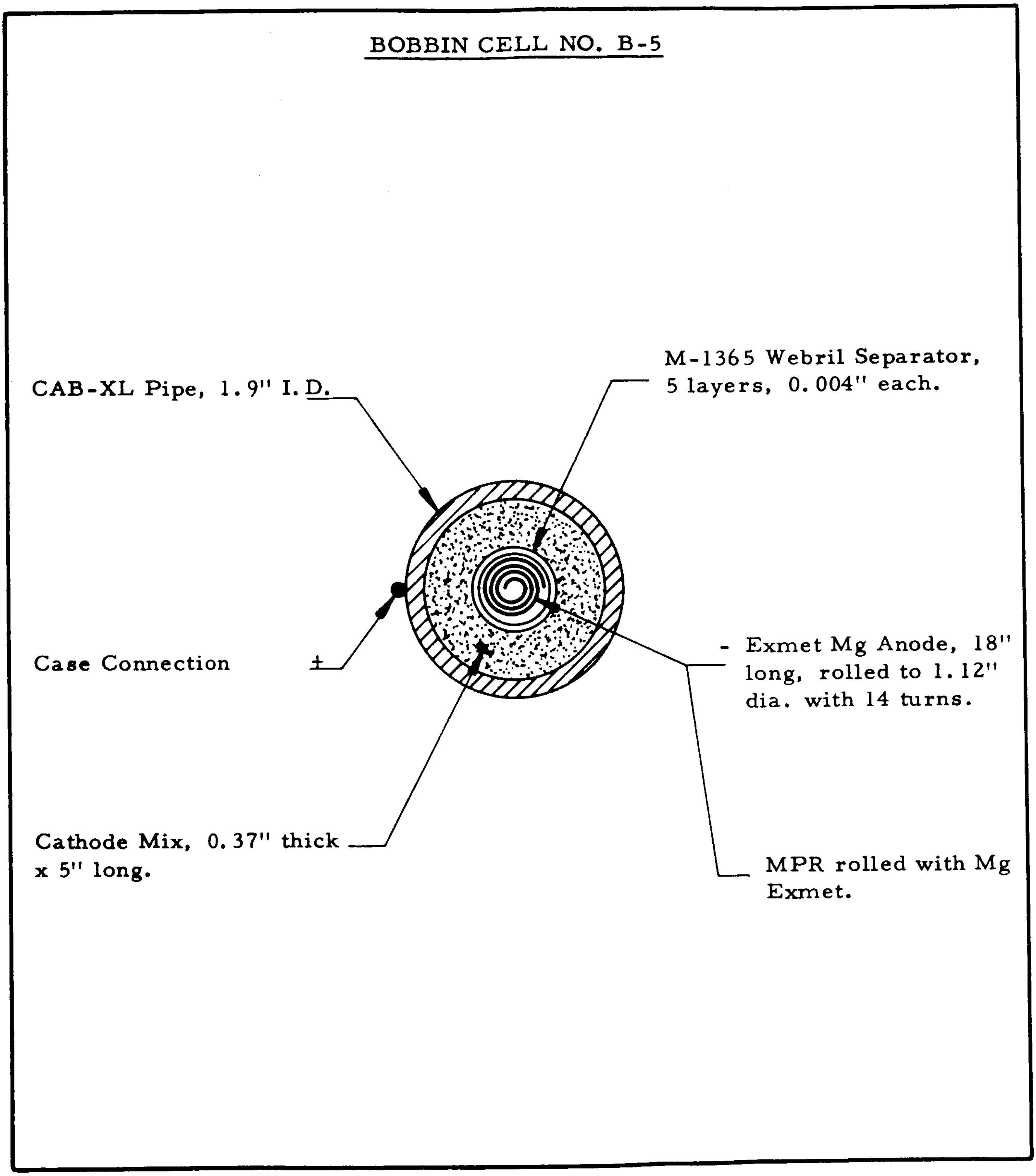
Figure 3

BOBBIN CELL NO. B-4




FORM FM-100

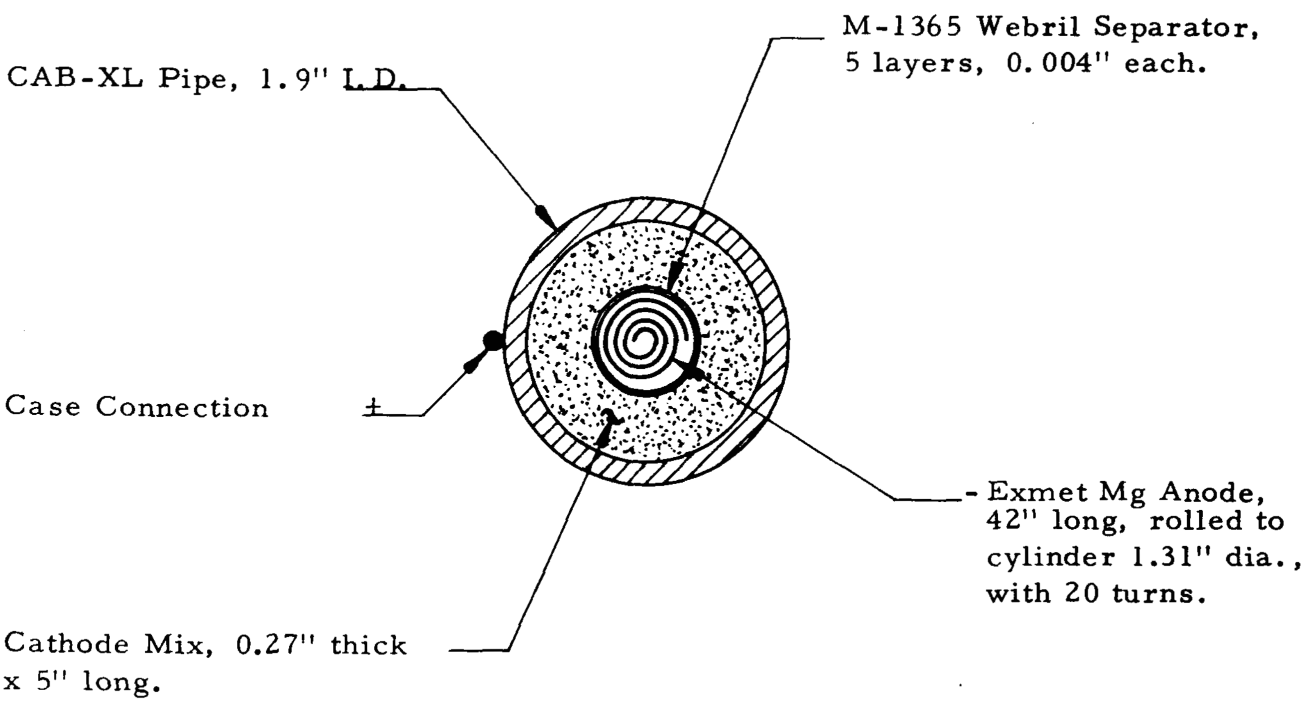
Figure 4




FORM FM-100

Figure 5

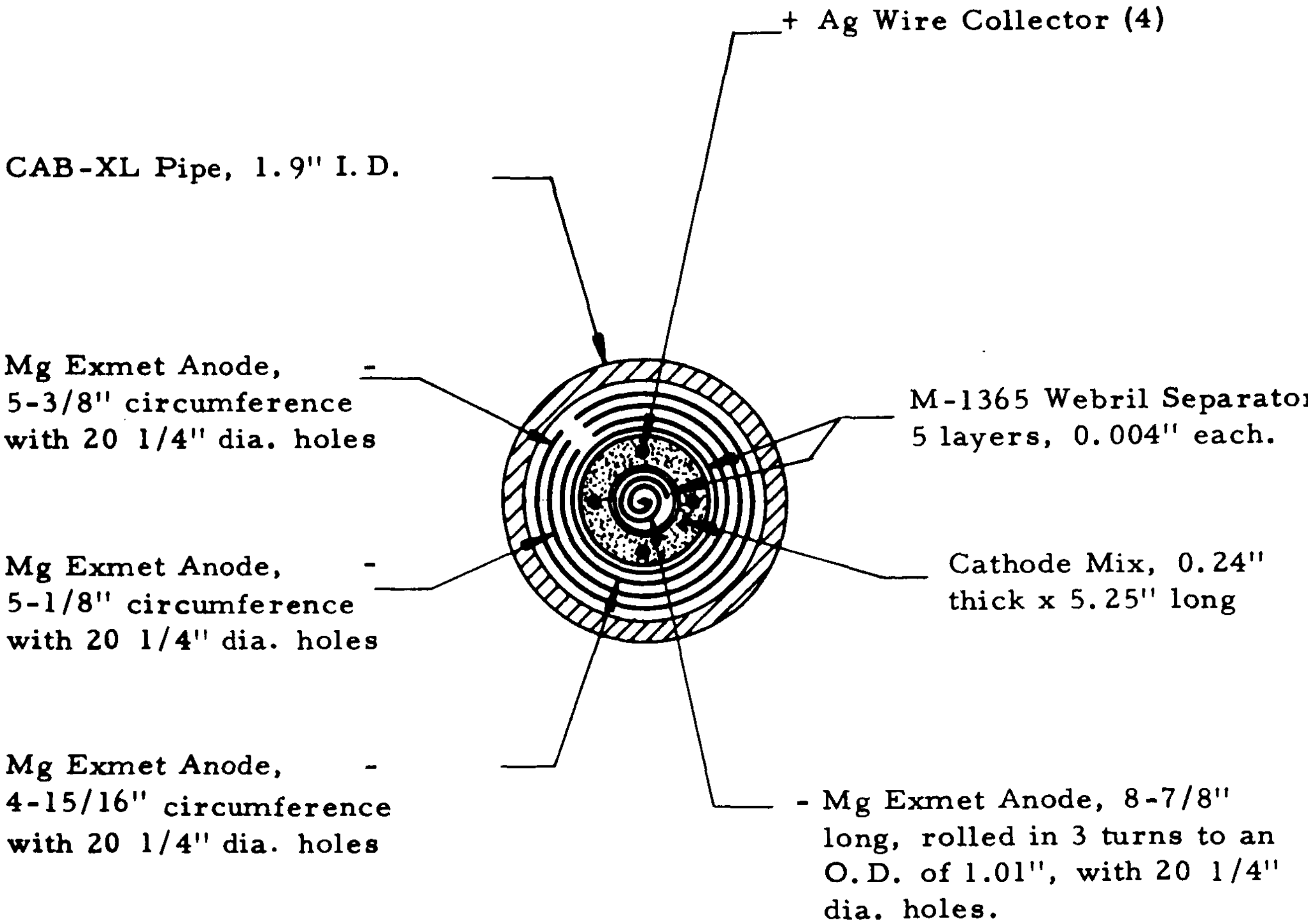
BOBBIN CELL NO. B-6




FORM FM-100

Figure 6

BOBBIN CELL NO. B-7

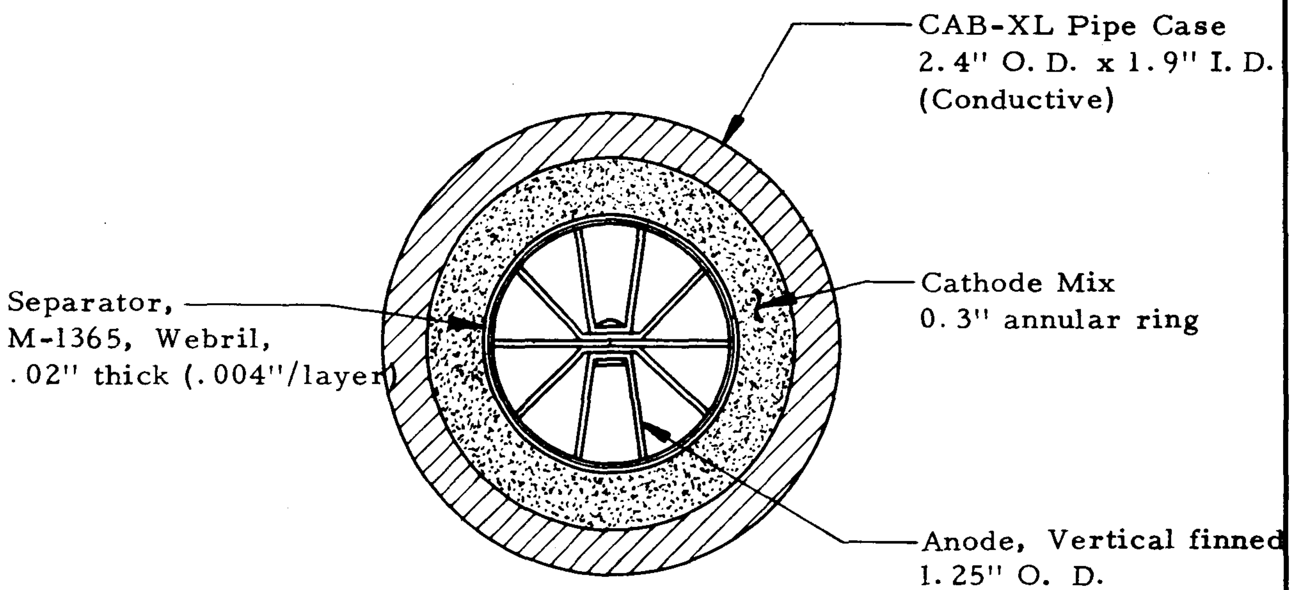



FORM FM-100

Figure 7

BOBBIN CELL NO. B-15

(thru present)




FORM FM-100

Figure 8

## 2. BOBBIN CELL CONSTRUCTION

A variety of designs were tried in the early stages until one suitable for most of the experimental work of Task I was devised. Upon completion of the first task, "Task II, Design" was carried to conclusion. In this, a self-contained ammonia cell in full hardware, excluding activator, was designed.

### 2.1. Task I, Experimental Cells

All of these cells had open tops. Some were full-length; some, half-length. The cell assembly is shown in Figure 9, page 43; the anode design, in Figure 10, page 44; and a cross-sectional view, in Figure 8 of Appendix B, page B-9. The construction steps follow in sequence:

1. Five (5) layers of M-1365 Webril separator paper are wrapped around a 1-1/4 inch diameter mandrel. The paper is folded over at the bottom to form a cylindrical cup, and all seams are sealed with acetone.

2. The anode is fabricated as shown in Figure 10, page 44.

3. A metal plug is pressed into a bottom of the plastic case.

4. The separator cup with mandrel in place is placed in the center of the case, and the cathode mixture is packed between the separator and the wall of the case in ten increments with a piston which fits the annular space. Each increment is packed to occupy 1/10 of the total cathode depth.

5. The mandrel is then removed from the separator cup and is replaced by the anode with its negative connection.

6. The positive connection is made by soldering a wire to several adjustable bands attached to the outside of the conductive plastic case. Seven clamps are used on full-sized cells; four, on the half-sized ones.

### 2.2. Task II, Design

This cell, a refined version of the experimental cell with a top as well as a bottom closure, is detailed in drawings B-1227, B-1228, A-1238, and A-1239 which are supplemented with a Parts and Materials List. These illustrations follow this construction procedure. The parts numbers will be shown in parentheses where appropriate. After all parts have been made, they are assembled in the following sequence:

1. The bottom metal plug (3) (silicone primed) is pressed into position in the plastic case (1), and disc (19) is inserted.

2. The hole in the bottom plug is stoppered, and then a silicone encapsulant (18) is poured onto the plug to a depth of 1/4 inch. After a 16 hour curing period, the stopper is removed.

3. Five layers of M-1365 Webril separator paper (8) are wrapped around a 1-1/4 inch diameter arbor and sealed with acetone. In the bottom end, a polypropylene disc (15) and a microporous rubber disc (16) are inserted. Then, the separator is folded over at the bottom and sealed, after which a second disc (15) is placed over the end. This separator cup with arbor in place is inserted in the case.

4. The cathode mixture (7) is packed between the separator and the case in ten increments with a hollow cylindrical piston. Each increment is packed to occupy 1/10 of the total cathode length.

5. The arbor is replaced by the anode (6), the bottom 1/4 inch diameter extension of which is insulated with a nylon sleve (17).

6. A 1/4 inch layer of silicone rubber (14) is poured on top of the cathode mix and is allowed to cure.

7. This is followed by a polypropylene spacer ring (13).

8. The top plug (2), with an insulating disc (12), is pressed into place.

9. Hose clamps (10) are then placed on the case and tightened. The end ones help to hold the plugs in place. The others, to which a silver wire (11) has been soldered, serve as current collectors.

10. A stainless steel male half union (5) for the electrolyte fill port and a nylon male half union (4) to insulate the extension of the anode from the metal plug and case are then inserted and tightened.

11. The finished cell is carefully tested for leaks under pressure. If free from leaks, it is ready for activation.

B-1227

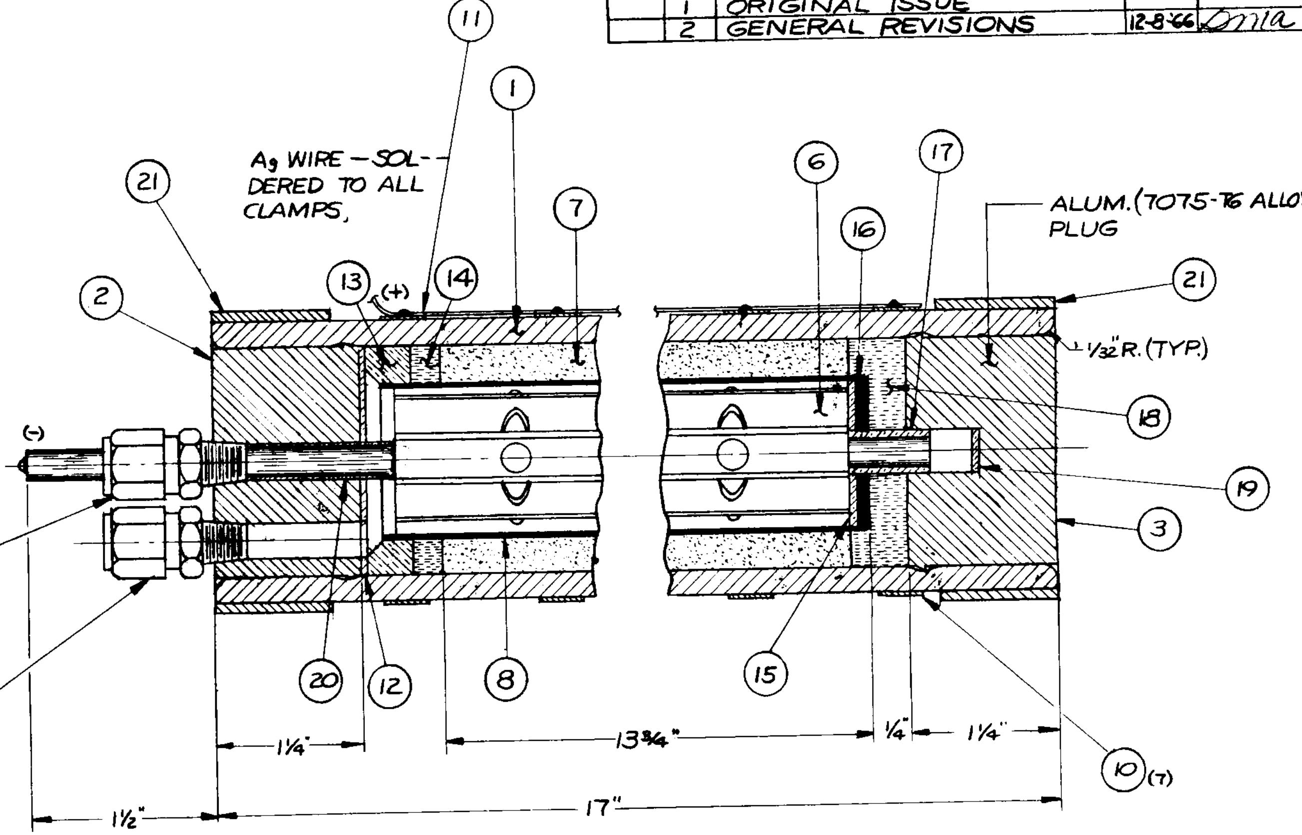
- NYLON OR POLYPROPYLENE
- SILICONE RUBBER
- CATHODE MIX
- SEPARATOR, WEBRIL M-1365
- MPR-SEALED TO SEPARATOR WITH ACETONE

ELECTOLYTE:
34 WT. % KSCN/$NH_3$ (ℓ) (9)

CATHODE MIX:

| | |
|---|---|
| $HgSO_4$ | 20 gr. |
| SULFUR | 96 gr. |
| GRAPHITE | 77 gr. |
| ACETYLENE BLACK | 19 gr. |
| TOTAL | 212 gr. |

ANODE:
MAGNESIUM, AZ31-B




| REVISION | | | | |
|---|---|---|---|---|
| ZONE | NO. | DESCRIPTION | DATE | APPROVED |
| | 1 | ORIGINAL ISSUE | | |
| | 2 | GENERAL REVISIONS | 12-8-66 | GMA |

CONTRACT NAS3-8503

UNLESS OTHERWISE SPECIFIED:
DECIMALS ± .005
ANGLES ±
FRACTIONS ± 1/16"
~~MATERIAL~~
WEIGHT ± 1 gr.
PERCENT ± 0.5

| | DATE | SIG. |
|---|---|---|
| DRAWN | 9/9/66 | AJG |
| CHECKED | 9/20/66 | [illegible] |
| APPROVED | 9/20/66 | GMA |

| NEXT ASS'Y | USE ON |
|---|---|
| APPLICATION | |

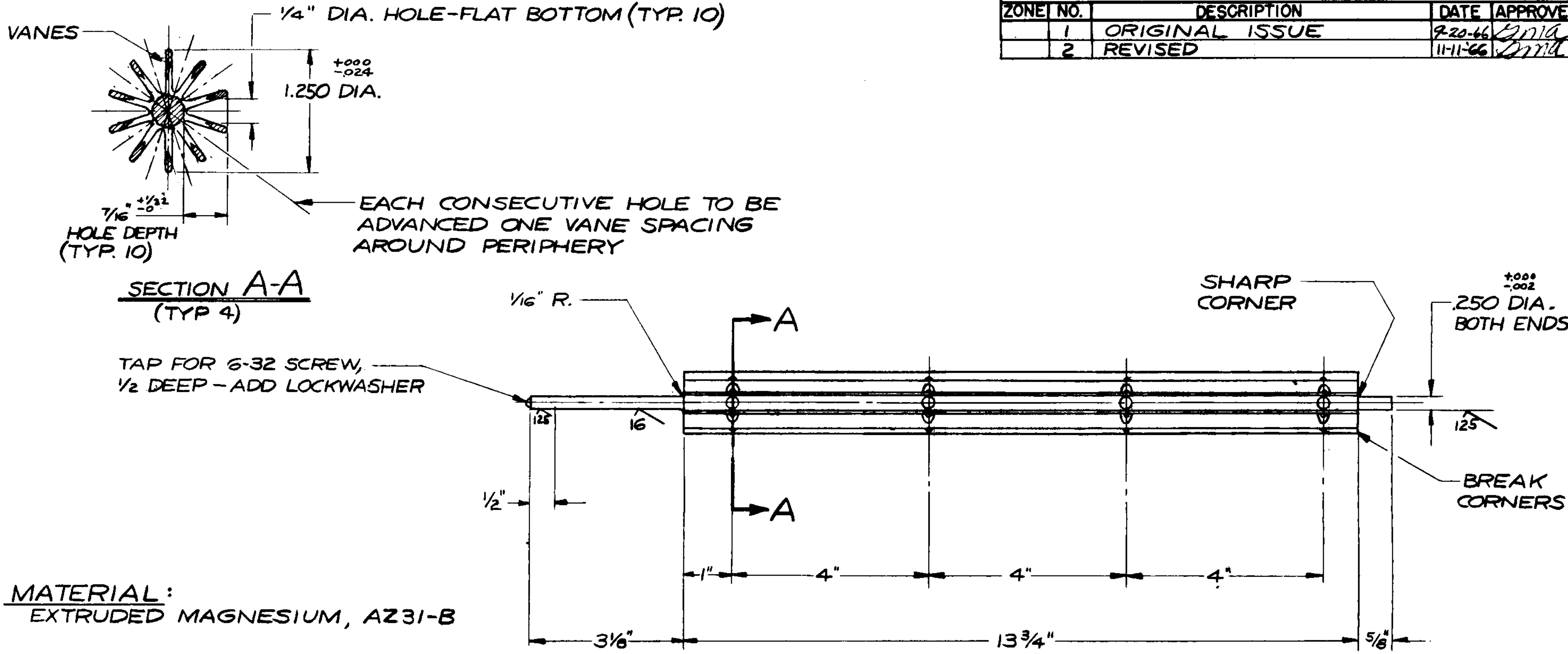
LIVINGSTON ELECTRONIC CORP.
MONTGOMERYVILLE, PENNA.

LOW TEMPERATURE AMMONIA BATTERY
— DESIGN LAYOUT —

SIZE B | CODE IDENT. | B-1227 | 2
SCALE 1/1 | SHEET

FORM FM-110

| REVISION | | | | |
|---|---|---|---|---|
| ZONE | NO. | DESCRIPTION | DATE | APPROVED |
| | 1 | ORIGINAL ISSUE | 9-20-66 | GMA |
| | 2 | REVISED | 11-11-66 | GMA |




MATERIAL:
EXTRUDED MAGNESIUM, AZ31-B

CONTRACT NAS 3-8503

| | | |
|---|---|---|
| NEXT ASS'Y | USE ON | |
| APPLICATION | | |

UNLESS OTHERWISE SPECIFIED:
DECIMALS ± .005
~~ANGLES~~ ±
~~MATERIAL~~
FRACTIONS ± 1/16"

| | DATE | SIG. |
|---|---|---|
| DRAWN | 9/9/66 | AJG |
| CHECKED | 9/20/66 | GLB |
| APPROVED | 9/20/66 | GMA |

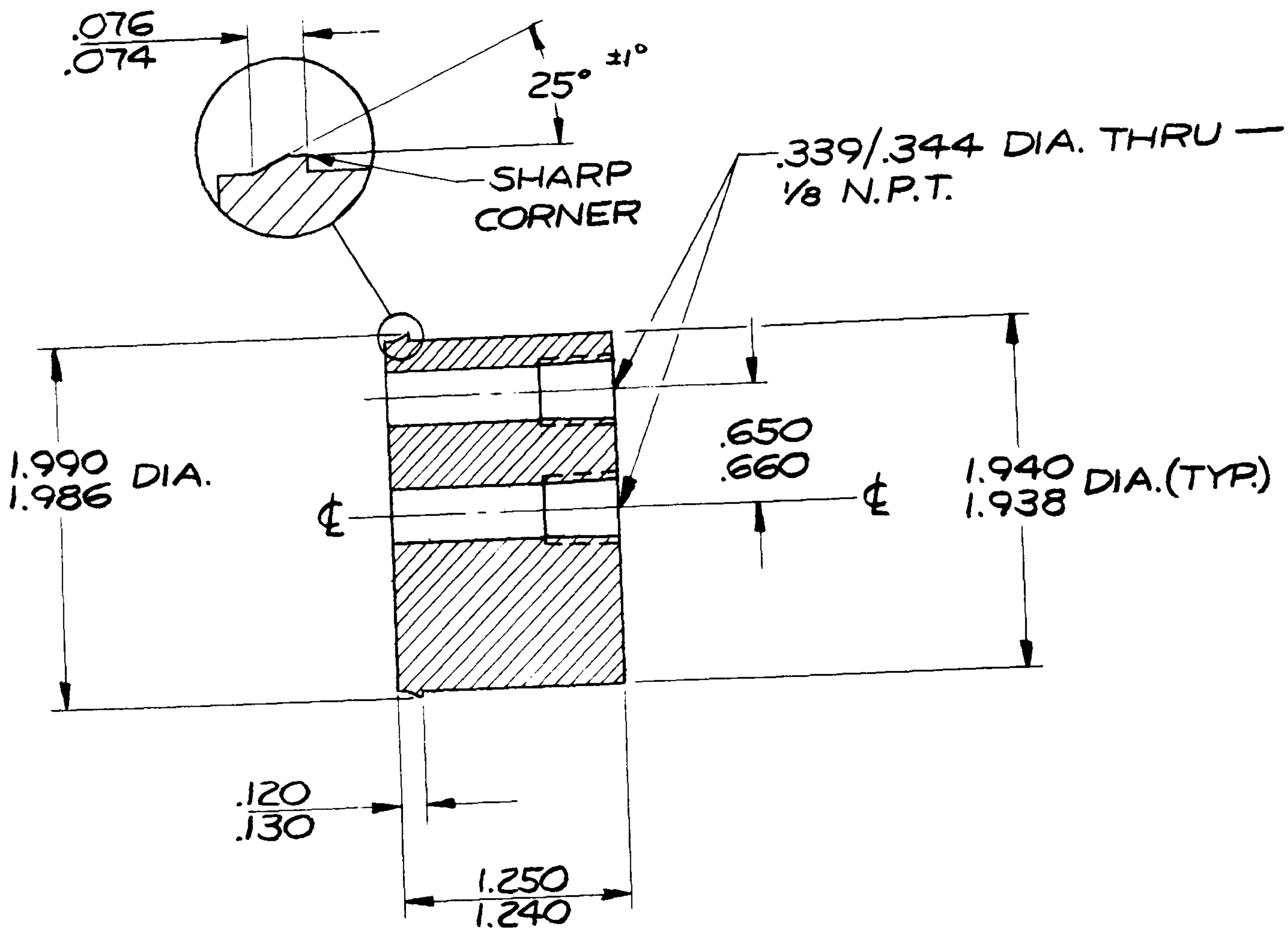
LIVINGSTON ELECTRONIC CORP.
MONTGOMERYVILLE, PENNA.

ANODE

| SIZE | CODE IDENT. | |
|---|---|---|
| B | | B-1228 2 |
| SCALE 1/2 | | SHEET |

FORM FM-110

A-1238 .2




CONTRACT NAS3-8503

| ISSUE | REVISION | BY | DATE | APPR |
|---|---|---|---|---|
| 2 | REDRAWN, REVISED | AJG | 11-11-66 | GMA |
| 1 | ORIGINAL ISSUE | AJG | 9-20-66 | GMA |

TOLERANCES UNLESS OTHERWISE SPECIFIED:
FRACTIONS ±
DECIMALS ±
ANGLES ±

NEXT ASS'Y

**LIVINGSTON ELECTRONIC CORP.**
MONTGOMERYVILLE, PENNSYLVANIA

| DRAWN | DATE | CHECKED | DATE | APPROVED | DATE |
|---|---|---|---|---|---|
| AJG | 11-11-66 | JSG | | GMA | 11-21-66 |

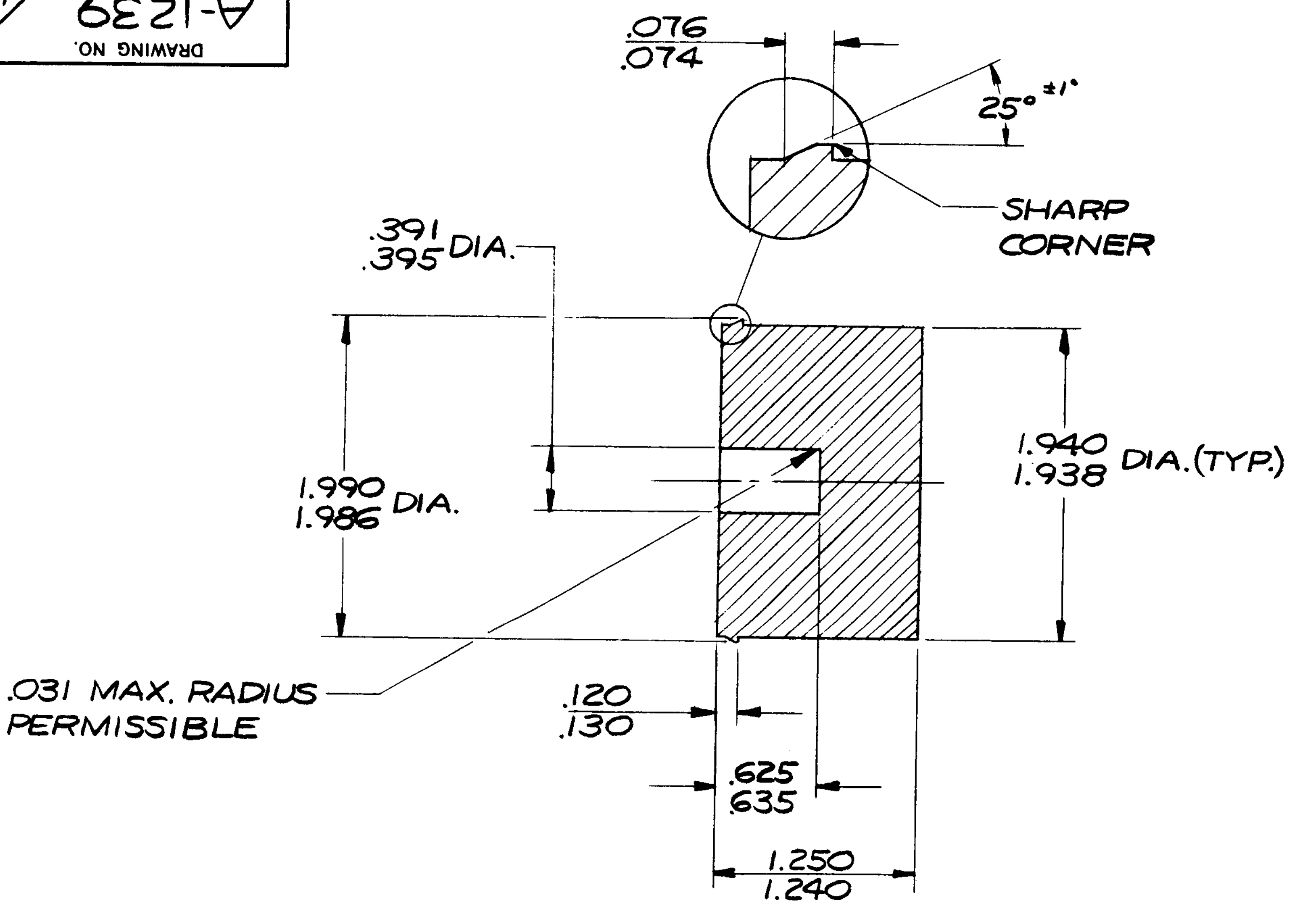
MATERIAL ALUMINUM, 7075-T6

FINISH 125

| SCALE | TITLE | DRAWING NO. |
|---|---|---|
| 1/1 | PLUG —TOP— | A-1238/2 |

FORM FM-113

DRAWING NO. A-1239 1




DO NOT SCALE DRAWING

CONTRACT NAS3-8503

| ISSUE | REVISION | BY | DATE | APPR |
|---|---|---|---|---|
| 2 | REDRAWN & REVISED | AJG | 11-16-66 | GMA |
| 1 | ORIGINAL ISSUE | AJG | 9-20-66 | GMA |

TOLERANCES UNLESS OTHERWISE SPECIFIED:
FRACTIONS ±
DECIMALS ±
ANGLES ±

NEXT ASS'Y

**LIVINGSTON ELECTRONIC CORP.**
MONTGOMERYVILLE, PENNSYLVANIA

| DRAWN | DATE | CHECKED | DATE | APPROVED | DATE |
|---|---|---|---|---|---|
| AJG | 11-16-66 | JLK | | GMA | 11-21-66 |

MATERIAL: ALUMINUM, 7075-T6

FINISH (WHERE NOT SPEC.) 125

SCALE 1/1 | TITLE PLUG —BOTTOM—

DRAWING NO A-1239 2

FORM FM-113

# PARTS AND MATERIALS LIST

Project #652 | Prepared By J. S. Gore | Approved By G. M. Armstrong

Contract NAS 3-8503 | Date September 20, 1966 | Date September 20, 1966

| Part No. | Req. | Item Description |
|---|---|---|
| 1 | 1 | Plastic Pipe - CAB-XL, 2" I. P. S. sch. 80; Cabot Corporation, Louisville, Ky. |
| 2 | 1 | Top Plug - Aluminum alloy 7075-T6 (Dwg. No. A1238); Metal Supply Co., Philadelphia, Pa. |
| 3 | 1 | Bottom Plug - Aluminum alloy 7075-T6 (Dwg. No. A1239); Metal Supply Co., Philadelphia, Pa. |
| 4 | 1 | Nylon Insulator - Nylon male half union, 1/4" tubing to 1/8" N. P. T.; Crawford Fitting Co., Solon, Ohio |
| 5 | 1 | Fill Port - Stainless steel male half union, 1/4" tubing to 1/8" N. P. T.; Crawford Fitting Co., Solon, Ohio |
| 6 | 1 | Anode - Extruded magnesium, alloy AZ31-B (Dwg. No. B1228); White Metal Rolling and Stamping Corporation, Brooklyn, N. Y. |
| 7 | 1 | Cathode - Dry packed powder |
| | | a. Mercuric sulfate - A. R. Grade; Mallinckrodt Chemical Works, St. Louis, Mo. |
| | | b. Sulfur - Sublimed; Matheson Co., Inc., E. Rutherford, N.J. |
| | | c. Carbon - Air spun graphite, Type 200-44; Joseph Dixon Crucible Co., Jersey City, N.J. |
| | | d. Carbon - Acetylene black; Shawinigan Products Corp., Englewood Cliffs, N. J. |
| 8 | 1 | Separator - Webril M-1365, acetate-cotton fabric; Kendall Co., Walpole, Mass. |
| 9 | 1 | Electrolyte - 34 weight percent KSCN in $NH_3$ (L) |
| | | a. KSCN - Reagent B & A Code 2144; Allied Chemical Co., New York, N. Y. |
| | | b. $NH_3$ (L) - Anhydrous; National Ammonia, Philadelphia, Pa. |
| 10 | 9 | Clamps - Stainless steel size #32; Ideal Corporation, Brooklyn, N. Y. |
| 11 | 1 | Connection - #18 AWG silver wire soldered to 7 clamps; T. B. Hagstoz & Sons, Philadelphia, Pa. |
| 12 | 1 | Insulator Disc - .040" polypropylene drilled for fill port and anode rod; Commercial Plastics and Supply Corporation of Penna., Philadelphia, Pa. |

# PARTS AND MATERIALS LIST

Project #652 Prepared By J. S. Gore Approved By G. M. Armstrong

Contract NAS 3-8503 Date September 20, 1966 Date September 20, 1966

| Part No. | Req. | Item Description |
|---|---|---|
| 13 | 1 | Spacer Ring - 1.875" O.D. x 1.300" I.D. x .375" high polypropylene; Commercial Plastics and Supply Corporation of Penna., Philadelphia, Pa. |
| 14 | 1 | Seal - Silicone rubber RTV 3110; Dow Corning Corp., Midland, Mich. |
| 15 | 2 | Disc - .040" polypropylene 1.250" O.D. x 0.375" I.D.; Commercial Plastics and Supply Corp. of Penna., Philadelphia, Pa. |
| 16 | 1 | Disc - .040" microporous rubber; American Hard Rubber Co., Butler, N.J. |
| 17 | 1 | Insulator Sleeve - Nylon 0.375" O.D. x 0.250" I.D. x 0.687" long; Commercial Plastics & Supply Corp. of Penna., Philadelphia, Pa. |
| 18 | 1 | Shock Absorber - Silicone rubber RTV 3110; Dow Corning Corp., Midland, Mich. |
| 19 | 1 | Disc - .040" polypropylene 0.531" dia.; Commercial Plastics and Supply Corp. of Penna., Philadelphia, Pa. |
| 20 | 1 | Insulator Sleeve - Polyvinyl chloride 0.250" I.D. x 0.312" O.D. x 1" long; Commercial Plastics and Supply Corp. of Penna., Philadelphia, Pa. |

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