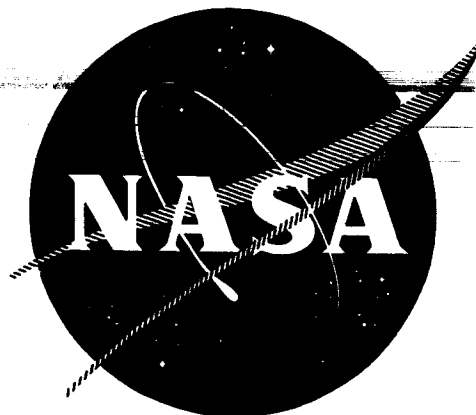




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FINAL REPORT

LOW TEMPERATURE BATTERY

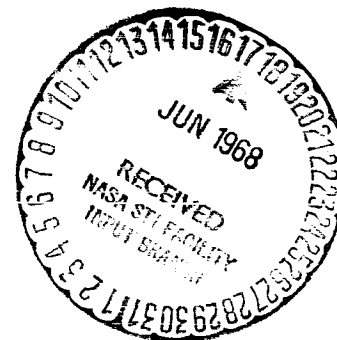
by

George M. Armstrong and Jon S. Gore

prepared for

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FINAL REPORT

14 December 1965 to 13 December 1967

LOW TEMPERATURE BATTERY

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

CONTRACT NAS 3-8503

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LOW TEMPERATURE BATTERY

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ABSTRACT

A low temperature, electrochemical, ammonia cell in hardware, excluding activator, has been developed with the capability of delivering 1.5 watts for six minutes and 0.3 watts for fifty-four minutes each hour, alternating continuously for a minimum of seventy-two hours to an end voltage of 1.5 at -73°C . The system employed was $\text{Mg/KSCN-NH}_3/\text{HgSO}_4:\text{S}$.

Representative groups of cells met the requirement after inactive stand at temperatures of $+20$ to 25° , -20° and $+65^{\circ}\text{C}$ for periods up to six months.

The environmental test requirements for vibration, acceleration, shock and acoustic noise were met by all of fourteen cells selected at random.

The best results obtained in hardware were as follows: 148 hours at $+20^{\circ}$, 44 hours at -20° , 58 hours at -40° , 90 hours at -73° and 88 hours at -90°C to a 1.5 volt cut-off under heavy load.

SUMMARY

The purpose of this program was to develop a self-contained, low temperature cell, excluding activator, based upon the battery system: $\text{Mg/KSCN-NH}_3/\text{HgSO}_4:\text{S}$. The capability of operating for at least 72 hours at -73°C with an alternating hourly discharge cycle of 0.3 watts for 54 minutes and 1.5 watts for 6 minutes was required. The desired discharge temperature range was $+20$ 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 had been achieved, full hardware was designed and evaluated. This was followed by the design modifications dictated by the results of test programs required by the contract.

A. Prismatic Cell Experiments

1. Separation: No. M-1365 Webril non-woven fabric 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.
2. Electrolyte Studies: Thirty-four (34) weight percent KSCN in liquid ammonia is a satisfactory electrolyte for use at -90°C and was adopted for use over the entire temperature range.

A number of other salts were examined for solubility and freezing characteristics in liquid ammonia at -87°C . Only lithium tetrafluoroborate and hexafluorophosphate appeared to be suitable candidates for further study.

3. 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°C and -40°C . Gold-plated copper Exmet or aluminum Exmet is recommended for use in this type of cell, especially at the higher temperatures.
4. Cathode Composition: Numerous combinations of components, including HgSO_4 , sulfur, graphite, acetylene black and paper pulp, were tested in prismatic cells. The best composition

on the average for discharge at -90°C appeared to be that containing 70 percent sulfur and 30 percent graphite.

5. 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.
6. 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:
 - a) Single-sided discharge employing only one working anode and cathode thicknesses of $1/8$ and $1/4$ inches.
 - b) Multiple anodes and cathodes with all anodes stacked on one side and all cathodes on the other, rather than in the conventional alternate method of stacking.
 - c) Cells containing reference electrodes, and
 - d) 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.

7. Resistance and Capacitance: Measurements were made on numerous cells. Three observations were made:
 - a) The origin of the capacitance values obtained appeared to be concentrated in the anode.
 - b) The addition of HgSO_4 to the cathode seemed to reduce the anode polarizing film substantially.
 - c) Capacitance values decrease markedly near the end of cell life.

B. Bobbin Cell Design, Construction and Testing

1. Task I. A., Preliminary Designs: 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 separator and a conductive case. The space between the fins served as an electrolyte reservoir. For convenience, all cells prior to the design of complete hardware and many of those built after this for special investigations were vented to the atmosphere during discharge.
 - a) 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 percent KSCN in liquid ammonia when the attempts to synthesize it were unsuccessful.
 - b) 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:

<u>Discharge Temp., °C</u>	<u>Hours to*</u>	
	<u>1.5V</u>	<u>1.3V</u>
-90	97	110
-63	158	176
-40	97	127

*Under heavy load.
2. Task I. B., Proposed Design: 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 preceding experimental work, and the formulation was that shown in No. 1, since No. 2 had not yet been developed. Upon discharge, an average life of 64 hours to 1.3 volts was achieved.

3. Task II, Design: A self-contained ammonia cell in hardware, excluding activator, was designed to meet the specifications of Task II for the purpose of building a number of such cells for test or delivery to NASA. The system, $\text{Mg/KSCN-NH}_3/\text{HgSO}_4\text{:S}$, including the design drawings and the cathode formulation (No. 2), page iv, was proposed and approved.
4. 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 under heavy load. Subsequent cells ran 88 hours initially: after a one week inactive stand at $+65^\circ\text{C}$, they ran 84 hours. In another set of cells, the anode was changed from a fabricated type to an extrusion, and the end plug design was improved. Tests similar to the preceding ones yielded 89 hours with no initial stand period and 79 hours after a one week stand at $+65^\circ\text{C}$.
5. Task IV, Manufacture and Test Cells: The design of Task III. B. was used in the construction of 58 cells for testing.
 - a) IV. A., Environmental Tests: The abstract of the report on environmental testing stated that there was no evidence of physical damage and that the resistance value exhibited throughout the tests was infinity. The discharge characteristics were affected little if at all by the tests.

Cells in groups of three were placed on inactive shelf stand under a variety of conditions and discharged at the temperatures specified. The discharge life to 1.5 volts final of each group is given for each stand test, as follows:

Task No.	Shelf Storage	Average Cell Life in Hours to 1.5 VF				
		Under Heavy Load at:				
		$+20^\circ\text{C}$	-20°C	-40°C	-73°C	-90°C
IV. B.	1 month at $+20$ to $25^\circ*$	93	42	46	60	74
IV. C.	6 months at $+65^\circ$				74	
IV. C.	6 months at -20°				81	

*Incomplete activation partly responsible for shorter cell life of IV. B. as compared with IV. D.

Task No.	Shelf Storage	Average Cell Life in Hours to 1.5 VF Under Heavy Load at:				
		+20°C	-20°C	-40°C	-73°C	-90°C
IV. D.	3 months at +20 to 25°	141	43	56	82	84
IV. E.	3 months at +20 to 25°, plus 3 months at +65°				80	
IV. E.	3 months at +20 to 25°, plus 3 months at -20°				85	

6. Special Studies: During the six months stand period of Task IV, the following areas were investigated:

- a) Methods of activation,
- b) Cell life at -20 and -40°,
- c) Methods of collecting current from the cases,
- d) Increases in temperature and pressure during cell discharge, and,
- e) Corrosion of aluminum alloy top plugs.

The activation procedure must insure the delivery of a definite quantity of electrolyte to each cell.

A limited number of experiments indicated that cell life at -20°C could be extended from 42 to about 55 hours by dissolving sulfur or a proprietary additive in the electrolyte. Further study would be required to improve cell life at these temperatures.

Satisfactory electrical contact between the case and the collector wire can be achieved by tightly clamping with a minimum of three adjustable bands.

The increase in cell temperature during discharge was negligible. An increase of a maximum of 10 degrees was observed at room temperature discharge.

The pressure increase is dependent upon the cell free space. A minimum of 45 cc of free space is required to ensure a maximum pressure of 600 pounds per square inch at room temperature. The greatest cell pressure is developed at the highest test temperature.

Corrosion of the aluminum alloy top plugs was eliminated by anodizing.

7. Task V, Manufacture Cells for Test and Delivery to NASA: The cell design was modified to allow more gas space and thereby to reduce operating pressures, and the means of collecting current was changed. Fifteen cells were built. After a two weeks stand at +20 to 25°C, groups of two were discharged over the temperature range with the following results: 139 hours at +20°, 40 hours at -20°, 57 hours at -40°, 90 hours at -73° and 72 hours at -90°C.

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1. INTRODUCTION

Due to freezing of the solvent, conventional aqueous batteries cannot perform at extremely cold temperatures unless they are heated externally; hence, the need for a power source to meet the conditions that are being encountered in space probe applications.

The purpose of this program (under a two year contract) was 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 to 1.5 VF (volts final). The first task was to devise methods of extending performance at -90°C from the one day previously achieved in Contract NAS 3-6009 to at least three days to 1.3 VF. In that contract, it was found that the system $\text{Mg/KSCN:NH}_3/\text{HgSO}_4\text{:S:C}$ provided 27 hours to a cut-off of 1.3 volts in a conventional bobbin cell (No. T-119) and 13 hours under the full cyclic load in a prismatic cell (T-132) which featured large cathode area but only 1/5 the required cathode weight. An electrolyte concentration of 34 percent KSCN in liquid ammonia is suitable for use at -90°C , as well as at higher temperatures. Prismatic cells were built and tested initially to establish the best parameters necessary for long life. The next step comprised the 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. This investigation was followed by 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 composition and electrolyte concentration and type.

After satisfactory operation in excess of 72 hours to 1.3 VF at -90° had been achieved with both the prismatic and bobbin configurations, a self-contained ammonia bobbin cell was designed for the purpose of fabricating a number of such cells for test and delivery to NASA, as required in Task II.

This design was evaluated in Task III by testing five such cells at -73°C . Two of the cells were subjected to inactive shelf storage at $+65^{\circ}\text{C}$ for one week prior to discharge. After some design modifications, a second set of five cells was tested in the same manner as the first set. The life of each of the ten cells was greater than the goal of 72 hours.

In Task IV, fifty replicate cells were constructed and divided at random into fourteen groups of three each and one lot of eight. One cell from each group of three was subjected to environmental tests, including vibration, acceleration, shock and acoustic noise, after which each cell was returned to its original group. The cells were then placed in inactive shelf storage at the specified temperatures of +20 to 25°, -20° or +65°C for periods up to six months. At the conclusion of the various periods of stand, the cells were activated and discharged at the temperatures designated in the contract. The 72 hour requirement was achieved at +20, -73 and -90°C, but the best cells that were discharged at -20 and -40°C ran only 44 and 56 hours, respectively.

Further modifications were made in the design for use in Task V, after which fifteen cells were built. Five groups, of two each, were discharged over the temperature range of +20 to -90°C. As in Task IV, the 72 hour goal was met or exceeded at +20, -73 and -90°, but the cell life averaged only 40 hours at -20° and 57 hours at -40°. The reasons for the shorter life at the two intermediate temperatures have not been determined.

The test conditions and results are summarized in the tables of Appendix A, along with the Notes to the Tables and Materials Identification. The cell designs are described in Appendix B with sketches, drawings, methods of construction and a Parts and Materials List. In addition, the method of preparation of electrolyte and selected pages from the Associated Testing Laboratories' report on the environmental tests are included.

2. TASK 1, -90°C STUDY AND TEST

The first task of this program comprised two parts and had as its objective the extension of ammonia cell operation at -90° from the one day previously achieved in Contract NAS 3-6009 to the goal of at least seventy-two (72) hours. Part A was an experimental investigation of the problem. Part B required the construction and testing of the type of cell most likely to meet the objective.

2. 1. Task I. A., Recommended Methods for Extending Ammonia Cell Operation at -90°C from One Day to the Goal of 72 Hours.

Prior to the experimental work, a study was made, and the following five methods of attack were submitted to the Project Manager for his consideration:

Method 1 - The development of prismatic cathode construction.

Method 2 - The collection of basic data on the physical and physico-chemical properties of cell components. Resistance measurements, polarization scans, chemical analyses, microscopy, vapor pressures and calorimetric determinations would be considered.

Method 3 - The exploration of other electrolyte solutes in ammonia, other oxidants, ion exchange membranes and separators.

Method 4 - The modification of bobbin-type cathode construction.

Method 5 - The evolution of better approaches to the study of the influence of geometry on cell operation.

Initially, the contractor was authorized by the Project Manager to begin the experimental activities of the "Minus 90°C Study and Test" task through the use of Methods 1 and 4.

The other methods were considered to be relevant but of lower priority than 1 and 4.

2. 2. Task I. A., Experimental Investigation

In Contract NAS 3-6009 (CR-54733), a prismatic cell (No. T-132) ran at -90° for 13 hours under the full cyclic load but with only 1/5 the required cathode weight. It seemed logical that the cell life could be extended greatly by either a five-fold increase in weight or a reduction in electrical loading to 1/5 the full load. It was decided, therefore, to initiate the studies with this configuration. This was followed by numerous special designs to aid in the transition to bobbin cells; and, finally, a bobbin type of cell was developed and tested extensively in order to evolve a unit with satisfactory electrical and mechanical characteristics.

2. 2. 1. Prismatic Cells

The work performed with this configuration is presented hereinafter. Supporting data are compiled in Appendix A, Table I, pages 66 - 87.

2. 2. 1. 1. Initial Cell Tests at -90°C

Cells P-1 and 2 were constructed with a prismatic cathode in a sealed separator. This unit was placed between two flat anodes, and a plastic envelope served as a case. A drawing and the method of construction may be found in Appendix B, pages 123 and 124. The cathode weight and the cyclic loading were 1/5 of those of a full-size cell. An average life of 61 hours to 1.3 volts was obtained with a $\text{HgSO}_4\text{:S:C}$ cathode.

In order to increase the operating life to at least 72 hours, a variety of experiments was designed to study the effects of separation, electrolyte volume, cathode collector materials, cathode composition, and plate thickness. Also, studies were made of methods of transition to the bobbin structure.

2. 2. 1. 2. Separation

A summary of some of the separator tests is given in Table I, page 5. The trial of a single (rather than a double) layer of SM-91 polypropylene fabric (Cells P3 & 4) reduced the life to 28 hours because of leakage at the seal and possibly through the fabric.

Cells 5 & 6, with a double layer of SM-91, should have run as well as 1 & 2. One reason for the inferior performance may be that the volume of electrolyte was too high. Other experiments (e.g., P-52 vs 7 to 10) have indicated that an excess of electrolyte is necessary but that its level should not extend above the electrical connections to the electrodes.

TABLE I

EFFECT OF TYPE AND THICKNESS OF SEPARATION ON CELL PERFORMANCECathode: HgSO_4 :Sulfur:Carbon = 5:1:3

Cell No. P-	Separator Thickness (in.)			Electrolyte Vol. (cc)	Ave. Hours* to 1.3V
	SM-91 ¹	M-1365 ²	MPR ³		
1 & 2	0.010	-----	-----	120	61
3 & 4	0.005	-----	-----	120	28
5 & 6	0.010	-----	-----	150	43
7 & 8	-----	0.020	-----	150	46
9 & 10	-----	0.020	-----	125	53
11 & 12	-----	0.008	0.030	125	50
53	-----	-----	0.060	150	117 ⁵
42	-----	-----	0.060	150	40 ⁵
51	-----	0.020	-----	150 ⁴	70
52	-----	0.020	-----	100	93
59	-----	0.028	-----	100	26
60	-----	0.028	-----	100	56

¹0.005" thick/layer.²0.004" thick/layer.³0.030" thick/layer.⁴100 cc initially; added 50 cc after 2 days, at which time the heavy load voltage recovered from 1.53 to 1.83.⁵Sealed MPR at edges.

*Under heavy load.

Microporous rubber, when used alone and sealed at the edges with rubber cement, provided a long life of 117 hours in one test, but only 40 hours in another. The reason for the difference was not obvious.

The M-1365 non-woven acetate and cotton separator absorbs the electrolyte very rapidly and is desirable for this reason. The table indicates a modest improvement through its use as the volume of electrolyte was

reduced from 150 cc to 125 cc and an increase to 93 hours with only 100 cc of electrolyte. The increase in thickness from 20 to 28 mils was detrimental, possibly because of increased resistance. The optimum was not established definitely because of the limited number of tests, but the 20 mil thickness was adopted as a suitable standard. This is made from 5 layers at 4 mils each.

2. 2. 1. 3. Electrolyte Studies

a. Concentration and Type: Twenty-five and 34 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 Table II.

TABLE II

EFFECT OF ELECTROLYTE CONCENTRATION AND KIND ON CELL LIFE

Cell No. P-	Cathode Composition		Electrolyte % as		Temp., °C	Hours to**	
	Sulfur %	Carbon %	Virgin	"Spent"*		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

*"Spent" electrolyte is the residual electrolyte from a similar cell after discharge.

**Heavy load.

***Aluminum Exmet collector grids; silver-plated copper Exmet in all other cells.

The S:C cells (P-131 and 132) ran at -63°C almost twice as long as P-125 which contained HgSO₄. Aluminum Exmet grids were used in these three

cells. At -90°C , P-128 and 129 ran well with "spent" electrolyte, but not as long as P-76 and 77 in which 34 percent KSCN was used.

The use of only 15 percent graphite in conjunction 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 1.5 V cut-off.

Therefore, the results are strongly in favor of the use of 34 percent KSCN in liquid ammonia as the electrolyte for prismatic cells having S:C cathodes. (Method of preparation, Appendix B, page 150.)

b. Volume and Level: The data of Table I, page 5, and of some later cell tests indicate 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 electrolyte level is too low, the cells suffer in life span. 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 permitted the use of a safe excess of electrolyte.

c. 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 in Table III, page 8.

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 only the last two of these salts have any potential value.

2. 2. 1. 4. Cathode Collector Grid Materials

The following materials were tested for use as cathode grids (described in Appendix A, Materials Identification, pages 63 and 64.)

Perforated aluminum plates

TABLE III

SOLUBILITY AND FREEZING CHARACTERISTICS OF SALTS OTHER THAN KSCN

<u>Salt</u>	<u>Concentration at -40°C</u>	<u>Observations at -87°C</u>
Lithium chloroaluminate (LiAlCl ₄)	Negligible	
Potassium chromate (K ₂ CrO 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 ₃ F)	30%	Solution froze.
Lithium tetrafluoroborate (LiBF ₄)	30%	Partial freezing - upper portion fluid.
Lithium hexafluorophosphate (LiPF ₆)	30%	Did not freeze.

Expanded metals (Exmet) - copper, silver, aluminum, lead, silver-plated copper and gold-plated copper.

There was no corrosion of the perforated Al plate, but the cathode paste did not adhere to it well. Ag-plated Cu Exmet was very satisfactory for use at -90°C; typical cell life of 111 hours to 1.3 volts was obtained. At higher temperatures, such as -63° and -40°, Cu, Ag and Pb were attacked severely; but Au-plated copper Exmet performed very well and corroded only slightly. Aluminum Exmet which was tested only at -63° provided longer life than any other metal. Our later experience with corrosion of aluminum alloy top end plugs at room temperature in bobbin cells suggest that it may be unsatisfactory for use at higher temperatures. The corrosion resistance of gold at temperatures above -40° was not determined.

2. 2. 1. 5. Cathode Composition

a. Cathodes With Mercuric Sulfate: 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 percent KSCN in liquid ammonia. Table IV contains the test results obtained with various combinations of HgSO_4 , S, and C.

TABLE IV
EFFECT ON PERFORMANCE OF VARIATIONS IN
THE RATIO OF SULFUR TO MERCURIC SULFATE

Cell No. P-	Mol ratio S: HgSO_4	HgSO_4 %	Sulfur %	Carbon %	Temp., °C	Hours to*	
						1.5V	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 Table VI, page 11.

b. Mg Anode Corrosion Losses: Since differences in the degree of anode corrosion had been observed, measurements were made on the anodes of several cells. After cells P-17 to 21 had been discharged, the anodes were removed, washed with light brushing to remove foreign deposits, dried and weighed to determine total loss of magnesium. The losses due to discharge were computed from the total coulombs generated. By deducting these losses from the total losses in each case, the corrosion losses were determined. A summary of the results follows in Table V.

TABLE V
EFFECT ON ANODE CORROSION OF VARIATIONS IN
THE RATIO OF SULFUR TO MERCURIC SULFATE

Cell No. P-	17	18	19	20	21
Oxidant	Mol Ratio of Sulfur:HgSO ₄				
	<u>100% S</u>	<u>4:1</u>	<u>2:1</u>	<u>1:1</u>	<u>100% HgSO₄</u>
Hours to 1.3V*	66	62	50	38	59
Hours on Discharge	109	109	110	87	87
<u>Mg Losses, % by Weight:</u>					
Due to Discharge	88.9	65.7	54.1	41.3	48.4
Due to Corrosion	11.1	34.3	45.9	58.7	51.6

*Under heavy load

It is noteworthy that HgSO₄ alone or in combination with sulfur is much more corrosive than sulfur.

c. Cathodes Without Mercuric Sulfate: In the following cells, mercuric sulfate was omitted and tests were designed to determine the optimum proportions of sulfur and graphite.

Table VI, page 11, and the accompanying graph, Figure 1, page 12, show the optimum composition of a S/C cathode for discharge at -90°C to be about 70 percent sulfur and 30 percent graphite.

Eighty-five percent sulfur appears to be better for discharge at -63°C.

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.

TABLE VI
EFFECT ON CELL LIFE OF VARIATIONS IN THE
PROPORTIONS OF SULFUR TO GRAPHITE

Cell No. P-	Sulfur %	Carbon %	Temp., °C	Hours to*	
				1.5V	1.3V
17,22,29,35	41.5	58.5	-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.

d. Acetylene Black and Paper Pulp: Acetylene black was substituted for part of the graphite in eight cells. Each met or exceeded the 72 hour requirement, but most of them did not run as long as similar cells containing no acetylene black. Refer to cells P-81 to 84 and 89 to 92, in Appendix A, pages 79 to 81.

Likewise, paper pulp was not a useful additive. Most of these cells (P-85 to 88) ran very well but did not outperform cells having no additive.

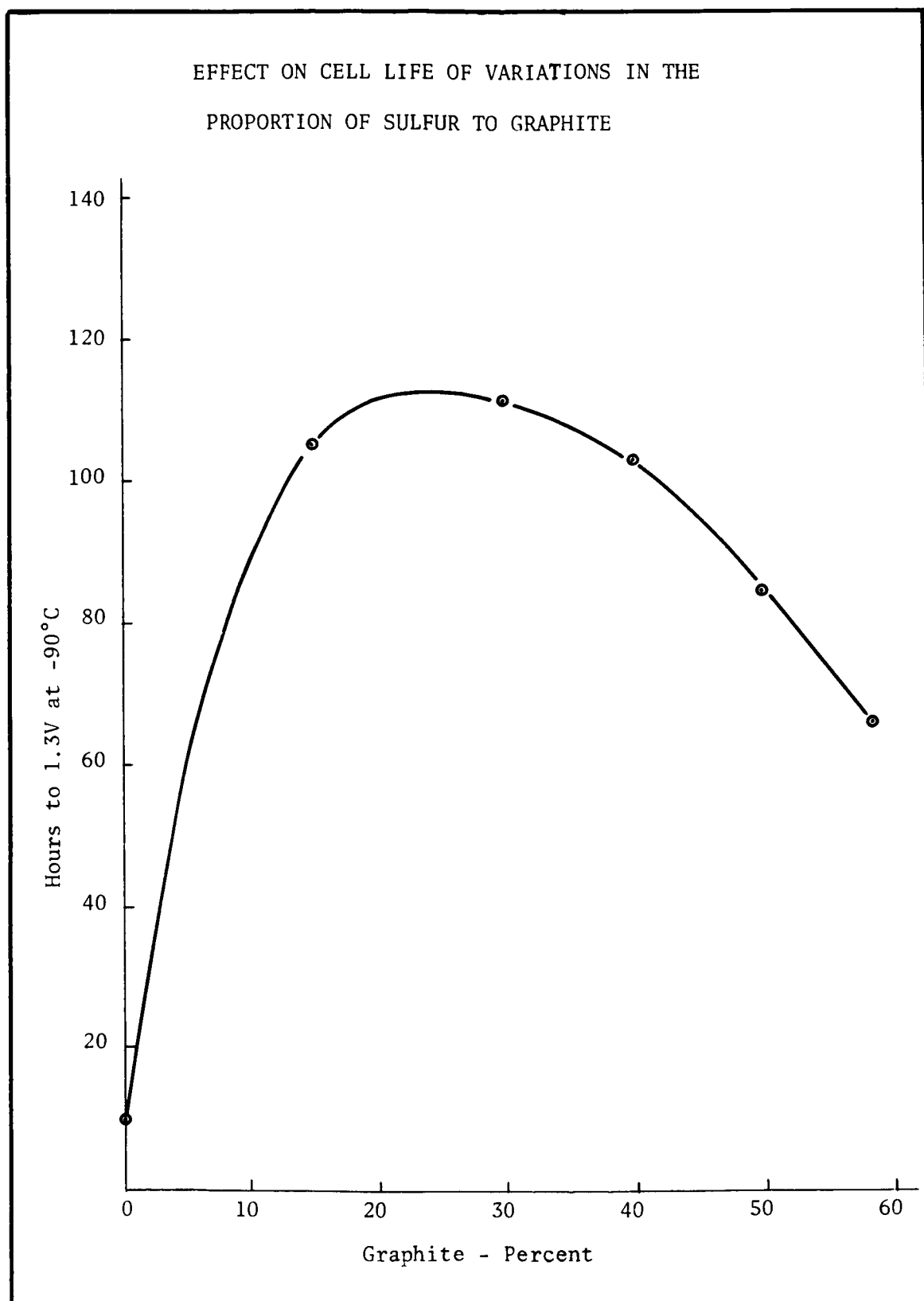


FIGURE 1

2. 2. 1. 6. 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 VII, 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 VII
EFFECTS OF POSITIVE ELECTRODE THICKNESS
AND CURRENT DENSITY ON PERFORMANCE

Cell No. P-	Thickness inch	HgSO ₄ g	Sulfur /g	Carbon /g	Loads, ohms	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**	5	1	3	48/240	0.22	49
47	1/16**	5	1	3	48/240	0.22	48
61	1/16***	5.95	1.19	3.57	48/240	0.22	82

*Under heavy load.

**Just enough paste to fill pores of collector grid.

***Grid surface covered somewhat better than in **.

The life span of HgSO₄/S prismatic 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. 2. 1. 7. Transition From Prismatic to Bobbin Cell Structures

A conventional prismatic or pasted-plate cell (as described and illustrated in Appendix B, pages 123 and 124, 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 .

a. 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 the 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:NH₃/S:HgSO₄: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 definition 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 sub-sections, a. 1. through a. 3., describe such cells and the conclusions which were drawn therefrom.

a. 1. Single Cathode, Single Working Anode: Cell No. P-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 usual 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 the usual current density resulting from the prorating of the load upon cathode theoretical capacity.

a. 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, page 16, and Table VIII, page 17. For example, in the table at 42 hours, channels 31 - 33 show the significant effect of anode current density upon output voltage.

a. 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, pages 18 and 19. Table IX, page 20, 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, pages 79 and 81. The anode current density was based on the combined areas of one face of each anode.

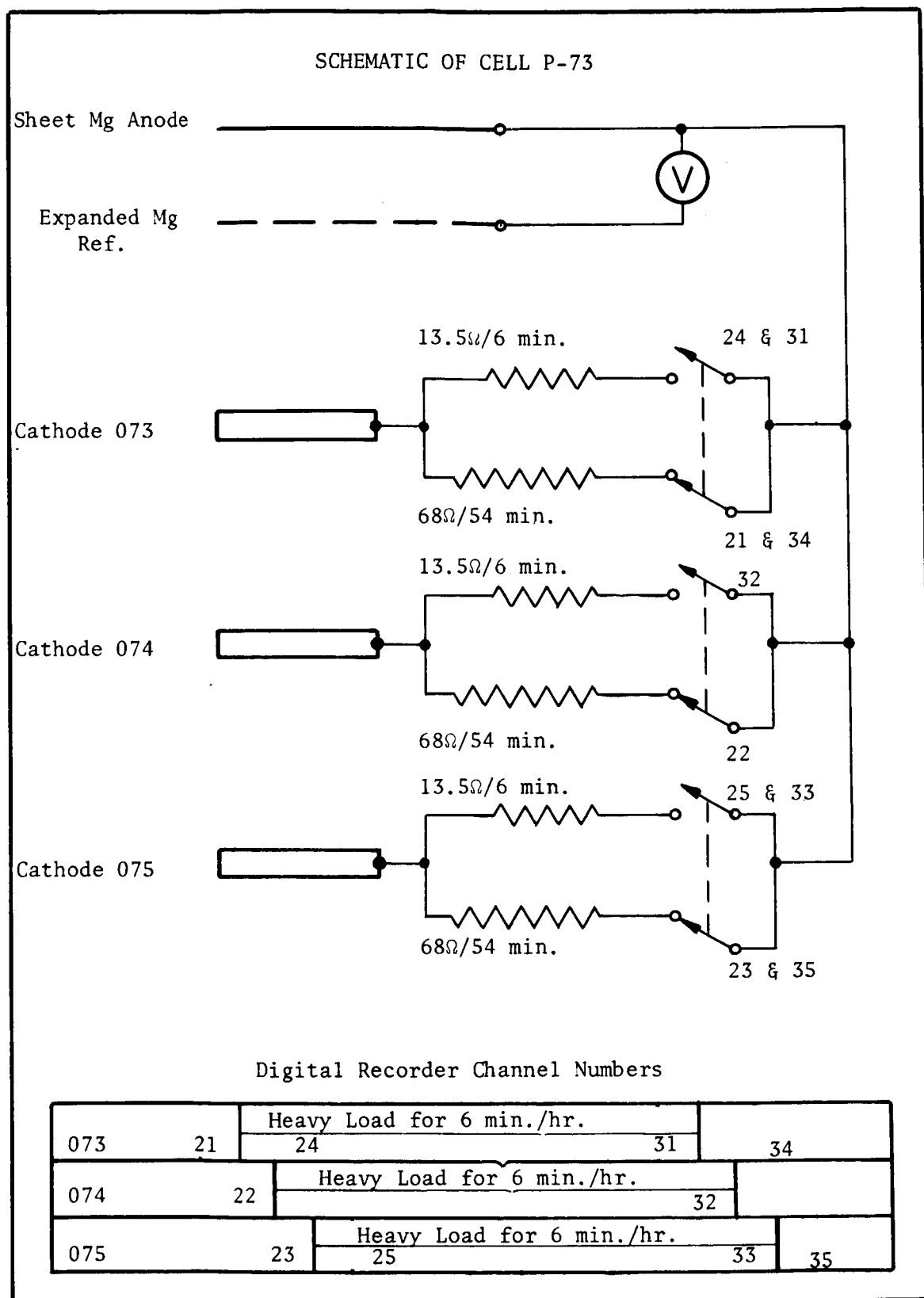


FIGURE 2

TABLE VIII

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.

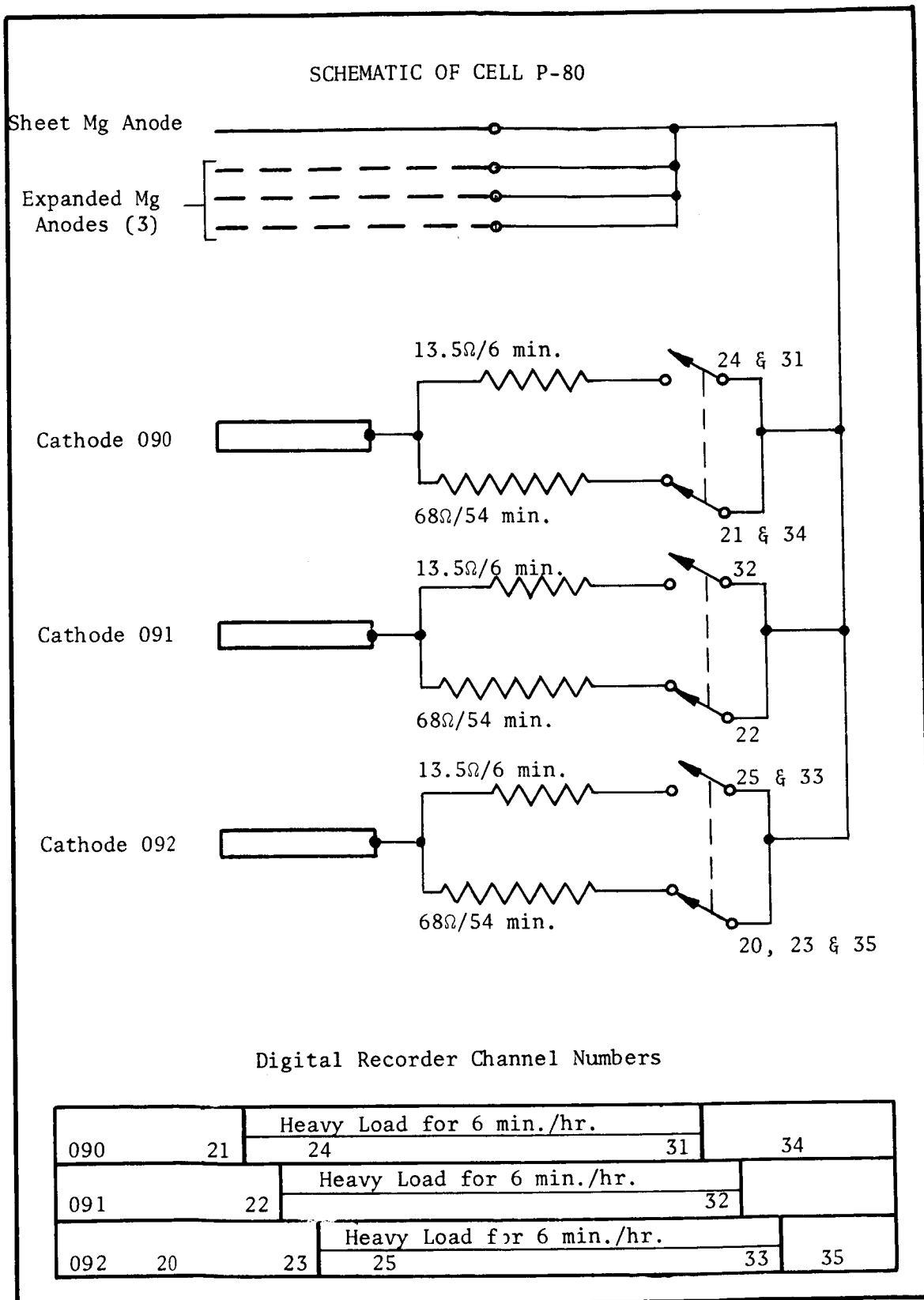


FIGURE 3

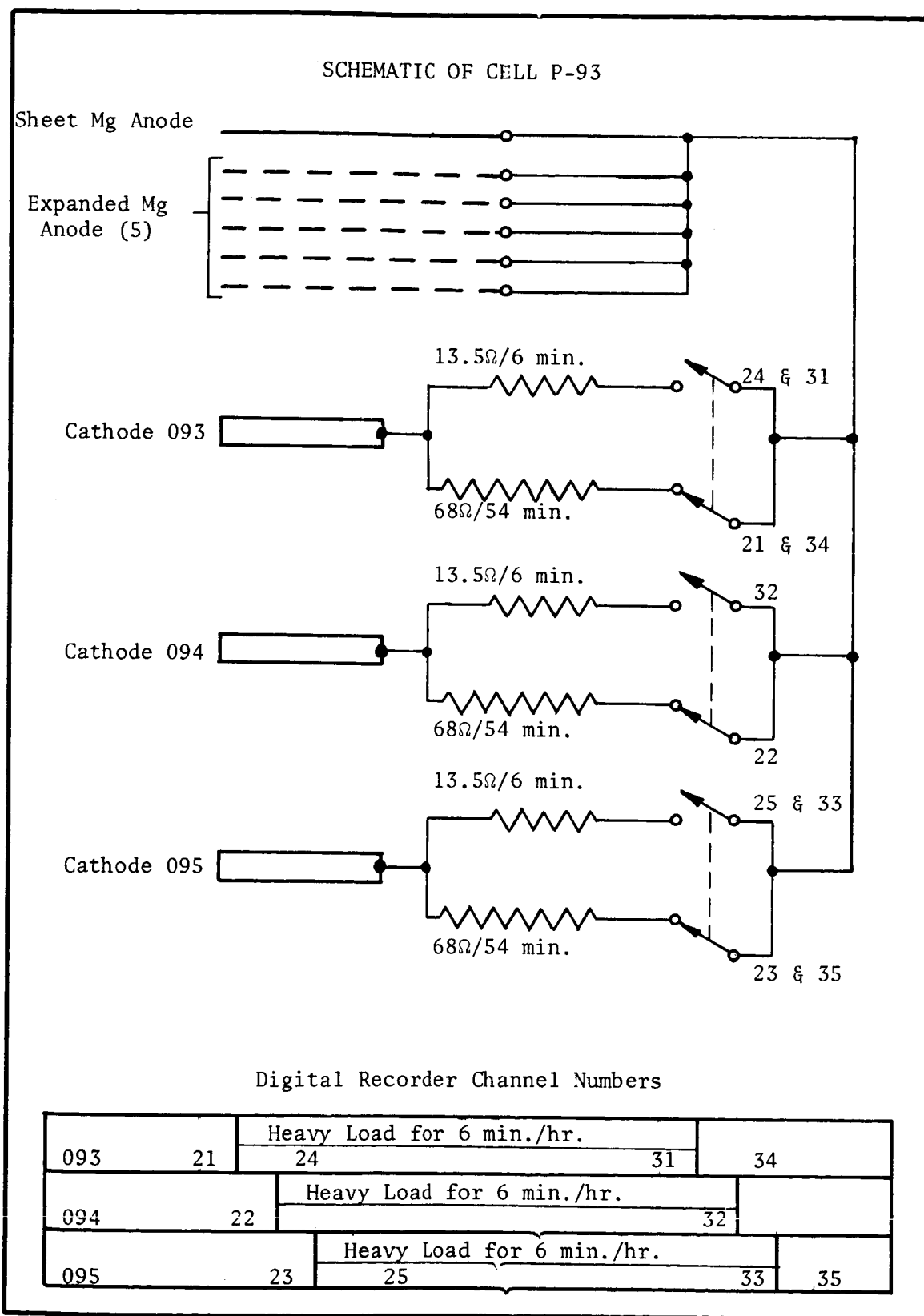


FIGURE 4

TABLE IX
PERIODIC CELL VOLTAGES, CELLS P-80 AND 93

Cell No. P-80
 Refer to Figure 3

Elapsed Time (Hours)	Channel Numbers										
	20	21	22	23	24	25	31	23	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	1.38	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

	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

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.

b. Edge Discharge, Cell No. P-55: This was a conventional $\text{HgSO}_4/\text{S/C}$ 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, page 22, 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 X, page 23. 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/cathode polarization. The reference in that case has to be perforated or expanded (Exmet). A complex cell, including this feature and several others, is presented under the next subsection.

c. Exploratory Flat-Plate Cell No. P-57: This cell (Figure 6, page 24) 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 part b, 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 were collected on this cell, but the significant points have been described, and these

¹ (Refer to Figure 1, Appendix B, page 124). 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.

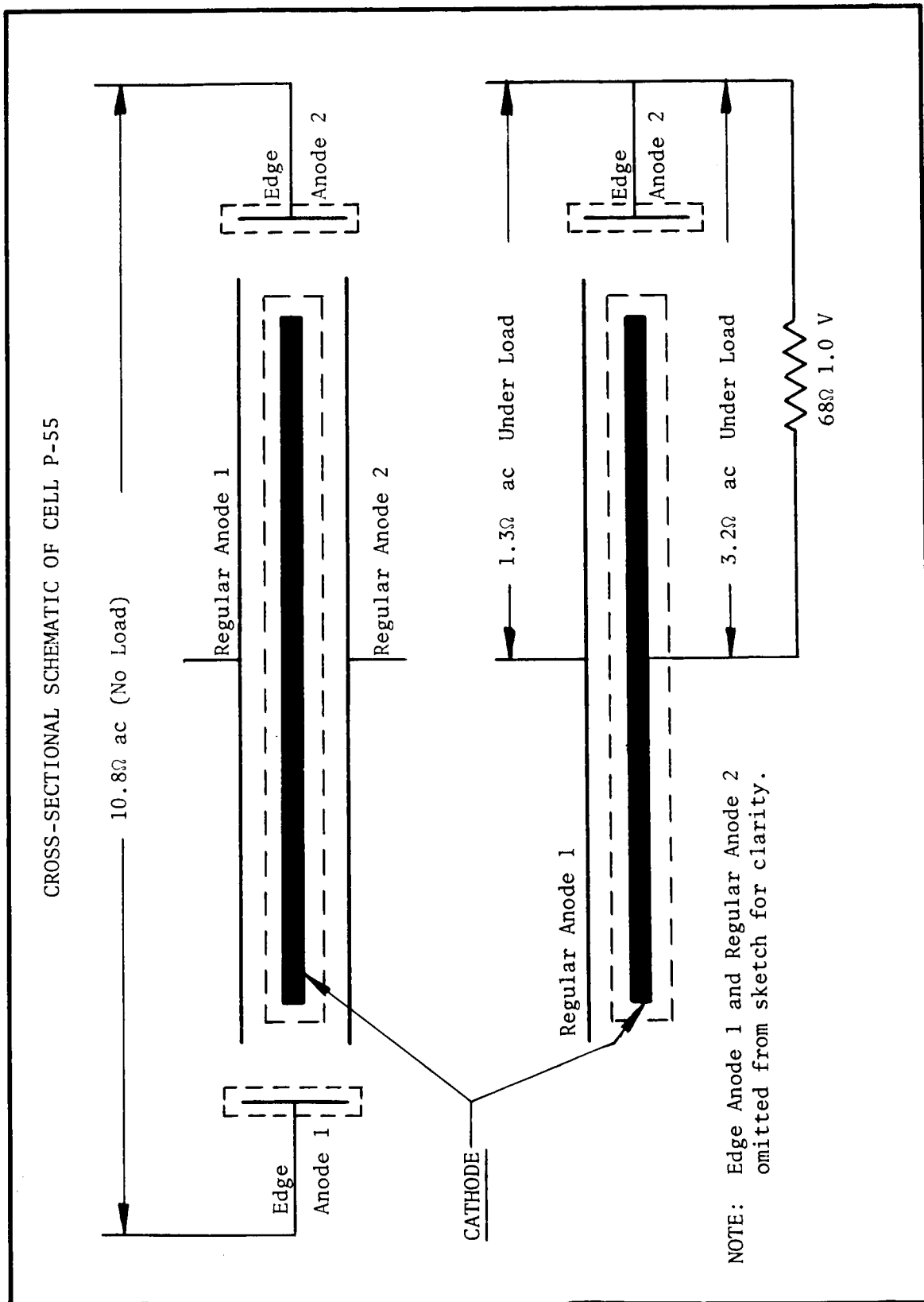


FIGURE 5

TABLE X

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

Same readings with cell on open circuit for 10 minutes:

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

Calculations (Refer to Figure 5):

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

I = Cell Current

E = Working cell voltage

R = External load resistance.

$$I = 1.00/68 = 0.0147 \text{ amperes.}$$

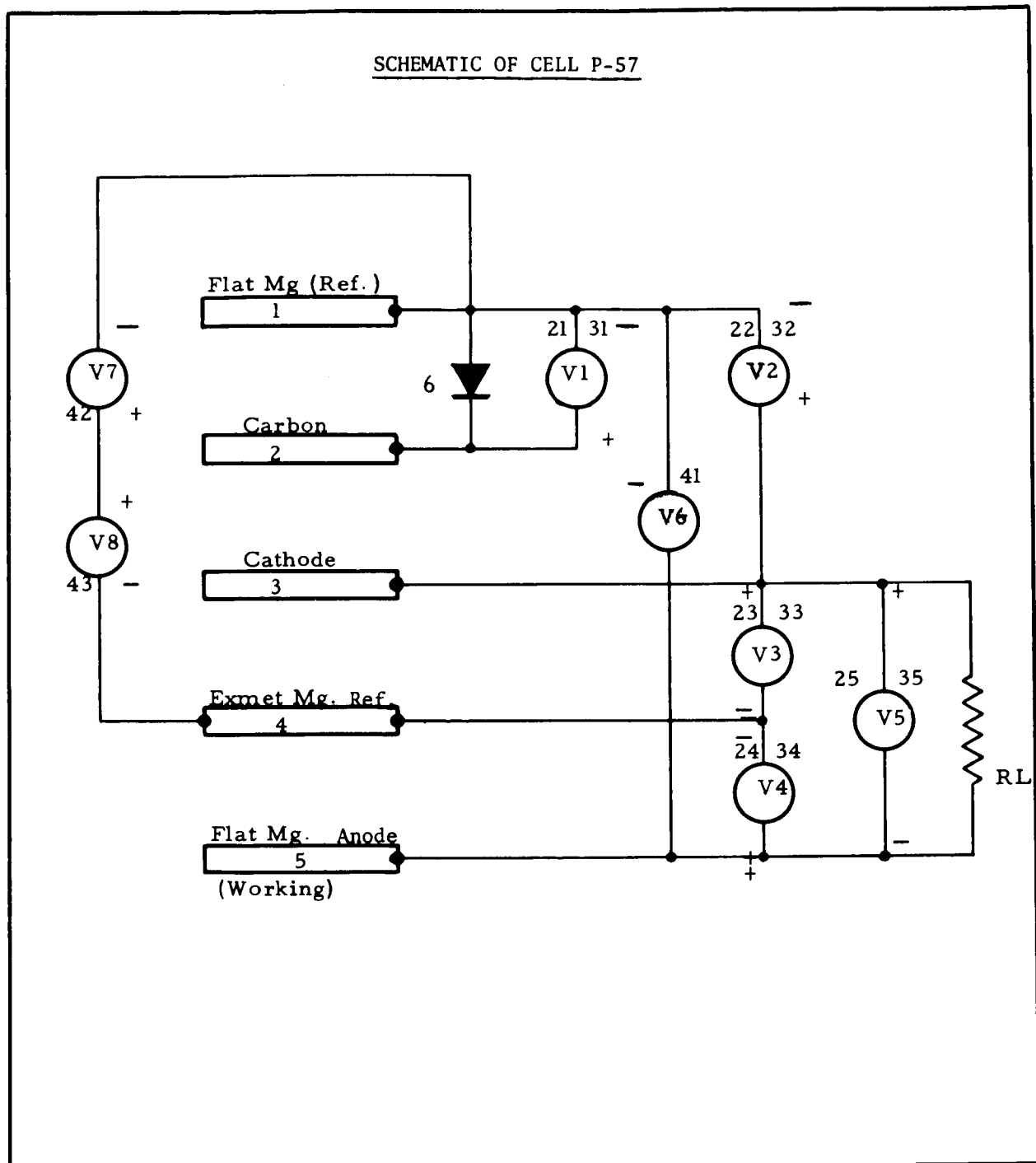
Ir where I = Cell current above

r = Cell ohmic resistance determined by ac measurements.

$$\text{Internal Ir loss} = 0.0147 \times 3.2 = 0.047 \text{ volts.}$$

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

SCHEMATIC OF CELL P-57



FORM FM-100

FIGURE 6

points will be further discussed in specific cells designed to illuminate these particular properties.

d. 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.

e. 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, page 26, is a schematic drawing of the electrodes and the electrical loading and shows the sequence of the digital voltage recordings. Table XI, page 27, 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.

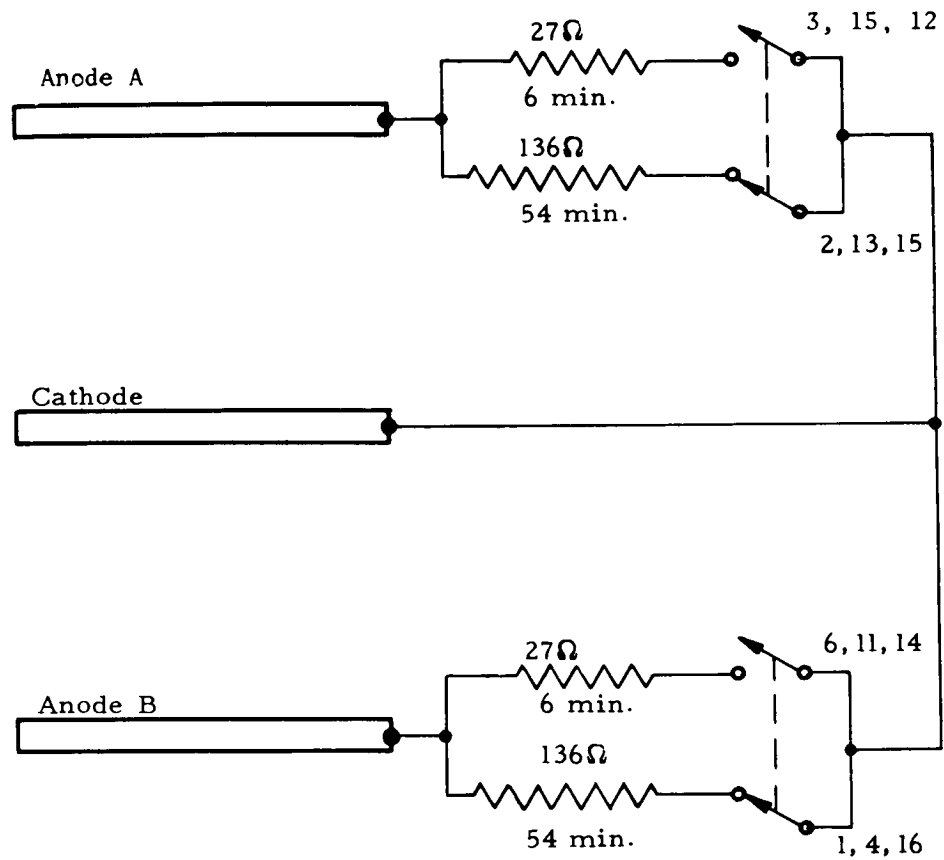
In general, the performance of the two anodes was much the same. As expected, the potential dropped as the load was increased and then recovered as the load was decreased. The effect of increased current density on the cathode is shown by channels 3 vs 5.

Further data reported on this cell are presented in the following part.

f. 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

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

SCHEMATIC OF CELL P-134



LOAD SCHEDULE WITH RECORDER CHANNEL NUMBERS

		Heavy load for 6 min. /hr.			
Anode A	2	3	5	12	13 15
Anode B	1	4	6	11	14 16

FIGURE 7

TABLE XI

PERIODIC CELL VOLTAGES, CELL NO. P-134

Refer to Figure 7

Anode: Channel No.: Hours	A		B		A		B		A		B		A		B	
	1	2	3	4	5	6	11	12	13	14	15	16				
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% →

is shown in Figure 8, page 29. 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. (Re: Sections 2. 3. 2. and 5., pages 36 and 43.

Heavy load resistor, $R_L = 2.7 \Omega$

Standard resistor, $R_S = 1.35 \Omega$

Standard capacitor, $C_S = 24950$ microfarads, with 0.0695Ω 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 comparison, the difference of 0.04Ω is negligible. In the case of the 13.5Ω 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.

Cell No. P-134, which had one cathode and two separately loaded anodes, is described in part e, page 25, and illustrated in Figure 7, page 26. The data in Table XII, page 30, seem to indicate that the origin of the capacitance values in the system, $Mg/KSCN:NH_3/S$, is in the anode.

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

$$1/17.9 + 1/19.5 \approx 1/10.4$$

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

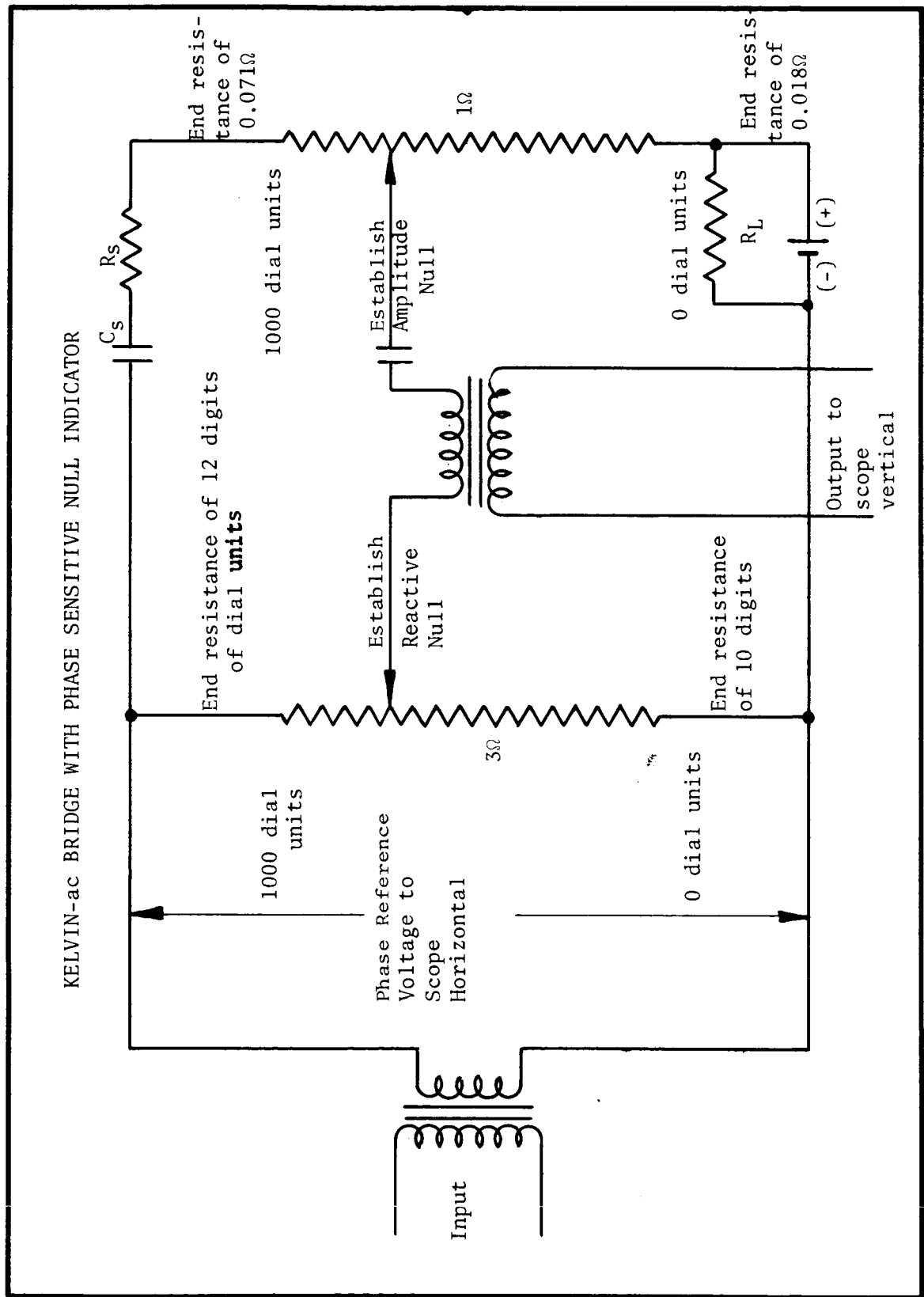


FIGURE 8

TABLE XII

RESISTANCE AND CAPACITANCE OF PRISMATIC CELL NO. P-134

	Elapsed Time Hours	Anode A to Cathode		Anode B to Cathode		Anode to Anode	
		mF ¹	Ω	mF ¹	Ω	mF ¹	Ω
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 ²	4	17.9 ³	0.66	19.5 ³	0.36	10.4 ³	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 ²	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 ²	47	14.0	0.78	13.8	1.78	7.4	1.38

¹ Capacitance in millifarads (mF).

² X = values obtained by extrapolation to zero current.

³ 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.

2. 2. 2. Bobbin Cell Design, Construction and Testing

The performance of prismatic cells was often unreliable due to a number of factors such as collector plate and connection corrosion, poor adhesion and cracking of the cathode pads and electrolyte level control.

The development of a five-plate cell would involve problems with internal connections and the design of a suitable case to withstand operating pressures at temperatures above the boiling point of the electrolyte.

Since cylindrical cells offer many advantages over prismatic cells in simplicity and ease of construction (especially for use at elevated pressure), the development of bobbin cells was started in Task I. 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, pages 125 to 136. All open top cells were activated by the following convenient method:

Activation Method No. 1:

Cold electrolyte was poured into cold cells. Some excess was used to compensate for evaporation and absorption. (Method of preparation of 34 percent KSCN electrolyte is given in Appendix B, page 150).

2. 2. 2. 1. Preliminary Designs for Task I

Nos. B-1, 2, and 3 were of simple open top construction with central rod anode and annular ring cathode. Since it was reasoned that the discharge time of all three was short 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 of the surface facing the cathode in cells B-4 through B-7. This relationship was valid for B-7 even though much of the additional area was provided by the use of external anodes in conjunction with the central coil. The proportionality between Nos. B-6 and 7 remained a direct ratio even though 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 to 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 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 and for much of the experimental work throughout the rest of the contract. Any modifications to this basic design will be explained in the later sections. The method of construction and figures 9, 10, and 11, may be found in Appendix B, pages 133 through 136.

2. 2. 2. 2. Electrolyte Studies at -90°C

During the discharge of the $\text{Mg/KSCN:NH}_3/\text{S}$ type cells, the K^+ ion is converted to an equivalent of Mg^{++} ion. The spent electrolyte $[\frac{1}{2} \text{Mg}(\text{SCN})_2]$ 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 percent KSCN ; others, with 25 percent KSCN . The composition of the cathode was varied also. The test results are summarized in Table XIII, page 33.

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) Five percent 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 percent spent electrolyte.

TABLE XIII
ELECTROLYTE STUDIES

Cell No. B-	Sulfur %	Carbon %	Acet. Black %	Electrolyte (% as KSCN)			Hours to*	
				Virgin	Spent	50% Virgin 50% Spent	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.

Attempts were made to synthesize $\text{Mg}(\text{SCN})_2$ 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.

2. 2. 2. 3. Cathode Composition (Sulfur, Graphite, Acetylene Black)

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

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 was obtained with 5, 10 and 50 percent acetylene black, and all of these cells performed better than the cathodes containing no acetylene black. Fifty percent acetylene black yielded the highest

TABLE XIV

EFFECT ON PERFORMANCE OF VARIATIONS IN CATHODE COMPOSITIONHalf-sized Cells:

Cell No. B-	Sulfur %	Carbon %	Acetylene Black, %	Cath. Wt. Total gms	Cathode Density g/in ³	Hours 1.5V	to* 1.3V	F/mol Sulfur
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	162	7.9	53	57	0.14
53	40	40	20	162	7.9	52	59	0.19

* Under heavy load.

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

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 was not determined because of the limited number of experiments.

2. 3. 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 XV. The method of construction and sketches are presented in Appendix B, pages 133 - 136.

TABLE XV

TASK 1. B., CONSTRUCTION/LOAD SPECIFICATIONS

<u>Cathode:</u>	Sulfur (grams/%)	96/50
	Carbon (grams/%)	77/40
	Acetylene Black (grams/%)	19/10
	Total cathode weight (grams)	192
	Thickness of annular ring (in.)	0.30
	Length (in.)	13.5
	Collector	CAB-XL Case
<u>Anode:</u>	AZ31B Mg Sheet	10 longitudinal fins
	Apparent Area (cm ²)	354
<u>Electrolyte (liquid NH₃ solvent):</u>		
	KSCN (%)	34
	Volume (cc)	575
<u>Net Cell Volume (in.³):</u>		43
<u>Load (Ω):</u>		2.7 for 6 minutes 13.5 for 54 minutes

2. 3. 1. Task I. B. 1., Testing of Cells Described in Section 2. 3.

The first set of five 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 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.

2. 3. 2. Cathode Composition (HgSO_4 , S, Graphite, Acetylene Black)

In an attempt to extend the cell life beyond that achieved in Task I. B. 1., experiments were conducted with mercuric sulfate as an additive to the S/C cathode. A summary of the results is displayed in Table XVI, page 37, and in Figure 9, page 38.

Mercuric sulfate (9.5 percent) 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-sized cell, and with B-59, a similar full-sized cell. Nos. B-57, 62, and 76 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 preceding groups of five (B-33 to 37 and 43 to 47) which did not contain any HgSO_4 . The percentage of HgSO_4 was varied in Nos. B-70 to 73 in order to determine the optimum proportion. The results, which are plotted in Figure 9, indicate maximum cell life with about 12% 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).

TABLE XVI
EFFECT OF MERCURIC SULFATE ON THE LIFE OF SULFUR CELLS

Cell No. B-	Cell Size	HgSO ₄ , %	Discharge Temp., °C	Hours to*	
				1.5V	1.3V
Task I. B. 1.	Full	0	-90	54	64
54	Half	9.5	-90	101	113
58	Half	9.5	-90	96	106
59	Full	9.5	-90	95	111
57	Half	¹	-90	64	84
62	Half	2	-90	71	82
76	Half	3	-73	64	71
70	Half	1.0	-73	62	73
71	Half	5.0	-73	85	105
72	Half	9.5	-73	112	136
73	Half	17.3	-73	110	123
61	Half	9.5	-63	158	176
60	Half	9.5	-40	97	127

* Under heavy load.

¹ The electrolyte was saturated with HgSO₄ (about 0.1%).

² Seven (7) grams of HgSO₄ were encapsulated in Webril separator paper, and the cylindrical capsule was placed in the anode compartment.

³ One (1) gram of HgSO₄ was added to the electrolyte.

Mercuric thiocyanate was substituted for the sulfate in Cell No. B-79 to determine whether the mercury ion or the sulfate ion were responsible for the improved performance. The cell life of 85 hours to 1.5 volts was inferior to the 112 hours from B-72 with HgSO₄ but much better than cells having no mercury salt at all. It is evident that the Hg⁺⁺ is a necessary ingredient. It is believed that Hg(SCN)₂ is more soluble in ammonia than HgSO₄. If true, this suggests two things:

1. If the mercury salts have a deteriorating effect during inactive stand, the thiocyanate might be added as a solute in the electrolyte after shelf stand, rather than as a cathode ingredient.
2. If a Hg salt exists that is less soluble in ammonia than the sulfate, it might yield longer life.

Since the increased life that can be obtained by the addition of mercury salts is far greater than the coulombic equivalent of the additive, some other factor is responsible for the improvement, possibly an effect on the anode. The anodes from discharged cells containing HgSO₄ were usually easier to clean and were etched more uniformly than those from S/C cells.

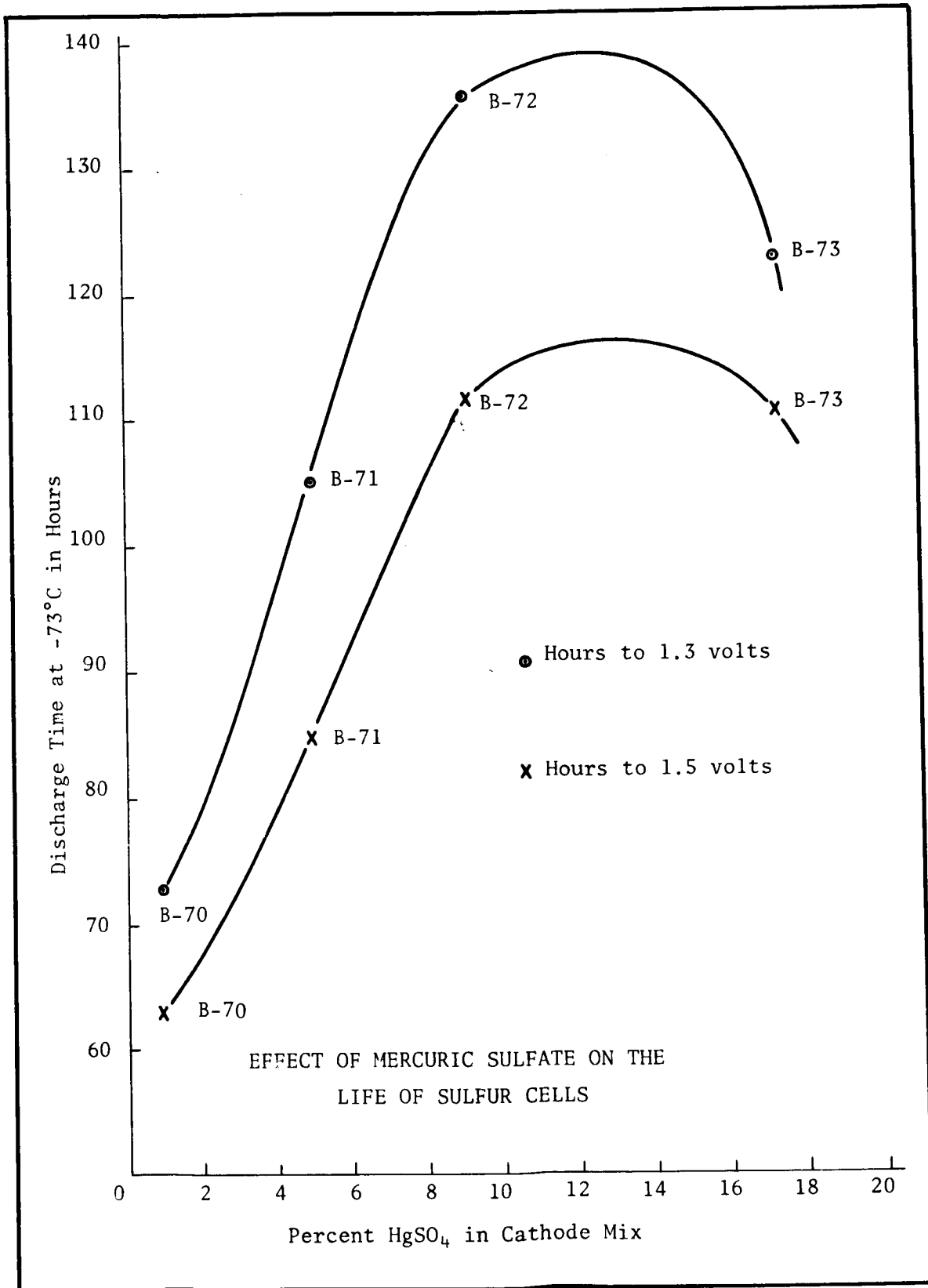


FIGURE 9

3. 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 LEL personnel and the Project Manager. He was presented with the assembly drawing, Figure 12, page 139, together with drawings of the anode and the end plugs. The design, the Method of Construction on page 137 and the Parts and Materials List (page 147) were approved. The cell was designed to accommodate electrodes of the type used in cell No. B-59 (Re: Section 2. 3. 2., page 36), and to perform in accordance with the following contract specifications:

1. Discharge temperature range: $+20^{\circ}\text{C}$ to -73°C .
2. Inactive storage temperature: $+65^{\circ}\text{C}$ maximum.
3. Cathode capacity: 25 ampere hours maximum theoretical based upon primary oxidant.
4. Minimum required peak anode current density: 1.5 mA/cm^2 .
5. Operating life: 72 hours continuous cycle to a 75 percent of nominal voltage cut-off at -73°C .
6. Discharge cycle: 0.3 watts for 54 minutes and 1.5 watts for 6 minutes alternating continuously, using fixed resistive loads based upon a nominal operating voltage for the battery system utilized.
7. Storage life: Six months maximum required.
8. Storage conditions: Reserve construction excluding activator, inactive.
9. Environmental conditions: As defined in Attachment "B" - capability to fulfill conditions. (Attachment "B" was modified on January 11, 1967, in NASA Change Order, Amendment No. 3). The environmental tests included vibration, acceleration, shock and acoustic noise.

4. TASK III, TEST AND REDESIGN

We were required to evaluate the Task II design by constructing a full-scale mockup cell, followed by the fabrication and testing of cells incorporating any necessary design changes. Finally, the design was modified again, and another set of cells was built and tested.

4. 1. Task III, Mockup Cells

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 . Activation was performed by the following method:

Activation Method No. 2:

Room temperature electrolyte was transferred into evacuated cells which were at the discharge temperature. The vapor pressure of the electrolyte was used to perform the transfer. The activator which contained excess electrolyte was left open to the cells throughout discharge.

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, page 100.

4. 2. Task III. A., Fabrication and Testing of Cells

The design from Task II was followed in the construction of five cells. Since the extruded magnesium was not available at the time, the anodes were fabricated from sheet and rod stock. Three of the cells were tested without an initial storage period (A. 1.), and the remaining two cells were discharged after having been on shelf storage at $+65^{\circ}\text{C}$ for one week (A. 2.). Method No. 2 was used for activation. The discharge temperature was -73°C . The cell performance is shown in Table XVII, page 41.

These two sets of tests exhibited a remarkably high level of reproducibility and very little effect from storage at $+65^{\circ}\text{C}$. The peak voltages under both light and heavy loads and the final open circuit voltages were slightly higher after exposure to $+65^{\circ}\text{C}$.

TABLE XVII

CELL PERFORMANCE, TASK III. A. 1. AND A. 2.

Cell No. B-	Task III	Shelf Storage		Hours to*	
		Weeks	Temp., °C	1.5V	1.3V
65	A.1.	None	---	85	96
67	A.1.	None	---	94	105
69	A.1.	None	---	85	92
66	A.2.	One	+65	85	93
68	A.2.	One	+65	84	94

*Under heavy load.

4. 3. Task III. B., Redesign, Fabrication and Testing of Cells

Certain modifications were made to the Task II design. The details are shown in Appendix B, pages 140 to 143, including revised drawings, the Method of Cell Closure, the Cell Cross Section (Figures 13 - 15, pages 141 - 143) and Method of Construction. The major changes were the substitution of extruded anodes for those formerly fabricated from sheet and rod stock and an improved plug design. In the original plug design, the interference ring was located near the center of each plug, and the length was 7/8 inch. The design has been revised to provide greater stability and to prevent cocking and leaking by increasing the length to 1-1/4 inches and by locating the interference ring at the front end of each plug (the end which enters the case first). Hydraulic pressure tests proved the new design to be superior. With the new design, no plug movement was detected at 600 psi. The plugs did move at 400 psi with the previous design. After approval of the changes, five cells were fabricated for testing in a manner identical with that described in Section 4. 2.

In an effort to improve activation, the following method was used in Task III. B. 1. and 2.:

Activation Method No. 3:

The cells were evacuated and then back-filled with argon at atmospheric pressure to provide a gas pocket above the liquid and to prevent over-filling. Electrolyte at room temperature was forced into the cells (at

-73°C) with an argon pressure of 30 psi above the vapor pressure of the electrolyte for a period of one minute, after which the activator valve was closed. After about 30 hours of discharge, a decline in voltage indicated a deficiency of electrolyte; so the activator valve was reopened for 10 seconds. As a result, the voltages recovered, and the cells ran well past the 72 hour goal.

The results of the cell testing are given in Table XVIII.

TABLE XVIII

CELL PERFORMANCE, TASK III. B. 1. and 2.

Cell No. B-	Task III.	Shelf Storage		Hours to*	
		Weeks	Temp., °C	1.5V	1.3V
81	B.1.	None	---	87	115
83	B.1.	None	---	91	112
85	B.1.	None	---	90	115
82	B.2.	One	+65	77	92
84	B.2.	One	+65	81	88

*Under heavy load.

The average cell life to 1.5 volts declined from 89 hours for B. 1. to 79 hours for B. 2.

The No. 3 Method of Activation proved to be unsatisfactory because it would be impractical to introduce additional electrolyte during the course of discharge.

Task III was concluded successfully; the life of every cell exceeded the 72 hour requirement.

5. RESISTANCE AND CAPACITANCE OF BOBBIN CELLS

The resistance and capacitance of a number of the preceding cells were determined, using the instrumentation and method of computation described in Section 2. 2. 1. 7., part f, pages 25, 28 and 29.

A summary of the measurements taken on 15 cells is shown in Table XIX, page 44. While the purpose of this study was to build a background of valid resistance readings in the face of series capacitance reactance, it was found that capacitance was more significant than resistance (as long as R was reasonable). Capacitance values decrease markedly near the end of cell life. While the cells of Table XIX include many construction and test variations, the general trend of decreasing capacitance with continued discharge is quite evident.

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

TABLE XIX

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.

6. METHODS OF BLENDING CATHODE INGREDIENTS

The cathode comprises four powders which vary widely in bulk density from the heaviest, HgSO_4 , through sulfur, graphite and acetylene black, the lightest. Only 10 percent by weight of HgSO_4 is used. Since it is the highest in density, the percent by volume is very small. Furthermore, it is in the form of relatively large needle crystals. For these reasons, it is believed that intensive mixing is required to obtain a uniform blend.

6. 1. Hand-Mixing

In prior experiments where very few identical cathodes were needed, the ingredients were weighed separately for each 10 percent portion of a cathode, mixed thoroughly by hand, and then packed into the cell to occupy 1/10 of the total cathode length.

The following other methods were explored:

6. 2. Ball-Milling

The cathode materials were made into a slurry with heptane and milled, after which the heptane was removed by evaporation. The resultant soft cake was pulverized and used in cells B-26 and 27. Nothing was gained by this procedure.

6. 3. Oster Blender

Both a dry and a wet mix (in heptane) were blended in a one quart Oster Blender. The cell life to 1.5 volts at -73°C was 113 hours for the dry mix and 95 hours for the wet mix. The performance was good, but the method was too slow.

6. 4. Patterson-Kelley Blender

Since a faster method was desired for the manufacture of fifty identical cells for Task IV, a four-quart P-K Twin Shell Blender was used to make multiple batches for half-sized test cells. Batch size and blending time were varied. In the last set of tests, the HgSO_4 crystals were reduced in size with a mortar and pestle before blending.

Half-sized, open-top cells were built with cathode materials that had been blended in several ways and were discharged at -73°C . The performance data are summarized in Table XX. All methods yielded cell life well in excess of 72 hours. Since no clearly defined trends were observed, the most intense mixing with the largest practical batch size was adopted for the cathode preparation for the 50 cells of Task IV and Task V. This is the same method that was used for cells B-99 to 102. That is, the HgSO_4 was first ground with mortar and pestle; then 848 gram batches (4 cathodes) were blended for 15 minutes in the four-quart P-K Twin Shell Blender.

TABLE XX

COMPARISON OF METHODS OF BLENDING CATHODE INGREDIENTS

Discharge Temperature: -73°C

	Cell No.	Hours to*		
	B-	1.5V	1.3V	
Anodes fabricated from sheet and rod stock	72	112	136	Hand-Mixed
	86	109	114	P-K Blender, 424 grams for 10 minutes.
	89	113	123	
	90	108	118	
	91	102	112	
	Average	108	117	
Extruded Anodes	92	110	122	Hand-Mixed
	93	110	128	P-K Blender, 848 grams for 3 minutes.
	94	93	103	
	95	95	106	
	96	83	95	
	97	103	107	
	98	112	121	
	Average	99	110	
	99	93	99	P-K Blender, 848 grams for 15 minutes.
	100	84	90	
	101	112	117	
	102	117	127	
	Average	101	108	

*Under heavy load.

7. TASK IV, MANUFACTURE AND TEST CELLS

Fifty-eight cells were manufactured for the purpose of environmental and performance testing under a range of operating temperatures (+20° to -90°C) and storage conditions (+65° to -20°C). The design was the same as that used in Task III. B. The construction and discharge specifications follow:

<u>Cathode Composition</u>	<u>grams</u>	<u>%</u>
Mercuric Sulfate	20	9.5
Sulfur	96	45.2
Graphite	77	36.3
Acetylene Black	<u>19</u>	<u>9.0</u>
TOTAL	212	100.0

Cathode Dimensions (Annular Ring Configuration)

Nominal O. D. = 1.9 inches; I. D. = 1.3 inches;
length = 13.5 inches.

Anode

AZ31B Magnesium Extrusion, finned type.
Apparent Area = 342 cm².

Electrolyte

34 percent KSCN in liquid ammonia.

Net Cell Volume (Approx.)

39 in³.

Discharge Cycle

0.3 watts (13.5 ohms) for 54 minutes and 1.5 watts (2.7 ohms) for 6 minutes alternating continuously, using fixed resistive loads based upon a nominal operating voltage (2.0 V) for the battery system utilized.

Operating Life

72 hours continuous cycle to a 75 percent of nominal voltage cut-off (1.5 V) at -73°C . All output calculations in the following tables for Tasks IV-B through E and for Task V are to the 1.5 volt cut-off under the heavier load and are based on total amount of oxidants.

After construction, the cells were evacuated, back-filled with argon and sealed for inactive shelf storage. Then, they were divided into fourteen groups of three each and two groups of eight each. Prior to the initiation of the shelf storage periods, one cell from each group of three was selected for the environmental tests.

7. 1. Task IV. A., Environmental Tests

(Refer to NASA Change Order, Amendment No, 3., January 11, 1967). The fourteen cells were subjected to the required environmental tests by Associated Testing Laboratories of Wayne, New Jersey. The kinds of tests included vibration, acceleration, shock and acoustic noise. (The acoustic noise tests were conducted by Noise Unlimited, Inc., and were witnessed by a representative of Associated Testing Laboratories, Inc.). The abstract of their report No. M429-7810, dated May 11, 1967, stated that "there was no evidence of physical damage to the Liquid Ammonia Batteries as a result of the environmental tests. In addition, the resistance value exhibited by the Batteries throughout the test program was infinity." The cells were returned to their respective groups for performance and shelf-storage tests. (Refer to page 152).

7. 2. Task IV. B., Cell Tests After One Month Storage at +20 to +25°C

Five groups of three cells each were stored for one month at 20 to 25°C and were then tested at the following temperatures: +20, -20, -40, -73 and -90°C . (The storage period was extended from two weeks to one month because of a delay in completing the environmental tests). Each group of cells, connected to a common manifold and activator, was evacuated, cooled to its discharge temperature and charged with a solution of 34 percent KSCN in liquid ammonia. The electrolyte was at room temperature, and its pressure (about 120 psig) was used to accomplish the transfer. After ten minutes, the large activator was replaced by a smaller one containing a reserve of 300 cc of electrolyte. This was open to the cells throughout the discharge. This was Activation Method No. 2, page 40.

The cell discharge results as reported in Table XXI, page 50, did not meet our expectations at any temperature. For example, other cells had run to 1.5 VF as follows:

- +20°C, Nos. IV-56 and 58, 113 and 128 hours, respectively.
- 40°C, No. B-40 (open top cell), 83 hours.
- 40°C, No. B-41 (open top cell), 99 hours.
- 40°C, No. B-60 (open top cell), 97 hours.
- 73°C, Task III cells averaged 88 hours.
- 90°C, B-54, 58 and 59 (open top cells) averaged 97 hours.

Gassing was observed in the nylon filling tubes, especially at +20, -20 and -40°. This and the fact that the reserve activator on the +20° cells had to be refilled on the second day of discharge indicated incomplete filling during the initial charging. Other methods of activation were devised and will be reported in sections that follow.

Since we had tested no closed cells at -40° and only one at -20° prior to this experience, the poor performance was unexpected and is not understood. The open top cells ran very well at -40° and at -90°C.

7. 3. Special Studies at -20 and -40°C

Cells were discharged at -20° and -40° with slightly improved results after activation with Method No. 4:

Activation Method No. 4:

The electrolyte and the cells were cooled to a temperature of -73°C and then the electrolyte was forced into the evacuated cells with argon at a pressure of 200 psig. The activation valve was left open for a period of two minutes. Since the cells became substantially full, it was necessary to bleed some electrolyte from the cells that were discharged at temperatures above -73°C.

Several other experiments were conducted in an effort to improve operation at -20°C. Half-sized cells were built in full-sized cases to provide space for some excess electrolyte and substantial room for the gas generated during discharge. An example, cell No. B-111, ran 50 hours which represented an improvement over Task IV. B. of about 20%. The cell (No. B-110) containing MPR instead of the standard separation discharged for only 27 hours to 1.5 VF.

Since a cell life of five to six days at room temperature had been demonstrated several times, attempts were made to learn whether or not the

TABLE XXI

TASK IV. B. CELL DISCHARGE DATA

After One Month Inactive Shelf Storage at 20 to 25°C

Cell No.	Discharge Temp., °C	Hours to* 1.5V/1.3V	Average Volts		Output to 1.5V*	
			Lt. Load	Hy. Load	Amp.Hrs.	Coul./g F/mol
02**	+20	85/94	2.00	1.71	16.9	524 0.21
10	"	96/103	1.97	1.65	18.7	580 0.23
18	"	97/104	2.00	1.72	19.3	599 0.23
26	-20	44/52	2.11	1.93	9.5	293 0.12
34**	"	41/50	2.10	1.92	8.8	271 0.11
42	"	42/56	2.11	1.93	9.0	279 0.11
03	-40	49/52	2.14	1.95	10.7	331 0.13
11	"	44/47	2.11	1.93	9.4	292 0.11
19**	"	46/48	2.12	1.92	10.0	309 0.12
27**	-73	60/63	2.07	1.81	12.5	387 0.15
35	"	59/67	2.08	1.87	12.3	382 0.15
43	"	62/68	2.09	1.85	13.1	405 0.16
04	-90	70/79	1.98	1.72	14.9	464 0.18
12**	"	67/76	1.98	1.72	13.3	413 0.16
20	"	85/89	1.98	1.74	16.9	525 0.21

* Under heavy load.

** Environmentally tested for shock, vibration, acceleration and acoustic noise.

presence of dissolved sulfur might be responsible. (Sulfur dissolves readily in ammonia at room temperature). Cell No. B-109 was activated cold, heated to $+20^{\circ}$ and discharged for 20 hours to dissolve sulfur and then cooled to -20° . It performed well for 20 hours at $+20^{\circ}$ and for an additional 64 hours at -20°C . Since this test was encouraging but not very practical, cell No. B-112 was activated with electrolyte containing 40 grams of dissolved sulfur per liter and was discharged at -20°C . Its life of 55 hours was a substantial step forward, but far short of the desired 72 hours.

The addition of a proprietary material to the electrolyte of No. B-114 to inhibit gas generation provided a cell life of 56 hours at -20° .

The improvements may have been due to either one of two factors or to both:

1. The additives, or
2. The presence of excess gas space which eliminated the need to bleed ammonia and gas from the cells during discharge.

7. 4. Task IV. C., Cell Tests After Storage at $+65^{\circ}$ and -20°C

Three cells were stored at $+65^{\circ}$ for six months, and another set of three cells were stored at -20° for the same period of time. All were activated by Method No. 4 (page 49) and were discharged at -73°C . The results are presented in Table XXII, page 52. Cell No. IV-09, which had been stored at $+65^{\circ}$, met the 72 hour requirement, but Nos. 36 and 44 were overheated by exposure to direct radiation from the oven heating coils. Hence, their performance was poor.

The cells that had been stored at -20° had an average life of 81 hours; so there were no adverse effects of shelf storage under these conditions.

7. 5. Task IV. D., Cell Tests After Three Months Storage at $+20$ to $+25^{\circ}\text{C}$

Five groups of three cells each were stored for three months at 20° to 25° and were then discharged at $+20$, -20 , -40 , -73 and -90°C . Activation Method No. 4 (page 49) was employed. The results of the tests as

TABLE XXII

TASK IV. C. CELL DISCHARGE DATA

After 6 Months Inactive Shelf Storage at +65°C							
Cell No.	Discharge Temp., °C	Hours to* 1.5V/1.3V	Average Volts		Output to 1.5V*		
			Lt. Load	Hy. Load	Amp.Hrs.	Coul./g	F/mol
09	-73	74/95	2.04	1.82	15.2	472	0.19
36	"	39/43	2.01	1.76	7.9	243	0.10
44**	"	42/46	2.02	1.78	8.5	264	0.10
<u>After 6 Months Inactive Shelf Storage at -20°C</u>							
05**	-73	82/96	2.10	1.90	17.4	540	0.21
13	"	81/101	2.09	1.90	17.1	532	0.21
21	"	80/94	2.10	1.91	17.0	528	0.21

* Under heavy load.

** Environmentally tested for shock, vibration, acceleration and acoustic noise.

given in Table XXIII, page 54, indicated a substantial improvement over Task IV. B., except at the discharge temperature of -20°C . The life at -40° increased from 46 to 56 hours, still short of the 72 hour goal. No adverse effects of the inactive shelf storage were observed.

7. 6. Task IV. E., Cell Tests After Dual Temperature Storage

Three cells were aged for three months at $+20$ to 25°C and for an additional three months at $+65^{\circ}$. A second set of three were exposed to a temperature of $+20$ to 25° for the first three months and to -20° for the last three months. After activation by Method No. 4 (page 49) all cells were discharged at -73°C . A summary of the test results is presented in Table XXIV, page 55. Cell No. IV-08 of the first group ran well for 80 hours to 1.5 VF which indicated no ill effects of exposure to $+65^{\circ}\text{C}$. However, cells IV-16 and 24 showed signs of severe overheating by radiation as in the case of cells IV-36 and 44 in Task IV. C., page 51. It is probable that the overheating was the cause of the poor performance. The average cell life of the second group was a very satisfactory 85 hours.

7. 7. Task IV. F., Disposition of the Remaining Eight Cells

All of the remaining eight cells required by the contract, plus seven of the eight extra cells built for Task IV, were discharged under a variety of conditions to improve the method of activation, to increase the cell life at -20° and -40° , to study the means of collecting current from the cases and to measure cell temperatures and pressures during discharge at room temperature.

7. 7. 1. Current Collectors

Various means of collecting current during discharge were studied rather extensively, but only the more important observations are reported herein.

Cell No. B-115, a full-sized cell, was constructed with 45 inches of 0.010 inch diameter platinum wire in the form of a triple loop imbedded in the cathode mixture. One end of the wire was brought out of the top of the cell through a Swagelok fitting. Two individually wired adjustable steel clamps were placed on the outside of the case. One was 3" below the top of the cathode; the other, 3" above the bottom. The amount of electrolyte was limited to provide about 50 cc of gas space, including 38 cc in the hollow anodized top plug and manifold. During activation, both the cell and electrolyte were at -73°C . Argon, at a

TABLE XXIII
TASK IV. D. CELL DISCHARGE DATA

Cell No.	Discharge Temp., °C	Hours to* 1.5V/1.3V	Average Volts		Output to 1.5V*		
			Lt. Load	Hy. Load	Amp.Hrs.	Coul./g	F/mol
29	+20	135/145	1.97	1.91	27.7	858	0.34
37**	"	141/149	1.97	1.86	28.6	888	0.35
45	"	148/156	1.95	1.84	29.7	906	0.35
06	-20	44/50	2.16	2.00	9.7	302	0.12
14	"	44/48	2.17	1.98	9.7	301	0.12
22**	"	40/48	2.18	2.02	8.9	277	0.11
30**	-40	56/60	2.19	2.02	12.5	389	0.15
38	"	56/59	2.19	2.02	12.5	389	0.15
46	"	56/59	2.19	2.01	12.5	389	0.15
07	-73	81/101	2.10	1.89	17.2	535	0.21
15**	"	81/102	2.10	1.89	17.2	535	0.21
23	"	84/108	2.09	1.89	17.5	542	0.21
31	-90	84/89	2.00	1.76	16.9	524	0.21
39	"	88/94	2.00	1.75	17.7	550	0.22
47**	"	81/87	2.01	1.78	16.4	509	0.20

* Under heavy load.

**Environmentally tested for shock, vibration, acceleration and acoustic noise.

TABLE XXIV

TASK IV. E. CELL DISCHARGE DATA

After 3 Months Inactive Shelf Storage at +20°; Followed by 3 Months at +65°C

Cell No.	Discharge Temp., °C	Hours to* 1.5V/1.3V	Average Volts		Output to 1.5V*	
			Lt. Load	Hy. Load	Amp.Hrs.	Coul./g F/mol
08**	-73	80/101	2.06	1.84	16.5	512 0.20
16	"	26/29	2.03	1.62	5.2	160 0.06
24	"	48/61	2.05	1.82	9.9	306 0.12

After 3 Months Inactive Shelf Storage at +20°; Followed by 3 Months at -20°C

32	-73	84/100	2.10	1.91	17.9	555 0.22
40**	"	87/107	2.10	1.90	18.4	571 0.22
48	"	85/108	2.10	1.89	18.0	560 0.22

* Under heavy load.

**Environmentally tested for shock, vibration, acceleration and acoustic noise.

pressure of 50 psig, was used to force the electrolyte into the cell. During discharge at +20 to 25°C, the Pt wire alone carried the load during most of the run, and the clamps were used primarily for O.C. reference voltages and for comparisons under load with the Pt. After 122 hours, the Pt wire and both clamps were connected to share the load current. This change increased the heavy load voltage from 1.58 to 1.64 and helped to extend the cell life to 151 hours to the 1.5 volt cut-off. Neither clamp by itself delivered a voltage as high as the Pt wire, but the combination of the two was slightly better than the Pt alone. This was checked between the 144th and 147th hours. The performance of the Pt wire is considered to be excellent, but it is believed that a single strand of 0.030 inch diameter wire might have been better. The cost of the wire is one disadvantage.

In order to test other types of collectors, two eleven inch long CAB-XL cases (nominal 2 inch pipe) were packed with graphite, fitted with end plugs and equipped with electrodes which extended through the top plugs into the graphite. The various collectors were installed on the outside walls of the cases, and the resistance to current flow through the graphite, case wall and each collector was measured at temperatures from ambient to -90°C. At 20 to 25°C, resistances from 0.04 ohms to 0.45 ohms were observed for single collectors.

The use of an aluminum sleeve had to be rejected because the resistance increased from 0.04 ohms at 20° to 19 ohms at -73°C. It was improved by rolling deep grooves in it, but the lowest resistance at -73°C was much too high at 2.7 ohms.

Single standard adjustable steel clamps averaged 0.26 ohms at 20° and 1.47 ohms at -90°C.

Other tests were made using silver foil, silver-plated copper Exmet and silver wire, each wrapped around the case and secured by a very tight clamp. The resistance with each type was practically the same: at +20°, 0.15 ohms; at -90°C, 0.40 ohms.

Cell No. IV-53 was discharged at -73°C to obtain realistic operating data on the various types of collectors. Seven individually wired and equally spaced collectors (numbered from 1 at the top, to 7 at the bottom) were applied to the case. Their description follows:

Nos. 1 and 5 - A band of Ag-plated copper Exmet was wrapped around the case and secured by a clamp.

Nos. 2, 4 and 6 - Ag wire was wrapped around the case twice and held in place with a clamp.

Nos. 3 and 7 - The Ag lead wire was passed under a clamp twice.

Throughout most of the run, No. 4 collector (located opposite the center of the cathode) carried all of the load. After 52 hours, reference readings on the other collectors showed the O.C. voltage to increase progressively with the distance from the loaded No. 4. This seemed to indicate preferential discharge in the vicinity of No. 4. The heavy load voltage was 1.78; maximum O.C. was 2.04.

At the 53rd hour, Nos. 2 + 4 + 6 gave 1.92 volts under heavy load; Nos. 2 + 4 provided 1.87 volts; an increase of 0.14 and 0.09 volts, respectively, over the voltage of No. 4.

At the 77th hour, heavy load voltages were as follows:

No. 4 = 1.54, Nos. 4 + 2 = 1.64, Nos. 2 + 4 + 6 = 1.74.

At the 79th hour, when the cell was failing rapidly, all seven clamps were loaded to give a voltage of only 1.50, with practically no benefit.

The data showed that the single No. 4 collector was sufficient to carry the load above cut-off for at least the required 72 hours, but that it probably would be advisable to employ two or three such collectors.

7. 7. 2. Temperature and Pressure Measurements During Discharge at Ambient Temperature With Predetermined Electrolyte Level.

The purpose of testing cell Nos. IV-33, IV-17, and IV-25, was to determine the feasibility of activation at room temperature, to get an idea of the amount of heat produced and to note the pressure generated during discharge.

Cell No. IV-33 was activated with a predetermined quantity of electrolyte to a level even with the top of the cathode. This cell had 12 cc of gas space inside the case and an additional 8 cc in the manifold above the cell for a total of 20 cc. The electrolyte was transferred within 20 seconds under the influence of a regulated argon pressure of 200 psig. The activation time observation was made possible by coloring the electrolyte with a small quantity (0.5g) of dissolved sulfur and watching the liquid transfer through a nylon activation tube. A single thermocouple was located on the outside of the cell case at the center of the cathode. A maximum temperature of 35°C was reached within the first few minutes after activation. It then gradually decreased to room temperature sometime after 5 hours of discharge. The cell was fitted with a safety relief valve rated at 370-430 psi. The pressure reached 350 psi within the first 3 hours of discharge. Twelve hours later, the pressure read 360 psi but it seems reasonable that the relief valve could have opened

during the night. At the 17th hour with the pressure at 375 psi the safety valve was observed to open and bleed out gas, dropping the pressure to 295 psi. Periodic venting occurred several times within the first 45 hours as indicated by pressure gauge observations. Some salt deposits were evident around the vent holes of the relief valve. Sometime after the 45th hour the relief valve again opened and never closed, as indicated by a zero reading on the pressure gauge and the rapid voltage decline to zero shortly after the 75 hour cut-off at 1.5 volts.

Cell No. IV-17 was similar to IV-33, but had a total of three thermocouples instead of one. The locations were:

- 1) Outside the case, one inch below electrolyte level,
- 2) Outside the case, located at the center of the cathode, and
- 3) Inside the center of the Mg anode at a point one inch below the electrolyte level.

The cell reached a maximum temperature of 35°C within the first few minutes as did No. IV-33, and there was virtually no difference among the three thermocouples. The temperature of the cell gradually reached room temperature after the first few hours.

The cell was fitted with a safety relief valve, but it was closed off via a needle valve so the pressure could not vent unless we felt it necessary. The pressure was vented at 3 hours from 395 psi to 240 psi; at 47 hours from 510 psi to 300 psi; at 74 hours from 440 psi to 360 psi and on a few other occasions during the remainder of the discharge.

The life of this cell was 143 hours to 1.5 VF.

Cell No. IV-25 was similar to IV-17 in all respects except that the cell was activated with a quantity of electrolyte which yielded a level one inch below the top of the cathode. This cell, therefore, had a total of 35 cc of gas space as compared to 20 cc for the cells IV-33 and IV-17. As a result, it was not necessary to vent the cell manually, but the pressure reached a maximum of 610 psi after 143 hours of discharge to a voltage of 1.3. This cell ran for 113 hours to 1.5 VF.

The maximum temperature reached was 33°C within a few minutes after activation with all three thermocouples reading about the same. As with cell No. IV-17, the temperature gradually dropped off after the first hour and eventually reached room temperature. It appears that the reduced quantity of electrolyte in this cell could be responsible for the decrease in run time as compared with cell No. IV-17, i.e., 113 hours vs 143 hours.

8. CORROSION OF ALUMINUM ALLOY TOP PLUG AT +20°C

The top end plugs of aluminum alloy corrode severely during discharge at +20°C. This has not affected cell life or caused any failures, but it is undesirable; so a full-sized cell (No. B-113) of standard composition and construction was equipped with an anodized top plug. It was activated with cell and electrolyte at -73°C and discharged at +20°C. After a 6 day discharge, no corrosion could be detected. The electrical resistance between the anodized plug and the outside of the plastic case was over 500 ohms, in contrast with 0.2 ohms with an untreated plug. The resistance to corrosion may have been due to the electrical isolation of the plug, to the chemically inert film formed as a result of anodization or to both. The cell life was 132 hours to 1.5 volts; 147 hours to 1.3 volts.

Method of Anodization:

Proprietary Method of The J. W. Rex Co., Lansdale, Pa.

The process consists of four steps:

- 1) The finished Al alloy plugs were degreased.
- 2) Then, they were etched for 10 seconds in NaOH solution at 135°F.
- 3) Anodization was done in a sulfuric acid bath at 70°F for one hour at a current density of 12 amperes per square foot which formed a coating of 0.6 to 0.8 mils of Al_2O_3 .
- 4) The coating was sealed in a nickel acetate dip.

9. TASK V, MANUFACTURE CELLS FOR TEST AND FOR DELIVERY TO NASA

Certain modifications in cell design and activation procedure, resulting from the cell evaluation tests of Task IV and from a number of special studies, were recommended to the Project Manager and approved by him. Provision was made for a larger gas space to reduce operating pressures. The current was collected from three areas. Each collector comprised a silver wire wrapped around the case twice and held firmly in place with an adjustable steel band. The cell assembly drawing is presented in Appendix B, Figure 16, page 146. The method of construction is given in the same Appendix on pages 144 to 145, and the Parts and Materials List on pages 147 to 149.

Fifteen cells were fabricated; five for delivery to NASA and ten for discharge in the manner prescribed. That is, each cell was tested individually on a discharge cycle of 0.3 watts for 54 minutes and 1.5 watts for 6 minutes, alternating continuously to a 75 percent of nominal voltage cut-off using two fixed resistive loads based upon the nominal voltage.

Two cells were tested at each of the following temperatures: +20, -20, -40, -73 and -90°C after two weeks of inactive shelf storage at 20 to 25°C. The free volume of each cell was determined by means of gas displacement, after which each cell was activated by the following method:

Activation Method No. 5:

The evacuated cells and activators containing 34 percent KSCN/liquid ammonia electrolyte were cooled to their respective discharge temperatures. Then, the cells were activated with that quantity of electrolyte which would leave a gas space above the liquid of 45 cc at room temperature. The electrolyte was delivered at a regulated pressure of 200 psig by using argon to augment the electrolyte vapor pressure. The transfer took place in 15 to 25 seconds. The actual gas space was dependent upon the cell temperature during discharge.

The results of the cell tests are summarized in Table XXV, page 61. The 72 hour requirement was met or exceeded on the average at +20, -73 and -90°C. As in Task IV, the cell life fell short of the goal at -20 and at -40°, the reasons for which are not understood. The actual electrolyte level was lowest at -90°C. This may have been part of the reason that the cells did not run approximately 84 hours, as in Task IV-D.

TABLE XXV

TASK V CELL DISCHARGE DATA

After 2 Weeks Inactive Shelf Storage at 20 to 25°C

Cell No.	Discharge Temp., °C	Hours to* 1.5V/1.3V	Average Volts		Output to 1.5V*		Max. Pressure after 3 days (psig)
			Lt. Load	Hy. Load	Amp. Hrs.	Coul./g F/mol	
01	+20	139/146	1.97	1.85	28.0	870	536
07	"	140/152	1.97	1.83	28.2	875	
02	-20	38/47	2.11	1.91	8.1	252	510
09	"	43/47	2.11	1.96	8.9	275	
03	-40	56/59	2.18	2.00	12.4	384	305
13	"	58/63	2.17	1.96	12.7	395	
05	-73	90/103	2.09	1.91	19.1	590	225
10	"	90/103	2.10	1.90	19.1	590	
06	-90	73/74	2.00	1.73	14.3	442	144
14	"	71/72	2.00	1.76	13.9	432	

*Under heavy load.

Activation Method No. 5: All cells plus activators at their discharge temperatures. Initial pressure for all cells, 200 psig.

10. APPENDIX A - ELECTROCHEMICAL CELL TESTS

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" diam., finned and fluted.
- g. Mg rod, 1/2" diam., four 1/8" x 1/8" vertical flutes.

REFRIGERATOR MALFUNCTION:

- h. Time-weighted average temperature.
- i. Maximum recorded temperature.

MATERIALS IDENTIFICATION

- j. HgSO₄. 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.
- ll. Acetylene Black. Shawinigan Products Corp., Englewood Cliffs, N.J.
- m. Binder. Polystyrene dissolved in toluene; (1.0g/100 ml).
- n. KSCN; Reagent; B & A. Code 2144; Allied Chemical Co., New York, New York. LEC Lot No. 8.
- nn. KSCN; Reagent; B & A. Code 2144; Allied Chemical Co., New York, New York. LEC Lot No. 9.

MATERIALS IDENTIFICATION (Continued)

- 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, Mich., 0.015" thick.
- q. AZ31B Mg sheet. Dow Chemical Co., Midland, Mich., 0.016" thick.
- qq. AZ31B Mg extrusion, 10 fins. White Metal Rolling & Stamping Corp., Brooklyn, N. Y.
- 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 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
- t. SM-91 Polypropylene non-woven fabric; 0.005" 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; 0.030"/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

MATERIALS IDENTIFICATION (Continued)

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

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

Original metal thickness, 20 mils
Metal symbol, Cu (copper)

Strand width, 30 mils
Mesh designation, 2/0

x. Pure Silver Exmet.

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

Original metal thickness, 5 mils
Metal symbol, Ag (silver)

Strand width, 8 mils
Mesh designation, 1/0

xx. Lead Exmet.

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

Original metal thickness, 25 mils
Metal symbol, Pb (lead)

Strand width, 25 mils
Mesh designation, 1/0

y. AZ31B Mg Exmet.

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

Original metal thickness, 16 mils
Metal symbol, Mg (magnesium)

Strand width, 30 mils
Mesh designation, 2/0E

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

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
Metal symbol, Al (aluminum)

Strand width, 40 mils
Mesh designation, 1/0

TABLE I
ELECTROCHEMICAL CELL TESTS - PRISMATIC CONFIGURATION

Cell Number P-	1	2	3	4	5	6
Major Variables	LOAD		Separator Thickness		Separator Thickness	
			Separator Broken		Volume KSCN Area	
Electrolyte Code: (All in liquid NH ₃).						
Temperature, Nominal, °C	-90	-90	-90	-90	-90	-90
Hours to End Voltage ^b (1.5/1.3V)	42/52	55/71	26/30	17/26	41/49	31/38
Cathode: HgSO ₄ ^j (g/%)	19.4/55.6	19.4/55.6	20/55.6	20/55.6	20/55.6	20/55.6
Sulfur ^k (g/%)	3.9/11.1	3.9/11.1	4/11.1	4/11.1	4/11.1	4/11.1
Cl ^l (g/%)	11.7/33.3	11.7/33.3	12/33.3	12/33.3	12/33.3	12/33.3
Paper Pulp (g/%)						
Acetylene Black ^{ll} (g/%)						
Collector Area (cm ²)	232 ^r	232 ^r	232 ^r	232 ^r	210 ^r	210 ^r
Anode Area (cm ²)	232 ^p	232 ^p	232 ^p	232 ^p	210 ^p	210 ^p
Anode Reference						
Separator Thickness: (in.) M-1365 ^u (in.) SM91 ^t (in.) MPR ^v						
	0.010	0.010	0.005	0.005	0.010	0.010
Electrolyte Code						
Electrolyte Volume (cc)	A 120 ⁿ	A 120 ⁿ	A 120 ⁿ	A 120 ⁿ	A 150 ⁿ	A 150 ⁿ
Net Cell Volume (in. ³) (Approx.)	9	9	9	9	10	10
Load ^a (ohms)						
	13.5/68	13.5/68	13.5/68	13.5/68	13.5/68	13.5/68
Peak Closed Circuit Voltage ^c						
End Voltage Under Light Load	2.25	2.24	2.28	2.18	2.20	2.18
	1.85	1.78	1.46	1.50	1.70	1.50
Peak Anode C.D. ^d (mA/cm ²)						
Obs. Coulombs/g Total Oxidants	0.68	0.68	0.68	0.64	0.75	0.74
Obs. F/Mol Total Oxidants	300	408	169	143	270	208
Watt Hours/in ³ . Net Cell	0.39	0.53	0.22	0.18	0.35	0.27
	0.38	0.52	0.22	0.18	0.32	0.24

FOLDOUT FRAME

FOLDOUT FRAME

TABLE I (Continued)

7	8	9	10	11	12
Separator Material M-1365 Webril		Fisher KSCN		Fisher KSCN MPR Separator	
-90	-90	-90	-90	-90	-90
44/48	41/44	44/51	49/55	45/52	41/48
20/55.6 4/11.1 12/33.3	20/55.6 4/11.1 12/33.3	20/55.6 4/11.1 12/33.3	20/55.6 4/11.1 12/33.3	20/55.6 4/11.1 12/33.3	20/55.6 4/11.1 12/33.3
210r	210r	210r	210r	210r	210r
210P	210P	210q	210q	210q	210q
0.020	0.020	0.020	0.020	0.008	0.008
				0.030	0.030
A 150 ⁿ 10	A 150 ⁿ 10	A 125 ^o 9	A 125 ^o 9	A 125 ^o 9	A 125 ^o 9
13.5/68	13.5/68	13.5/68	13.5/68	13.5/68	13.5/68
2.35 1.55	2.30 1.45	2.22 1.58	2.22 1.53	2.18 1.55	2.23 1.55
0.81 277 0.36 0.34	0.80 250 0.32 0.30	0.77 283 0.37 0.37	0.77 305 0.40 0.40	0.76 285 0.37 0.37	0.81 268 0.35 0.35

TABLE I (Continued)

13	14	15	16	17
Volume of Electrolyte		Pure Cu Collectors, MPR Separators		S/HgSO ₄ Mol Ratio (Constant Wt. & Vol of C) 100% S
-90	-90	-90	-90	-90
10/13	78/83	68/75	43/54	53/66
20/55.6	20/55.6	20/55.6	20/5.66	0
4/11.1	4/11.1	4/11.1	4/11.1	8.5/41.5
12/33.3	12/33.3	12/33.3	12/33.3	12/58.5
210 ^r	210 ^r	210 ^s	210 ^s	210 ^r
210 ^q	210 ^q	210 ^q	210 ^q	210 ^q
0.020	0.020	0.008	0.008	0.008
		0.030	0.030	0.030
A 50 ^o 7.5	A 50 ^o 7.5	A 100 ^o 7.5	A 100 ⁿ 7.5	A 100 ⁿ 7.5
13.5/68	13.5/68	13.5/68	13.5/68	13.5/68
2.12	2.11	2.22	2.08	2.06
1.97	1.60	1.62	1.80	1.65
0.68	0.70	0.75	0.70	0.69
70	448	416	288	323
0.09	0.58	0.54	0.37	0.42
0.11	0.68	0.65	0.43	0.48
				0.64
				1040*
				0.35*
				0.50

*Includes meter drain since 5 mA movement was used. Load was approximately 10% heavy.

TABLE I (Continued)

18	19	20	21	22
Sulfur to Mercuric Sulfate Molal Ratio (Constant Weight and Volume of Graphite)				
4S:1 HgSO ₄	2S:1 HgSO ₄	1S:1 HgSO ₄	100% HgSO ₄	100% S
-90	-90	-90	-90	-90
51/62	44/50	34/38	55/59	64/71
11.8/40.8 5.1/17.7 12/41.5	16.6/51.5 3.6/11.2 12/37.3	20.6/59.2 2.2/6.3 12/34.5	29.0/70.7 0 12/29.3	0 8.5/41.5 12/58.5
210 ^r	210 ^r	210 ^r	210 ^r	210 ^r
210 ^q	210 ^q	210 ^q	210 ^q	210 ^q
0.008	0.008	0.008	0.008	0.008
0.030	0.030	0.030	0.030	0.030
A 100 ⁿ 7.5	A 100 ⁿ 7.5	A 100 ⁿ 7.5	A 100 ⁿ 7.5	A 100 ⁿ 7.5
13.5/68	13.5/68	13.5/68	13.5/68	13.5/68
2.17 1.57	2.22 1.60	2.22 1.54	2.24 1.87	2.00 1.66
0.75 480 0.42 0.52	0.76 330 0.41 0.43	0.77 222 0.38 0.33	0.76 272 0.84 0.52	0.65 1042 0.35 0.54

TABLE I (Continued)

23	24	25	26	27
Sulfur to Mercuric Sulfate Molal Ratio (Constant Weight and Volume of Graphite)				
4S:1 HgSO ₄	2S:1 HgSO ₄	1S:1 HgSO ₄	100% HgSO ₄	100% HgSO ₄
-90	-90	-90	-90	-90
42/50	14/15	54/63	8/9	22/24
11.8/40.8 5.1/17.7 12/41.5	16.6/51.5 3.6/11.2 12/37.3	21.5/60.0 2.3/6.4 12/33.6	29.0/70.7 0 12/29.3	29.0/70.7 0 12/29.3
210 ^r	210 ^r	210 ^r	210 ^r	210 ^r
210 ^q	210 ^q	210 ^q	210 ^q	210 ^q
0.008	0.008	0.008	0.008	0.020
0.030	0.030	0.030	0.030	0.030
A 100 ⁿ 7.5	A 100 ⁿ 7.5	A 100 ⁿ 7.5	A 100 ⁿ 7.5	A 100 ⁿ 7.5
13.5/68	13.5/68	13.5/68	13.5/68	13.5/68
2.22 1.58	2.20 1.93	2.26 1.65	2.25 2.15	2.20 2.17
0.77 394 0.35 0.43	0.77 98 0.12 0.13	0.78 384* 0.66* 0.60	0.77 42 0.13 0.08	0.74 110 0.34 0.21

* Includes meter drain since 5 mA movement was used. Load was approximately 10% heavy.

TABLE I (Continued)

28	29	30	31	32
Sulfur to Mercuric Sulfate Molal Ratio (Constant Weight and Volume of Graphite)				Sulfur to Carbon Ratio by Weight
2S:1 HgSO ₄	100% S	4S:1 HgSO ₄	1S:1 HgSO ₄	∞
-90	-70 ⁱ	-70 ⁱ	-70 ⁱ	-90
72/83	52/62	52/67	54/59	0/8
16.6/51.5	0	11.8/40.8	21.5/60.0	0
3.6/11.2	8.5/41.5	5.1/17.7	2.3/6.4	25/100
12/37.3	12/58.5	12/41.5	12/33.6	0
210 ^w	210 ^w	210 ^w	210 ^w	210 ^w
210 ^q	210 ^q	210 ^q	210 ^q	210 ^q
0.020	0.020	0.020	0.020	0.020
0.030	0.030	0.030	0.030	0.030
A	A	A	A	A
100 ⁿ	100 ⁿ	100 ⁿ	100 ⁿ	100 ⁿ
7.5	7.5	7.5	7.5	7.5
13.5/68	13.5/68	13.5/68	13.5/68	13.5/68
2.25	2.04	2.23	2.30	1.65
1.77	1.53	1.59	1.67	1.65
0.77	0.69	0.76	0.79	0.47
551	923	530	363*	36
0.68	0.31	0.47	0.62*	0.01
0.73	0.48	0.59	0.58	0.05

* Includes meter drain since 5 mA movement was used. Load was approximately 10% heavy.

TABLE I (Continued)

33	34	35	36	37	38
Sulfur to Carbon Ratio by Weight			Mol Ratio	Mol Ratio	Weight Ratio
5.7	1.0	0.7	4S:1 HgSO ₄	1S:1 HgSO ₄	S:C=5.7
-90	-90	-90	-90	-90	-63 ⁱ
109/113	79/85	60/67	70/78	69/73	74/113
0	0	0	11.8/40.8	21.5/60.0	0
21/85	11/50	8.5/41.5	5.1/17.7	2.3/6.4	21/85
3.7/15	11/50	12/58.5	12/41.5	12/33.6	3.7/15
210 ^w	210 ^w	210 ^w	210 ^w	210 ^w	210 ^w
210 ^q	210 ^q	210 ^q	210 ^q	210 ^q	210 ^q
0.020	0.020	0.020	0.020	0.020	0.020
0.030	0.030	0.030	0.030	0.030	0.030
A	A	A	A	A	A
100 ⁿ	100 ⁿ	100 ⁿ	100 ⁿ	100 ⁿ	100 ⁿ
7.5	7.5	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
1.98	2.05	2.00	2.26	2.27	2.03
1.90	1.73	1.51	1.63	1.67	1.80
0.64	0.66	0.66	0.77	0.78	0.64
667	983	985	621	413	680
0.22	0.33	0.33	0.55	0.70	0.23
0.85	0.67	0.51	0.069	0.65	0.88

TABLE I (Continued)

39	40	41	42	43	44
Weight Ratio: S:C = 1.0	<u>Pure Cu Collector</u> Wt. Ratio S:C=0.7		MPR Sealed Edges	Thick Cathodes, 0.70". Details in text.	Thick Cathodes, 0.62". Details in text.
-63 ⁱ	-57 ⁱ	-57 ⁱ	-63 ⁱ	-63 ⁱ	-63 ⁱ
36/43	42/44	48/50	36/40	36/38	19/20
0	20/55.6	0	20/55.6	100/55.0	100/55.6
11/50	4/11.1	8.5/41.5	4/11.1	20/11.0	20/11.1
11/50	12/33.3	12/58.5	12/33.3	60/33.0 1.8/1.0	60/33.3
210 ^w	210 ^s	210 ^s	210 ^w	210 ^w	210 ^w
210 ^q	210 ^q	210 ^q	210 ^q	210 ^q	210 ^q
0.020	0.020	0.020	None	0.020	0.020
0.030	0.030	0.030	0.060	0.030	0.030
A 100 ⁿ 7.5	A 100 ⁿ 7.5	A 100 ⁿ 7.5	A 150 ⁿ 10	A 350 ⁿ 27	A 320 ⁿ 25
13.5/68	13.5/68	13.5/68	13.5/68	2.7/13.5	2.7/13.5
2.10 1.93	2.00 1.60	1.96 1.70	2.30 1.51	2.26 2.05	2.18 1.92
0.67 502 0.17 0.35	0.69 228 0.30 0.34	0.65 725 0.24 0.37	0.79 227 0.29 0.27	3.7 214 0.28 0.47	2.9 110 0.14 0.25

TABLE I (Continued)

45	46	47	48	49	50
Separation	<u>Thin Cathodes</u>		<u>Pure Cu Collector</u>		Discharged with only one anode.
-90	-90	-90	-90	-90	-90
27/28	37/49	31/48	17/21	41/51	14/15
20/55.6	5/55.6	5/55.6	20/55.6	0	20/55.6
4/11.1	1/11.1	1/11.1	4/11.1	8.5/41.5	4/11.1
12/33.3	3/33.3	3/33.3	12/33.3	12/58.5	12/33.3
210^w	210^w	210^w	210^s	210^s	210^w
210^q	210^q	210^q	210^q	210^q	210^q
0.020	0.020	0.020	0.020	0.020	0.020
0.030	-----	-----	0.030	0.030	0.030
A	A	A	A	A	A
100 ⁿ	100 ⁿ	100 ⁿ	100 ⁿ	100 ⁿ	100 ⁿ
7.5	7.5	7.5	7.5	7.5	7.5
13.5/68	48/240	48/240	13.5/68	13.5/68	13.5/68
2.27	2.24	2.23	2.12	1.97	2.26
1.88	1.65	1.62	1.88	1.77	2.10
0.77	0.22	0.22	0.71	0.66	1.47
158	304	298	113	744	84
0.20	0.39	0.38	0.15	0.25	0.11
0.25	0.12	0.12	0.17	0.38	0.13

TABLE I (Continued)

51	52	53	54	55	
Omitted MPR		MPR Sealed at edges.	Thick Cathode.	Added Extra Anodes Along Two Edges.	
				Edge Anodes Loaded.	Regular Anodes Loaded.
-90	-90	-90	-90	-90	-90
61/70	81/93	98/117	20/30	0/1	10/13
20/55.6	20/55.6	20/55.6	100/55.0	20/55.6	
4/11.1	4/11.1	4/11.1	20/11.0	4/11.1	
12/33.3	12/33.3	12/33.3	60/33.0	12/33.3	
			1.8/1.0		
210 ^w	210 ^w	210 ^w	210 ^w	210 ^w	210 ^w
210 ^q	210 ^q	210 ^q	210 ^q	16 ^q Regular ^q	210 ^q Edge ^q
0.020	0.020	None	0.020	0.020	0.020
-----	None	0.060	-----	-----	-----
A 100 ⁿ +50 7.5	A 100 ⁿ 7.5	A 150 ⁿ 10	A 350 ⁿ 27	A 100 ⁿ 7.5	
13.5/68	13.5/68	13.5/68	2.7/13.5	13.5/68	
2.25	2.23	2.27	2.21	2.09	2.24
1.61	1.76	1.65	2.04	2.05	2.04
0.76	0.72	0.76	3.42	6.32	0.75
393	519	660	165	----	72
0.51	0.67	0.85	0.21	----	0.09
0.62	0.82	0.73	0.36	----	0.11

TABLE I (Continued)

56	57	58	59	60	61
MPR Sealed at edges.	5-Electrode Research Cell. See Text.	Wt. Ratio S:C = 5.7	Separation 7 Layers		Thin Cathode
-90	-90	-90	-90	-90	-90
34/40	25/27	53/89	24/26	55/56	73/82
20/55.6	20/55.6	0	20/55.6	20/55.6	5.95/55.6
4/11.1	4/11.1	21/85	4/11.1	4/11.1	1.19/11.1
12/33.3	12/33.3	3.7/15	12/33.3	12/33.3	3.57/33.3
210 ^w	105 ^w	210 ^w	210 ^w	210 ^w	210 ^w
210 ^q	105 ^q 1 ^q , 1 ^y	210 ^q	210 ^q	210 ^q	210 ^q
-----	0.020	0.020	0.028	0.028	0.020
0.060	-----	-----	-----	-----	0.030
A 150 ⁿ 10	A 250 ⁿ 17	A 100 ⁿ 7.5	A 100 ⁿ 7.5	A 100 ⁿ 7.5	A 100 ⁿ 7.5
13.5/68	13.5/68	13.5/68	13.5/68	13.5/68	48/240
2.27	2.24	1.98	2.24	2.24	2.20
1.52	1.67	1.82	2.08	2.01	1.50
0.78	1.46	0.62	0.75	0.75	0.22
226	318	526	145	312	431
0.29	0.41	0.17	0.19	0.40	0.56
0.27	0.22	0.67	0.23	0.49	0.20

TABLE I (Continued)

62	63	65	66	69	
Separation 2 Layers.	Ag Exmet Collector (x)	Paste on One Side of Grid.		3-Electrode Cell	
		Paste Facing Anode.	Grid Facing Anode.	Sulfur Electrode	Carbon ¹ Electrode
-90	-90	-90	-90	-90	-90
40/64	54/66	42/47	67/69	81/202	25
0	20/55.6	20/55.6	20/55.6	0	0
11.0/50	4/11.1	4/11.1	4/11.1	21/85	0
11.0/50	12/33.3	12/33.3	12/33.1	3.7/15	16/100
210 ^w	210 ^x	105 ^w	105 ^w	105 ^w	105 ^w
210 ^q	210 ^q	105 ^y	105 ^y	105 ^q	105 ^q
		(q)	(q)		
0.008	0.020	0.020	0.020	0.020	0.020
A 100 ⁿ 7.5	A 150 ⁿ 10	A 150 ⁿ 10	A 150 ⁿ 10	A 150 ⁿ 10	A 150 ⁿ 10
13.5/68	13.5/68	13.5/68	13.5/68	13.5/o.c.	68
2.00	2.22	2.22	2.24	1.65 ^d	1.41
1.80	1.49	1.59	1.47	2.05 o.c.	0.65
0.64	0.77	1.51	1.52	1.16	--
726	366	260	385	377	64
0.24	0.47	0.34	0.50	0.13	--
0.49	0.43	0.30	0.45	0.32	--

TABLE I (Continued)

70	71	72	73	74	75
Single Anode Discharge.	1/4" Cathode Anode Discharge.	Single	5-Electrode Research Cell. 3 Cathodes.	Single Anode Ag Exmet Collector (x)	2-Anodes Ag Exmet Collector (x)
-90	-90	-90	-90	-90	-90
54/85	11/13	17/19	See text	4/27	0/56
0	40/55.0	40/55.6	0	0	0
21/85	8/11.0	8/11.1	63/85	21/85	21/85
3.7/15	24/33.0	24/33.3	11.1/15	3.7/15	3.7/15
	0.72/1.0				
105 ^w	105 ^w	105 ^w	315 ^w	105 ^x	210 ^x
105 ^q	105 ^q (q)	105 ^q (q)	105 ^q (y)	105 ^q	210 ^q
0.020	0.020	0.020	0.020	0.020	0.020
A 150 ⁿ 10	A 150 ⁿ 10	A 150 ⁿ 10	A 200 ⁿ 21	A 130 ⁿ 9	A 130 ⁿ 9
13.5/68	6.75/34	6.75/34	4.5/22.7	13.5/68	13.5/68
1.91	2.00	2.18	1.90	1.83	1.80
1.77	1.90	1.78	1.61*	1.76	1.77
1.14	2.67	3.02	3.02	1.15	0.49
490	68	104	----	153	312
0.16	0.09	0.14	----	0.05	0.10
0.46	0.15	0.24	----	0.16	0.31

*End voltage (heavy load) = 0.68.

TABLE I (Continued)

76	77	78	79	80	81
Sulfur:Carbon Weight Ratio:				Research Cell. 3 Cathodes, 4 Anodes. See text.	Acetylene Black, 15% Carbon.
2.33	2.33	1.50	1.50		
-90	-90	-90	-90	-90	-87 ^h
99/141	100/120	93/103	94/106	36/47	85/118
0	0	0	0	0	0
17/70	17/70	14/60	14/60	63/85	21/85.0
7.3/30	7.3/30	9.3/40	9.3/40	11.1/15	3.3/13.4
					0
					0.4/1.6
210 ^w	210 ^w	210 ^w	210 ^w	315 ^w	210 ^w
210 ^q	210 ^q	210 ^q	210 ^q	420 ^{1q, 3y}	210 ^q
0.020	0.020	0.020	0.020	0.020	0.020
A 125 ⁿ 9	A 125 ⁿ 9	A 125 ⁿ 9	A 125 ⁿ 9	A 300 ⁿ 21	A 125 ⁿ 9
13.5/68	13.5/68	13.5/68	13.5/68	4.5/22.7	13.5/68
1.99	1.99	2.00	2.00	1.95	2.09
1.52	1.73	1.68	1.67	1.82	1.77
0.70	0.70	0.70	0.70	0.93	0.67
1035	882	918	945	276	721
0.34	0.29	0.30	0.31	0.09	0.24
0.90	0.77	0.65	0.67	0.38	0.80

TABLE I (Continued)

82	83	84	85	86	87
Acetylene Black			Paper Pulp		
15% Carbon	30% Carbon		30% Carbon		15% Carbon
-87 ^h	-86 ^h	-89 ^h	-90	-90	-90
82/121	80/87	83/108	75/89	72/109	68/100
0	0	0	0	0	0
21/85	17/70.0	17/70.0	17/69.3	17/67.9	21/84.2
2.9/11.8	6.6/27.1	5.9/24.2	7.3/29.7	7.3/29.1	3.7/14.8
			0.25/1.0	0.75/3.0	0.25/1.0
0.8/3.2	0.7/2.9	1.4/5.8			
210 ^w	210 ^w	210 ^w	210 ^w	210 ^w	210 ^w
210 ^q	210 ^q	210 ^q	210 ^q	210 ^q	210 ^q
0.020	0.020	0.020	0.020	0.020	0.020
A 125 ⁿ 9	A 125 ⁿ 9	A 125 ⁿ 9	A 100 ⁿ 7.5	A 120 ⁿ 8.5	A 110 ⁿ 8
13.5/68	13.5/68	13.5/68	13.5/68	13.5/68	13.5/68
2.08	2.03	2.09	2.01	1.99	1.97
1.71	1.70	1.62	1.80	1.73	1.73
0.67	0.66	0.68	0.63	0.64	0.62
738	643	818	657	800	590
0.24	0.21	0.27	0.22	0.27	0.20
0.81	0.56	0.73	0.69	0.73	0.71

TABLE I (Continued)

88	89	90	91	92	93
Paper Pulp	Acetylene Black				Research Cell. 3 Cathodes, 6 Anodes. See Text.
15% Carbon	15% Carbon	15% Carbon	30% Carbon		
-90	-90	-90	-90	-90	-90
45/69	44/72	76/85	52/80	81/86	42/58
0	0	0	0	0	0
21/82.5	21/85.0	21/85	17/70	17/70	63/85
3.7/14.5	3.3/13.4	2.9/11.8	6.6/27.1	5.9/24.2	11.1/15
0.75/3.0	0				
210 ^w	0.4/1.6 210 ^w	0.8/3.2 210 ^w	0.7/2.9 210 ^w	1.4/5.8 210 ^w	315 ^w
210 ^q	210 ^q	210 ^q	210 ^q	210 ^q	630 ^{1q, 5y}
0.020	0.020	0.020	0.020	0.020	0.020
A 130 ⁿ 9	A 100 ⁿ 7.5	A 100 ⁿ 7.5	A 100 ⁿ 7.5	A 100 ⁿ 7.5	A 300 ⁿ 21
13.5/68	13.5/68	13.5/68	13.5/68	13.5/68	4.5/22.7
1.95	1.96	1.96	1.98	1.99	1.96
1.72	1.85	1.87	1.89	1.86	1.79
0.60	0.60	0.62	0.62	0.65	0.62
405	422	499	584	631	340
0.13	0.14	0.17	0.19	0.21	0.11
0.43	0.54	0.63	0.60	0.66	0.46

TABLE I (Continued)

94	95	96	97	99	100
<u>Single Anode Discharge.</u>		<u>Replicates of Cells</u> <u>P-76 & P-77</u>		<u>Silver-Plated Copper</u> <u>Exmet Collectors.^w</u>	
5-1/4" Holes in Anodes.				No Holes in Anodes.	
-85 ^h	-85 ^h	-84 ^h	-84 ^h	-63	-63
54/58	43/55	73/105	67/80	51/75	42/50
0	0	0	0	0	0
17/70	17/70	17/70	17/70	21/85	17/70
7.3/30	7.3/30	7.3/30	7.3/30	3.7/15	7.3/30
105 ^w	105 ^w	210 ^w	210 ^w	210 ^w	210 ^w
105 ^q	105 ^q	210 ^q	210 ^q	210 ^q	210 ^q
0.020	0.020	0.020	0.020	0.020	0.020
A 100 ⁿ 7.5	A 100 ⁿ 7.5	A 100 ⁿ 7.5	A 100 ⁿ 7.5	A 125 ⁿ 9	A 125 ⁿ 9
13.5/68	13.5/68	13.5/68	13.5/68	13.5/68	13.5/68
2.02	2.01	2.06	2.00	2.08	2.06
1.84	1.81	1.77	1.78	1.64	1.64
1.30	1.30	0.67	0.66	0.70	0.70
428	405	785	587	456	374
0.14	0.13	0.26	0.19	0.15	0.12
0.45	0.42	0.83	0.61	0.50	0.33

TABLE I (Continued)

101	102	103	104	105	106	107
Silver-Plated Copper Exmet Collectors. ^w					Pb Exmet Collector. ^{xx}	
No Holes in Anodes.						
-63	-63	-63	-63	-63	-63	-63
44/54	66/75	38/48	28/49	49/75	42/54	37/56
0	0	0	0	0	0	0
17/70	17/70	17/70	17/70	21/85	17/70	17/70
7.3/30	7.3/30	7.3/30	7.3/30	3.7/15	7.3/30	7.3/30
210 ^w	210 ^w	210 ^w	210 ^w	210 ^w	210 ^{xx}	210 ^{xx}
210 ^q	210 ^q	210 ^q	210 ^q	210 ^q	210 ^q	210 ^q
0.020	0.020	0.020	0.020	0.020	0.020	0.020
A 125 ⁿ 9	A 125 ⁿ 9	A 125 ⁿ 9	A 125 ⁿ 9	A 125 ⁿ 9	A 125 ⁿ 9	A 125 ⁿ 9
13.5/68	13.5/68	13.5/68	13.5/68	13.5/68	13.5/68	13.5/68
2.03	2.12	2.08	2.07	2.06	1.75	1.79
1.64	1.58	1.66	1.75	1.64	1.69	1.68
0.69	0.71	0.71	0.70	0.70	0.60	0.61
401	571	361	367	454	367	386
0.13	0.19	0.12	0.12	0.15	0.12	0.13
0.35	0.51	0.32	0.33	0.50	0.30	0.31

TABLE I (Continued)

108	109	110	111	112	113	114
<u>Perforated Aluminum Collectors^{yy}</u>				<u>Gold-Plated Copper Exmet Collectors.^{ww}</u>		
-63	-40	-63	-40	-63	-63	-40
0/0	0/0	15/44	13/37	64/75	65/73	38/52
0	0	0	0	0	0	0
21/85	21/85	17/70	17/70	17/70	17/70	17/70
3.7/15	3.7/15	7.3/30	7.3/30	7.3/30	7.3/30	7.3/30
210 ^{yy}	210 ^{yy}	210 ^{yy}	210 ^{yy}	210 ^{ww}	210 ^{ww}	210 ^{ww}
210 ^q	210 ^q	210 ^q	210 ^q	210 ^q	210 ^q	210 ^q
0.020	0.020	0.020	0.020	0.020	0.020	0.020
A 125 ⁿ 9	A 125 ⁿ 9	A 125 ⁿ 9	A 125 ⁿ 9	A 125 ⁿ 9	A 125 ⁿ 9	A 125 ⁿ 9
13.5/68	13.5/68	13.5/68	13.5/68	13.5/68	13.5/68	13.5/68
1.21	1.56	1.89	2.09	2.07	2.07	2.15
----	1.46	1.75	1.77	1.55	1.83	1.82
----	----	0.57	0.61	0.67	0.67	0.73
----	----	313	280	567	552	400
----	----	0.10	0.09	0.19	0.18	0.13
----	----	0.26	0.25	0.51	0.49	0.36

TABLE I (Continued)

115	116	117	118	119	120
Au Plated Cu Exmet Collector ^{WW}	Silver-Plated Copper Collectors ^W	<u>Temperature Cathode Composition</u>			
-40	-40	-40	-63	-63	-40
34/39	8/11	30/35	32/38	35/39	35/51
0	0	0	20/55.6	20/55.6	20/55.6
17/70	17/70	17/70	4/11.1	4/11.1	4/11.1
7.3/30	7.3/30	7.3/30	12/33.3	12/33.3	12/33.3
210 ^{WW}	210 ^W	210 ^W	210 ^W	210 ^W	210 ^W
210 ^Q	210 ^Q	210 ^Q	210 ^Q	210 ^Q	210 ^Q
0.020	0.020	0.020	0.020	0.020	0.020
A 125 ⁿ 9	A 125 ⁿ 9	A 125 ⁿ 9	A 125 ⁿⁿ 9	A 125 ⁿⁿ 9	A 125 ⁿⁿ 9
13.5/68	13.5/68	13.5/68	13.5/68	13.5/68	13.5/68
2.14	2.05	2.11	2.13	2.24	2.32
1.72	1.46	1.57	1.52	1.40	1.47
0.72	0.69	0.72	0.73	0.77	0.80
298	82	274	206	218	291
0.10	0.03	0.09	0.27	0.28	0.38
0.27	0.07	0.25	0.26	0.29	0.39

TABLE I (Continued)

121	125	126	127	128	129
Temperature Note* Cathode Composition		Virgin Electrolyte Cathode Composition		"Spent" Electrolyte Cathode Composition	
-40	-63	-90	-90	-90	-90
29/38	41/43	0/95	17/89	25/110	90/113
20/55.6	20/55.6	0	0	0	0
4/11.1	4/11.1	21/85	21/85	17/70	17/70
12/33.3	12/33.3	3.7/15	3.7/15	7.3/30	7.3/30
210 ^w	210 ^{zz}	210 ^w	210 ^w	210 ^w	210 ^w
210 ^q	210 ^q	210 ^q	210 ^q	210 ^q	210 ^q
0.020	0.020	0.020	0.020	0.020	0.020
A 125 ⁿⁿ 9	B 125 ⁿⁿ 9	B 200 ⁿⁿ 13	B 200 ⁿⁿ 13	D 200 13	D 200 13
13.5/68	13.5/68	13.5/68	13.5/68	13.5/68	13.5/68
2.31	2.24	1.84	1.86	1.89	1.86
1.39	1.54	1.74	1.76	1.71	1.71
0.80	0.77	0.53	0.57	0.55	0.54
217	240	538	506	782	794
0.28	0.31	0.18	0.17	0.26	0.26
0.29	0.32	0.38	0.36	0.45	0.46

* Electrolyte Concentration, Aluminum Exmet Collector.

TABLE I (Continued)

130	131	132	133	134	
Temperature Concentra- tion of Electrolyte	Electrolyte Concentra- tion, Al Exmet Collector		Mg(SCN) ₂ Electrolyte S Treatment	Each Anode Loaded Separately With 1/2 Usual Load.	
				Anode A	Anode B
-63	-63	-63	-90	-90	
25/30	45/82	57/83	0/12	69/110	71/113
20/55.6	0	0	0	0	
4/11.1	17/70	17/70	17/70	17/70	
12/33.3	7.3/30	7.3/30	7.3/30	7.3/30	
210 ^w	210 ^{zz}	210 ^{zz}	210 ^w	210 ^w	
210 ^q	210 ^q	210 ^q	210 ^q	210 ^q	
0.020	0.020	0.020	0.020	0.020	
B 125 ⁿⁿ 9	B 125 ⁿⁿ 9	B 125 ⁿⁿ 9	G 125 9	A 125 ⁿⁿ 9	
13.5/68	13.5/68	13.5/68	13.5/68	27/136	27/136
1.98	2.05	2.05	1.71	1.91	1.88
1.50	1.75	1.79	1.65	1.69	1.53
0.67	0.64	0.65	0.48	0.62	0.63
155	612	620	80	392	399
0.20	0.20	0.20	0.03	0.13	0.13
0.19	0.54	0.55	0.06	0.33	0.33

TABLE II
ELECTROCHEMICAL CELL TESTS - BOBBIN CONFIGURATION

Separator, M-1365 ^u , 5 layers at 0.004"/layer = 0.020" thick.	Cell Number B-					
	Inverse Bobbins, Central Rod Anodes		Inverse Bobbins, Coiled Central Exmet Anodes, M-1365 Separation ^u			
	Major Variables		Major Variables			
Electrolyte Code: (All in liquid NH ₃).	Porous Polyethylene Separators ^{zz}		M-1365 ^u Separation		Acetylene Black	
	MPRV in Anode Coil		MPRV in Anode Coil		MPRV in Anode Coil	
	MPRV in Anode Coil		MPRV in Anode Coil		MPRV in Anode Coil	
End voltage under heavy load = 1.30.	Temperature, Nominal, °C		-90		-90	
	Hours to End Voltage ^b (1.5/1.3V)		2/4		0/0	
	Cathode: HgSO ₄ ^j Sulfur ^k Cl ^l		100/55.6 20/11.1 60/33.3		0 42.5/70 18.2/30	
	Acetylene Black ^{ll}		120		60.7	
	Total Weight (g)		2W		1W,C	
	Cathode Collector, Ag Wire (W), Case (C)		0.45/5.5		0.35/5	
	Cathode Thickness/length (in.)		Mg rod ^f 46		Mg rod ^g 51	
	Anode, Central		A ⁿ		A ⁿ	
	Anode, Apparent area (cm ²)		200		190	
	Anode, Outer (cylindrical)		16		17	
	Anode, Apparent area (cm ²)		2.7/13.5		5.4/27	
	Electrolyte Code		A ⁿ		A ⁿ	
	Electrolyte Vol.at Discharge Temp. (cc)		200		300	
	Net Cell Volume (in. ³) (Approx.)		16		25	
	Load ^a (ohms)		2.7/13.5		5.4/27	
	h.-Time-weighted average temp.	Peak Closed Circuit Voltage ^c		2.11		1.99
End Voltage Under Light Load		2.08		1.87		
Peak Anode C.D. ^{d,e} (mA/cm ²)		10.8		2.65		
i.-Maximum recorded temperature.	Obs. Coulombs/g Total Oxidants		Ni1		114	
	Obs. F/Mol Total Oxidants		Ni1		0.07	
	Watt Hours/in. ³ Net Cell		----		0.18	

TABLE II (Continued)

7	8 ¹	9 ¹	10 ²	11 ²
Inverse Bobbins. Holes in Anodes. Coiled Central Exmet Anode	<u>Annular Ring Cathodes</u>		<u>Central Bobbin Cathodes</u>	
Added Outer Anode.	Exmet Anodes	Sheet Anodes	Exmet Anodes	Sheet Anodes
-84 ^h	-82 ^h	-81 ^h	-81 ^h	-90
50/70	18/42	10/21	1/18	0/0
0	0	0	0	0
47.6/70	47.6/70	47.6/70	84/70	84/70
20.4/30	20.4/30	20.4/30	36/30	36/30
68	68	68	120	120
4W	4W	4W	2W	2W
0.24/5.3	0.24/7	0.25/5.5	1.16/7.3	1.16/7.3
Coil ^y	Coil ^y	Coil ^q		
108	144	120		
3 sheets ^y	2 sheets ^y	2 sheets ^q	2 sheets ^y	2 sheets ^q
167	226	188	175	181
A ⁿ	A ⁿ	A ⁿ	A ⁿ	A ⁿ
340	400	300	300	350
27	27	23	27	27
5.4/27	5.4/27	5.4/27	2.7/13.5	2.7/13.5
2.02	1.82	1.84	1.68	1.70
1.80	1.67	1.70	1.64	1.65
1.21	0.77	0.92	2.79	2.66
461	260	130	121	----
0.15	0.09	0.04	0.04	----
0.38	0.20	0.12	0.16	----

¹ Design similar to B-7, except both central & outside anode layers were separated by MPR^V strips. 1/4" holes in anodes.

² Two outer anodes separated by MPR^V strips. 1/4" holes in anodes.

TABLE II (Continued)

12	13	14	15	16
Central Anode. 6 Longitudinal Fins. <u>Annular Ring Cathode</u>	Central & Outside Anodes.	2 Outside Anodes. Central Bobbin Cathode.	Central Anode. 10 Longitu- dinal fins.	Central Exmet Coil and 3 Outer Anodes.
-82 ^h	-90	-90	-90	-90
19/26	23/56	0/22	54/62	25/42
0	0	0	0	0
84/70	63/70	98/70	84/70	61.6/70
36/30	27/30	42/30	36/30	26.4/30
	0	0	0	0
120	90	140	120	88
C	4W	2W	C	4W
0.37/5.5	0.24/6.75	1.16/10	0.30/6.75	0.25/5.25
Fins ^q 186	Coil ^y 139 2 sheets ^y 218	2 sheets ^y 242	10 Fins ^q 171	Coil ^y 108 3 sheets ^y 167
A ⁿ 250 23	A ⁿⁿ 400 27	A ⁿⁿ 500 35	A ⁿⁿ 400 31	A ⁿⁿ 350 27
5.4/27	5.4/27	2.7/13.5	5.4/27	5.4/27
1.90 1.70	1.84 1.78	1.80 1.71	1.94 1.82	1.91 1.84
1.59 94 0.03 0.15	0.79 264 0.09 0.27	2.14 132 0.04 0.15	1.78 226 0.08 0.28	1.06 209 0.07 0.21

TABLE II (Continued)

17	19	20	21	22	
"Spent" Electrolyte		Mg(SCN) ₂ Electrolyte		1/2 Virgin + 1/2 "Spent" Electrolyte	
	Acetylene Black	S:C	HgSO ₄ :C		Cumulative Hours
-90	-90	-90	-90	-40	-63
36/63	80/91	2/6	1/3	26/30	59/72
0	0	0	110/55.6	0	
84/70	44.4/50	44.4/50	22/11.1	44.4/50	
36/30	40/45	40/45	66/33.3	40/45	
0	4.4/5	4.4/5	0	4.4/5	
120	88.8	88.8	198	88.8	
C	C	C	C	C	
0.30/6.75	0.30/6.75	0.30/6.75	0.30/6.5	0.30/6.25	
10 Fins ^q	10 Fins ^q	10 Fins ^q	10 Fins ^q	10 Fins ^q	
171	171	171	165	158	
D	D	C	C	E	
400	350	400	300	450	
31	28	31	25	33	
5.4/27	5.4/27	5.4/27	5.4/27	5.4/27	
1.91	1.92	1.94	2.01	2.16	2.02
1.83	1.79	1.76	1.95	1.84	1.89
1.79	1.83	1.74	1.81	2.37	1.93
228	624	41	----	221	297
0.08	0.21	0.01	----	0.07	0.10
0.28	0.44	0.03	----	0.14	0.18

TABLE II (Continued)

23	24	25	26	27
Electrolyte Concentration & Kind. Acetylene Black.	1/2 Virgin + 1/2 "Spent" Electrolyte	S:C Ratio. No Acety- lene Black	Ball-milled in Heptane.	Electrolyte Concentration
-90	-90	-90	-90	-90
66/73	71/84	51/51	56/67	40/47
0	0	0	0	0
44.4/50	44.4/50	44.4/50	45/50	45/50
40/45	40/45	44.4/50	40.5/45	40.5/45
4.4/5	4.4/5	0	4.5/5	4.5/5
88.8	88.8	88.8	90	90
C	C	C	C	C
0.30/6.75	0.30/6.75	0.30/6.75	0.30/6.75	0.30/6.75
10 Fins ^q 171	10 Fins ^q 171	10 Fins ^q 171	10 Fins ^q 171	10 Fins ^q 171
Ann	E	Ann	Ann	Bnn
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	1.99	1.94	1.94	1.99
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

TABLE II (Continued)

28	29	30	31	32
Full Sized Cell. 20% Acetylene Black.	90% KSCN + 10% Mg(SCN) ₂ 20% Acetylene Black.	10% Acetylene Black.	Electrolyte Concentration.	50% Acetylene Black. No graphite. Mixed in heptane & dried.
-90	-90	-90	-90	-90
53/57	30/41	68/76	43/53	67/75
0	0	0	0	0
81/50	50/50	48/50 ^{kk}	48/50 ^{kk}	35/50 ^{kk}
48.5/30	30/30	38/40	38/40	0
32.5/20	20/20	10/10	10/10	35/50
162	100	96	96	70
C	C	C	C	C
0.30/13.5	0.30/6.75	0.30/6.75	0.30/6.75	0.30/6.75
10 Fins ^q 342	10 Fins ^q 171	10 Fins ^q 171	10 Fins ^q 171	10 Fins ^q 171
A ⁿⁿ	F	A ⁿⁿ	B ⁿⁿ	A ⁿⁿ
575	450	350	400	400
48	34	28	31	31
2.7/13.5	5.4/27	5.4/27	5.4/27	5.4/27
1.95	2.01	2.01	2.06	2.01
1.82	1.82	1.79	1.82	1.75
1.85	1.89	1.93	1.99	1.88
431	257	498	352	674
0.14	0.09	0.17	0.12	0.22
0.33	0.17	0.39	0.25	0.35

TABLE II (Continued)

33	34	35	36	37	38	39	40
TASK I. B. 1.							
Cells B-33 to B-40 were packed with a rod, as usual.							
-90	-90	-90	-90	-90	-63	-63	-40
56/63	61/70	48/53	51/56	54/63	59/73	47/61	83/100
0					0	0	0
85/50					42.5/50	48/50	48/50
68/40					34/40	38.5/40	38.5/40
17/10	Replicates of Cell B-33.				8.5/10	9.5/10	9.5/10
170					85	96	96
C					C	C	C
0.30/13.5					0.30/6.75	0.30/6.75	0.30/6.75
10 Finsq					10 Finsq	10 Finsq	10 Finsq
342					171	171	171
Ann					Ann	Ann	Ann
660					450	450	530
53					34	34	34
2.7/13.5					5.4/27	5.4/27	5.4/27
1.97	1.99	1.97	1.95	1.96	2.10	2.10	2.16
1.81	1.80	1.78	1.76	1.80	1.82	1.57	1.97
1.86	1.90	1.87	1.87	1.88	2.04	2.06	2.19
459	514	387	407	459	551	408	681
0.15	0.17	0.13	0.14	0.15	0.18	0.14	0.23
0.34	0.38	0.28	0.29	0.34	0.33	0.27	0.46

TABLE II (Continued)

41	42	43	44	45	46	47
The Cathodes of Cell N: B-41 and All Following Cells Were Packed With An Annular Sleeve Piston.						
	Dense Pack.	TASK I. B. 1.				
-40	-90	-90	-90	-90	-90	-90
99/108	49/61	55/77	52/58	57/65	52/58	55/63
0	0	0	Replicates of Cell No. B-43.			
48/50	120/50	96/50				
38.5/40	96/40	77/40				
9.5/10	24/10	19/10				
96	240	192				
C	C	C				
0.30/6.75	0.30/13.5	0.30/13.5				
10 Fins ^q 171	10 Fins ^q 342	10 Fins ^q 342				
Ann	Ann	Ann	Ann	Ann	Ann	Ann
545	676	676	676	660	697	676
34	55	55	55	55	55	55
5.4/27	2.7/13.5	2.7/13.5	2.7/13.5	2.7/13.5	2.7/13.5	2.7/13.5
2.15	1.97	1.96	1.98	1.96	1.97	1.94
1.95	1.80	1.80	1.79	1.77	1.77	1.77
2.18	1.88	1.89	1.85	1.85	1.86	1.86
736	314	495	375	419	375	403
0.24	0.10	0.16	0.12	0.14	0.12	0.13
0.50	0.30	0.39	0.30	0.33	0.30	0.32

TABLE II (Continued)

48	49	50	51	52	53
7 Collect- or Clamps on Case. Temp. ³	Cu Exmet Sleeve on Case Secured by 14 Clamps. Temp. ⁴	Replicates of Cell No. B-49.		S:C Ratio.	Increased Acetylene Black.
-55 ⁱ	-51 ⁱ	-90	-90	-90	-90
67/116	47/127	56/61	62/69	61/68	52/59
Replicates of Cell No. B-43.				0 77/40 96/50 19/10 192 C 0.30/13.5	0 65/40 65/40 32/20 162 C 0.30/13.5
10 Fins ^q 342	10 Fins ^q 342	10 Fins ^q 342	10 Fins ^q 342	10 Fins ^q 342	10 Fins ^q 342
A _{nn} 663 55	A _{nn} 687 55	A _{nn} 650 55	A _{nn} 650 55	A _{nn} 650 55	A _{nn} 690 55
2.7/13.5	2.7/13.5	2.7/13.5	2.7/13.5	2.7/13.5	2.7/13.5
2.08 1.85	2.14 1.85	1.99 1.79	1.98 1.80	1.98 1.81	1.98 1.78
2.06 772 0.26 0.63	2.18 862 0.29 0.72	1.96 397 0.13 0.32	1.91 449 0.15 0.36	1.91 548 0.18 0.35	1.90 563 0.19 0.30

³ Temp.: 24 hours at -90°C; 20 hours from -90°C to -55°C; balance of test at -65°C.

⁴ Temp.: 18 hours from -90°C to -51°C; balance at -65°C.

TABLE II (Continued)

54	55	56	57	58
<u>Mercuric Sulfate</u>		HgSO ₄	Electrolyte Saturated	HgSO ₄
Half-size		Temp.	With HgSO ₄ ^j	Half-size
		KSCN Conc.		
-90	-90	-63	-90	-90
101/113	59/72	68/76	64/84	96/106
10/9.5	106/47	53/47		10/9.5
48/45	20/9	10/9	48/50	48/45
38/36	90/40	45/40	38/40	38/36
10/9.5	10/4	5/4	10/10	10/9.5
106	226	113	96	106
C	C	C	C	C
0.03/6.75	0.30/13.5	0.30/6.75	0.30/6.75	0.30/6.75
10 Fins ^q	10 Fins ^q	10 Fins ^q	10 Fins ^q	10 Fins ^q
171	342	171	171	171
A ⁿⁿ	A ⁿⁿ	B ⁿⁿ	A ⁿⁿ	A ⁿⁿ
425	660	625	425	425
28	55	28	28	28
5.4/27	2.7/13.5	5.4/27	5.4/27	5.4/27
2.12	2.17	2.25	1.99	2.13
1.77	1.56	1.43	1.81	1.80
2.09	2.21	2.32	1.92	2.17
631	372	406	546	592
0.25	0.50	0.54	0.18	0.23
0.62	0.42	0.45	0.43	0.58

TABLE II (Continued)

59	60	61	62
Mercuric Sulfate			HgSO ₄ ^j in Webril Capsule in Anode Space.
Full-size	Temp.	Temp.	
-90	-40	-63	-90
95/111	97/127	158/176	71/82
20/9.5	10/9.5	10/9.5	
96/45.2	48/45.2	48/45.2	48/50
77/36.3	38,5.36.3	38.5/36.3	38.5/40
19/9.0	9.5/9.0	9.5/9.0	9.5/10
212	106	106	96
C	C	C	C
0.30/13.5	0.30/6.75	0.30/6.75	0.30/6.75
10 Fins ^q	10 Fins ^q	10 Fins ^q	10 Fins ^q
342	171	171	171
A ⁿⁿ	A ⁿⁿ	A ⁿⁿ	A ⁿⁿ
740	640	570	450
55	28	28	28
2.7/13.5	5.4/27	5.4/27	5.4/27
2.09	2.19	2.22	1.95
1.79	1.90	1.78	1.76
2.10	2.26	2.26	1.92
615	724	1010	526
0.24	0.28	0.40	0.17
0.61	0.73	1.02	0.41

TABLE II
ELECTROCHEMICAL CELL TESTS - BOBBIN CONFIGURATION

Separator, M-1365 ^u , 5 layers at 0.004"/layer = 0.020" thick.	Cell Number B-									
	63	64	65	67	69	66	68			
	Task III			Task III. A. 1.		Task III. A. 2.				
Electrolyte = 34 Wt.% KSCN ⁿⁿ in liquid NH ₃ .	Major Variables									
	"Mockup" Cells			No Storage Period		One week storage at +65°C (Unactivated)				
Case served as cathode collector.	All Cell Features Identical With Cell No. B-63.									
	Case closed (C) or open (O)									
	Temperature, Nominal, °C									
End voltage under heavy load = 1.50.	Hours to End Voltage ^b (1.5/1.3V)									
	81/101	87/97	85/96	94/105	85/92	85/93	84/94			
	Cathode: HgSO ₄ ^j (g/%) Sulfur ^k (g/%) Cl ^l (g/%) Acetylene Black ^{ll} (g/%) Total Weight (g) Cathode: Thickness/length (in.)									
All finned anodes were made from AZ31B Mg:	20/9.5 96/45.2 77/36.3 19/9 212 0.30/13.5									
	Anode: Central									
	Anode, Apparent Area (cm ²)									
(q) - Fabricated from sheet & rod.	q 342									
	Electrolyte Vol. at Discharge Temp. (cc)									
	Net Cell Volume (in ³ .) (Approx.)									
(qq) - Extruded.	Cells Open to Electrolyte Reservoir During Discharge.									
	500 39									
	Load ^a (ohms)									
	2.7/13.5									
	Peak Closed Circuit Voltage ^c									
	End Voltage Under Light Load									
	2.18	2.19	2.14	2.16	2.14	2.18	2.17			
	1.99	1.97	1.96	1.97	1.96	1.95	1.97			
	Peak Anode C.D. ^{d,e} (mA/cm ²)									
	Obs. Coulombs/g Total Oxidants									
	486	521	505	562	505	512	503			
	Obs. F/mol Total Oxidants									
	Watt Hours/in ³ . Net Cell									
	0.19	0.20	0.20	0.22	0.20	0.20	0.20			
	0.74	0.79	0.76	0.85	0.76	0.78	0.77			

TABLE II (Continued)

70	71	72	73	76	77
<u>Proportion of Mercuric Sulfate</u>				<u>HgSO₄ Added To Electrolyte</u>	
				1 gram	20 grams
0	0	0	0	0	0
-73	-73	-73	-73	-73	-73
62/73	85/105	112/136	110/123	64/71	28/39
1/1	5/5	10/9.5	20/17.3		
48/49.5	48/47.5	48/45.2	48/41.3	48/50	48/50
38.5/39.7	38.5/38.1	38.5/36.3	38.5/33.2	35.5/40	38.5/40
9.5/9.8	9.5/9.4	9.5/9	9.5/8.2	9.5/10	9.5/10
97	101	106	116	96	96
0.30/6.75	0.30/6.75	0.30/6.75	0.30/6.75	0.30/6.75	0.30/6.75
q	q	q	q	q	q
171	171	171	171	171	171
400	325	375	400	325	350
28	28	28	28	28	28
5.4/27	5.4/27	5.4/27	5.4/27	5.4/27	5.4/27
2.14	2.17	2.15	2.12	2.09	1.95
1.95	1.98	1.90	1.90	1.98	1.87
2.07	2.19	2.16	2.12	2.07	1.81
434	558	668	552	444	185
0.15	0.22	0.26	0.25	0.15	0.06
0.39	0.53	0.70	0.68	0.38	0.15

TABLE II (Continued)

75	74	78	79	80
Anode Experiments			Hg(SCN) ₂ 10g/9.5%	20Ω Fixed Load
Cylindrical Sheet Anode ^q Note ⁵ .	1/2" Rod Anode	1/2" Rod Anode, Fluted ^g 1g HgSO ₄ in Electrolyte		
0	0	0	0	0
-73	-73	-73	-73	-73
72/112	51/55	54/63	85/105	114/130
10/9.5	10/9.5		0	10/9.5
48/45.2	48/45.2	48/50	48/45.2	48/45.2
38.5/36.3	38.5/36.3	38.5/40	38.5/36.3	38.5/36.3
9.5/9	9.5/9	9.5/10	9.5/9	9.5/9
106	106	96	106	106
0.30/6.75	0.30/6.75	0.30/6.75	0.30/6.75	0.30/6.75
q	rod	g	q	q
166	68	68	171	171
325	325	300	360	300
28	28	28	28	28
5.4/27	5.4/27	5.4/27	5.4/27	20 ⁶
2.02	2.10	2.09	2.12	2.08
1.89	1.90	1.98	1.87	1.50
1.81	5.26	5.19	2.15	0.60
413	299	375	502	655
0.16	0.12	0.13	0.20	0.26
0.41	0.30	0.32	0.52	0.70

⁵ Erratic voltage during 1st day.⁶ Cyclic load 1st 2 hours only.

TABLE II (Continued)

81	83	85	82	84
Extruded Mg Anodes Used For 1st Time. Method of Activation Modified.				
<u>TASK III. B. 1. No Storage Period.</u>			<u>TASK III. B. 2. One Week Storage at +65°C (Unactivated)</u>	
All Cell Features Identical With Cell No. B-81.				
C				
-73				
87/115	91/112	90/115	77/92	81/88
20/9.5				
96/45.2				
77/36.3				
19/9				
212				
0.30/13.5				
qq				
342				
450 ⁷				
39				
2.7/13.5				
2.18	2.18	2.19	2.12	2.16
1.96	1.95	1.96	1.95	1.95
2.11	2.16	2.16	1.96	2.11
550	577	571	472	510
0.22	0.23	0.22	0.18	0.20
0.90	0.95	0.93	0.75	0.83

⁷ Average difference in reservoir contents before and after activation.

TABLE II (Continued)

87	88	86	89	90	91
Osterizer dry. 53g/1 min.	Osterizer, 800 ml heptane, 212g cathode. Mixed 3 min.	Patterson-Kelley Twin Shell Blender. 424 grams Mixed 10 Minutes (net).			
All Cell Features, Except Method of Mixing, Identical With Cell No. B-87.					
0					
-73					
113/124	95/111	109/114	113/123	108/118	102/112
10/9.5					
48/45.2					
38.5/36.3					
9.5/9					
106					
0.30/6.75					
q					
171					
375					
28					
5.4/27					
2.16	2.19	2.19	2.21	2.19	2.19
1.98	1.94	2.02	2.02	2.00	2.00
2.18	2.23	2.19	2.21	2.16	2.18
715	611	696	722	696	642
0.28	0.23	0.27	0.28	0.27	0.25
0.60	0.51	0.59	0.60	0.55	0.53

TABLE II (Continued)

92	93	94	95	96	97	98
Hand-mixed.	Patterson-Kelley Twin Shell Blender. 848 grams Blended for 3 Minutes. Extruded Magnesium Anodes.					
	All Cell Features, Except Method of Mixing, Identical With No. B-92.					
0						
-73						
110/122	110/128	93/103	95/106	83/95	103/107	112/121
10/9.5						
48/45.2						
38.5/36.3						
9.5/9						
106						
0.30/6.75						
qq						
171						
375						
28						
5.4/27						
2.17	2.19	2.17	2.18	2.19	2.19	2.19
2.00	2.01	2.01	2.01	1.96	1.99	1.98
2.14	2.23	2.20	2.20	2.25	2.22	2.28
690	700	588	600	513	651	705
0.27	0.27	0.23	0.24	0.20	0.25	0.28
0.78	0.80	0.67	0.68	0.57	0.74	0.80

TABLE II (Continued)

99	100	101	102	103
Patterson-Kelley Twin Shell Blender. 848 grams Blended for 15 Minutes. HgSO ₄ was Mortar and Pestled. Extruded Magnesium Anodes.				Incomplete Activation.
These Four Cells Are Replicates.				
0				C
-73				-73
93/99	84/90	112/117	117/127	46/51
10/9.5				20/9.5
48/45.2				96/45.2
38.5/36.3				77/36.3
9.5/9				19/9
106				212
0.30/6.75				0.30/13.5
qq				qq
171				342
375				
28				39
5.4/27				2.7/13.5
2.14	2.17	2.24	2.24	2.24
2.04	2.04	2.03	2.03	2.02
2.16	2.22	2.31	2.31	2.25
590	542	720	758	300
0.23	0.21	0.28	0.30	0.10
0.67	0.63	0.83	0.88	0.50

TABLE II (Continued)

106	107	108	109	110
Hand-mixed Cathodes. Cathode Aged 5-1/2 Months.	Freshly Mixed. ⁸	P-K Blender as in B-93.	Notes ⁹ & ¹¹ .	MPR Separator. Notes ¹⁰ & ¹¹ .
0	0	0	C	C
-73	-73	-73	-20	-20
102/116	89/93	81/89	84/94	27/28
10/9.5	10/9.5	10/9.5	10/9.5	10/9.5
48/45.2	48/45.2	48/45.2	48/45.2	48/45.2
38.5/36.3	38.5/36.3	38.5/36.3	38.5/36.3	38.5/36.3
9.5/9	9.5/9	9.5/9	9.5/9	9.5/9
106	106	106	106	106
0.30/6.75	0.30/6.75	0.30/6.75	0.30/6.75	0.30/6.75
qq	qq	qq	qq	qq
171	171	171	171	171
350	350	375	312	312
28	28	28	24	24
5.4/27	5.4/27	5.4/27	5.4/27	5.4/27
2.22	2.22	2.24	2.31	2.32
2.04	2.05	2.10	1.94	2.02
2.25	2.25	2.28	2.41	2.43
660	580	529	550	180
0.22	0.19	0.17	0.22	0.07
0.77	0.68	0.62	0.76	0.25

⁸ Fresh cathode, hand-mixed; all others from B-103 to B-115 aged 4-1/2 months or longer.

⁹ Discharged for 20 hours at +20°C; continued at -20°C.

¹⁰ Discharged for 20 hours at +20°C, then 8 hours at -20°C, continued at +20°C. Life and output cover total run at +20°C and -20°C.

¹¹ B-109, 110, 111, 112 and 114 were half-sized cells in full-sized cases to provide for excess electrolyte and for substantial gas space.

TABLE II (Continued)

111	112	113	114	115
Note ¹¹ :	Corrosion Inhibitor. 40g S/L of Electrolyte. Note ¹¹ .	Act. Method. Anodized Plug. Al Sleeve Collector.	5% by Vol. Corrosion Inhibitor. Note ¹¹ .	Act. Method Pt Wire Collector. Top Plug Hollow and Anodized.
C	C	C	C	C
-20	-20	+20	-20	+20
50/54	55/65	132/147	56/60	151/161
10/9.5	10/9.5	20/9.5	10/9.5	20/9.5
48/45.2	48/45.2	96/45.2	48/45.2	96/45.2
38.5/36.3	38.5/36.3	77/36.3	38.5/36.3	77/36.3
9.5/9	9.5/9	19/9	9.5/9	19/9
106	106	212	106	212
0.30/6.75	0.30/6.75	0.30/13.5	0.30/6.75	0.30/13.5
qq	qq	qq	qq	qq
171	171	342	171	342
312	312	452	312	452
24	24	39	24	39
5.4/27	5.4/27	2.7/13.5	5.4/27	2.7/13.5
2.29	2.24	2.21	2.22	2.26
1.97	2.03	1.72	1.93	1.72
2.16	2.32	2.23	2.28	2.27
337	366	816	368	935
0.13	0.14	0.32	0.14	0.37
0.46	0.50	1.28	0.50	1.47

⁸ Fresh cathode, hand-mixed; all others from B-103 to B-115 aged 4-1/2 months or longer.

⁹ Discharged for 20 hours at +20°C; continued at -20°C.

¹⁰ Discharged for 20 hours at +20°C, then 8 hours at -20°C, continued at +20°C. Life and output cover total run at +20°C and -20°C.

¹¹ B-109, 110, 111, 112 and 114 were half-sized cells in full-sized cases to provide for excess electrolyte and for substantial gas space.

TABLE III-A

PERIODIC CELL VOLTAGES - PRISMATIC CELLS

Test No.	High Load Voltage After: (Hours)						Low Load Voltage After: (Hours)						Hours to: ^d	
	12	24	36	48	60	72	12	24	36	48	60	72	1.5V	1.3V
P- 1	1.70	1.73	1.64	1.38	1.18	1.10	2.10	2.13	2.10	1.92	1.76	1.70	42	52
P- 2	1.83	1.73	1.60	1.55	1.41	1.28	2.10	2.10	2.02	1.98	1.85	1.77	55	71
P- 3	1.87	1.58	0.95	----	----	----	2.05	1.75	1.07	----	----	----	26	30
P- 4	1.65	1.38	0.97	----	----	----	1.83	1.58	1.05	----	----	----	17	26
P- 5	1.97	1.84	1.68	1.32	1.12	----	2.15	2.10	1.95	1.70	1.45	----	41	49
P- 6	1.93	1.61	1.38	----	----	----	2.09	1.81	1.58	----	----	----	31	38
P- 7	2.27	2.18	1.73	1.30	----	----	2.30	2.28	1.91	1.53	----	----	44	48
P- 8	2.25	2.08	1.66	1.13	----	----	2.28	2.22	1.80	1.27	----	----	41	44
P- 9	1.93	2.11	1.59	1.37	1.11	----	2.12	2.20	1.75	1.63	1.33	----	44	51
P-10	2.08	2.09	1.63	1.51	1.12	----	2.17	2.18	1.80	1.70	1.30	----	49	55
P-11	1.94	1.98	1.60	1.41	1.10	----	2.10	2.12	1.77	1.63	1.30	----	45	52
P-12	2.16	1.94	1.55	1.30	0.99	----	2.21	2.10	1.73	1.55	1.18	----	41	48
P-13a	1.42	----	----	----	----	----	2.00	----	----	----	----	----	10	13
P-13b	----	1.92	1.96	1.92	1.60	1.54	----	2.09	2.13	2.12	1.84	1.77	73	83
P-14	1.95	2.02	1.90	1.75	1.55	1.38	2.14	2.15	2.13	1.97	1.80	1.67	68	75
P-15	1.90	1.77	1.62	1.36	1.25	----	1.98	1.95	1.95	1.86	1.75	----	43	54
P-16	1.88	1.73	1.63	1.48	1.32	----	1.95	1.92	1.92	1.84	1.66	----	47	61
P-17	1.73	1.69	1.63	1.53	1.40	1.03	1.97	1.95	1.90	1.85	1.80	1.30	53	66
P-18	2.09	1.93	1.65	1.54	1.32	1.13	2.15	2.05	1.83	1.73	1.57	1.35	51	62
P-19	2.13	2.05	1.60	1.37	1.06	0.98	2.19	2.17	1.80	1.64	1.27	1.13	44	50
P-20	2.15	2.05	1.40	0.95	----	----	2.21	2.17	1.62	1.09	----	----	34	38
P-21	x	2.12	1.95	1.74	1.24	----	x	2.22	2.17	2.11	1.83	----	55	59
P-22	1.80	1.77	1.72	1.65	1.55	1.27	2.00	1.98	1.96	1.90	1.85	1.63	64	71

TABLE III-A (Continued)

PERIODIC CELL VOLTAGES - PRISMATIC CELLS

Test No.	High Load Voltage After: (Hours)					Low Load Voltage After: (Hours)					Hours to: ^d			
	12	24	36	48	60	72	12	24	36	48	60	72	1.5V	1.3V
P-23	2.15	1.72	1.60	1.33	1.10	----	2.21	1.90	1.79	1.62	1.33	----	42	50
P-24	1.89	----	----	----	----	----	2.08	----	----	----	----	----	14	15
P-25	2.19	2.14	1.97	1.55	1.42	----	2.24	2.24	2.20	1.92	1.72	----	54	63
P-27	2.02	1.27	----	----	----	----	2.19	2.17	1.77	1.92	1.99	----	22	24
P-28	2.08	1.77	2.17	1.91	1.69	1.50	2.23	2.16	2.26	2.18	1.97	1.88	72	83
P-29	1.80	1.80	1.92	1.60	1.33	----	2.03	2.02	2.07	1.92	1.62	----	52	62
P-30	2.15	1.93	2.02	1.60	1.39	----	2.22	2.16	2.13	1.90	1.67	----	52	67
P-31	2.08	2.18	2.26	1.62	1.27	----	2.25	2.26	2.31	1.97	1.64	----	54	59
P-33	1.72	1.73	1.67	1.70	1.63	1.64	1.98	1.99	1.98	1.98	1.96	1.95	109	113
P-34	1.83	1.81	1.74	1.81	1.73	1.66	2.02	2.01	1.99	2.02	1.99	1.95	79	85
P-35	1.80	1.77	1.79	1.78	1.53	----	2.00	2.00	1.99	1.96	1.87	----	60	67
P-36	2.17	2.17	1.77	1.74	1.58	1.45	2.25	2.25	2.00	1.98	1.88	1.75	70	78
P-37	2.20	2.18	2.15	1.59	1.62	1.35	2.26	2.27	2.25	1.95	2.00	1.72	69	73
P-38	1.79	1.66	1.62	1.59	1.53	1.52	2.03	1.90	1.88	1.87	1.85	1.86	74	113
P-39	1.88	1.69	1.32	1.34	1.23	----	2.09	1.98	1.96	1.51	1.90	----	36	43
P-40	1.93	1.92	1.75	1.25	----	----	1.97	1.97	1.95	1.50	----	----	42	44
P-41	1.78	1.80	1.55	1.48	----	----	1.92	1.94	1.87	1.75	----	----	48	50
P-42	2.23	1.70	1.46	1.05	----	----	2.30	1.85	1.66	1.24	----	----	36	40
P-45	2.03	1.81	0.81	----	----	----	2.24	2.04	1.71	----	----	----	27	28
P-48	1.61	1.13	----	----	----	----	1.95	1.67	----	----	----	----	17	21
P-49	1.67	1.56	1.57	1.37	1.17	----	1.95	1.90	1.85	1.80	1.64	----	41	51
P-52	2.01	2.03	1.98	1.81	1.66	1.54	2.23	2.23	2.21	2.03	1.90	1.85	81	93
P-53	2.16	2.11	1.94	1.84	1.73	1.65	2.26	2.25	2.22	2.18	2.12	2.00	98	117

TABLE III-A (Continued)

PERIODIC CELL VOLTAGES

Prismatic Cells

Test No.	High Load Voltage After: (Hours)						Low Load Voltage After: (Hours)						Hours to: d	
	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	0.93	----	----	2.24	2.12	2.12	----	----	----	24	26
P-60	2.08	2.04	1.86	1.52	0.73	----	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	0.70	----	----	----	----	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 (Continued)

PERIODIC CELL VOLTAGES

Prismatic Cells

Test No.	High Load Voltage After: (Hours)					Low Load Voltage After: (Hours)					Hours to: ^d			
	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
P-106	1.65	1.62	1.56	1.40	1.17	----	1.71	1.72	1.70	1.70	1.63	----	42	54

TABLE III-A (Continued)

PERIODIC CELL VOLTAGES

Prismatic Cells

Test No.	High Load Voltage After: (Hours)					Low Load Voltage After: (Hours)					Hours to: d			
	12	24	36	48	60	72	12	24	36	48	60	72	1.5V	1.3V
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*	2.07	2.07	2.07	2.02	1.93	1.62*	64*	75*
P-113	1.90	1.89	1.85	1.75	1.59	1.32*	2.07	2.06	2.06	2.02	1.95	1.79*	65*	73*
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	0.70	----	----	----	----	1.45	0.92	----	----	----	----	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

*Recorder failure; voltage estimated.

TABLE III-B
PERIODIC CELL VOLTAGES

Test No.	Bobbin Cells												Hours to: d	
	High Load Voltage After: (Hours)						Low Load Voltage After: (Hours)							
	12	24	36	48	60	72	12	24	36	48	60	72	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*	----	----	1.75	1.66	1.66	1.68	----	----	18	42*
B- 9	1.45	1.21	1.26	1.31	----	----	1.78	1.65	1.69	1.75	----	----	10	21
B-10	1.33	0.95	----	----	----	----	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
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

*Temperature increase; voltage estimated.

TABLE III-B (Continued)

PERIODIC CELL VOLTAGES

Bobbin Cells

Test No.	High Load Voltage After: (Hours)					Low Load Voltage After: (Hours)					Hours to: d			
	12	24	36	48	60	72	12	24	36	48	60	72	1.5V	1.3V
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

TABLE III-B (Continued)

PERIODIC CELL VOLTAGES

Bobbin Cells

Test No.	High Load Voltage After: (Hours)						Low Load Voltage After: (Hours)						Hours to: d	
	12	24	36	48	60	72	12	24	36	48	60	72	1.5V	1.3V
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
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
B-65	1.75	1.81	1.82	1.80	1.69	1.66	2.00	2.05	2.05	2.05	2.04	2.04	85	96
B-66	1.75	1.85	1.86	1.85	1.74	1.68	1.98	2.05	2.05	2.05	2.04	2.02	85	93
B-67	1.78	1.84	1.85	1.82	1.74	1.73	2.10	2.05	2.06	2.06	2.05	2.05	94	105
B-68	1.75	1.83	1.83	1.83	1.74	1.66	1.99	2.04	2.05	2.05	2.04	2.00	84	94
B-69	1.70	1.76	1.79	1.79	1.70	1.65	2.00	2.05	2.05	2.05	2.04	2.02	85	92
B-70	1.88	1.87	1.87	1.85	1.51	1.30	2.08	2.08	2.07	2.07	1.98	1.88	62	73
B-71	1.88	1.88	1.89	1.80	1.65	1.61	2.06	2.06	2.05	2.04	2.02	2.02	85	105

TABLE III-B (Continued)

PERIODIC CELL VOLTAGES

Bobbin Cells

Test No.	High Load Voltage After: (Hours)						Low Load Voltage After: (Hours)						Hours to: d	
	12	24	36	48	60	72	12	24	36	48	60	72	1.5V	1.3V
B-72	1.95	1.79	1.78	1.75	1.77	1.74	2.12	1.95	1.96	1.95	1.94	1.93	112	136
B-73	1.94	1.93	1.71	1.71	1.70	1.68	2.09	2.09	1.95	1.91	1.90	1.91	110	123
B-74	1.87	1.74	1.71	1.63	1.14	----	2.06	1.92	1.94	1.93	1.84	----	51	55
B-75	1.43	1.13	1.54	1.60	1.52	1.45	1.98	1.79	1.93	1.95	1.90	1.89	72	112
B-76	1.92	1.89	1.90	1.84	1.62	1.27	2.09	2.08	2.08	2.06	2.02	1.92	64	71
B-77	1.65	1.54	1.84	1.13	----	----	1.95	1.92	1.83	1.71	----	----	28	39
B-78	1.85	1.73	1.68	1.62	1.33	----	2.06	1.98	1.98	1.98	1.91	----	54	63
B-79	1.91	1.80	1.76	1.74	1.70	1.66	2.07	1.86	1.95	1.94	1.92	1.90	85	105
B-80*	2.05	1.90	1.90	1.86	1.85	1.89	-	-	-	-	-	-	114	130
B-81	1.83	1.84	1.80	1.80	1.81	1.76	2.10	2.06	2.05	2.06	2.05	2.04	87	115
B-82	1.74	1.71	1.74	1.71	1.69	1.57	2.10	2.02	2.03	2.01	2.00	1.96	77	92
B-83	1.83	1.87	1.85	1.89	1.86	1.78	2.08	2.06	2.05	2.07	2.06	2.03	91	112
B-84	1.75	1.82	1.83	1.82	1.80	1.69	2.05	2.05	2.05	2.04	2.04	2.00	81	88
B-85	1.86	1.87	1.80	1.89	1.80	1.82	2.10	2.06	2.06	2.07	2.06	2.04	90	115
B-86	2.00	1.84	1.86	1.85	1.86	1.80	2.18	2.04	2.06	2.06	2.09	2.09	109	114
B-87	1.98	1.81	1.80	1.85	1.81	1.80	2.15	2.06	2.06	2.06	2.05	2.03	113	124
B-88	2.05	1.90	1.90	1.90	1.90	1.80	2.18	2.06	2.07	2.06	2.08	2.05	95	111
B-89	2.02	1.85	1.82	1.80	1.87	1.80	2.17	2.06	2.06	2.07	2.05	2.05	113	123
B-90	1.97	1.77	1.80	1.84	1.83	1.80	2.17	2.03	2.05	2.05	2.05	2.05	108	118
B-91	2.00	1.85	1.80	1.79	1.74	1.70	2.17	2.04	2.05	2.05	2.05	2.00	102	112

*This half-sized cell was discharged through a 20 Ω load resistor rather than the normal cyclic load; 20 Ω being the weighted average.

TABLE III-B (Continued)

PERIODIC CELL VOLTAGES

Bobbin Cells

Test No.	High Load Voltage After: (Hours)						Low Load Voltage After: (Hours)						Hours to: d	
	12	24	36	48	60	72	12	24	36	48	60	72	1.5V	1.3V
B- 92	1.96	1.81	1.82	1.82	1.75	1.75	2.16	2.05	2.05	2.04	2.04	2.03	110	122
B- 93	2.05	1.87	1.90	1.90	1.82	1.81	2.18	2.05	2.05	2.07	2.05	2.05	110	128
B- 94	2.02	1.84	1.85	1.86	1.86	1.66	2.17	2.04	2.05	2.05	2.05	2.04	93	106
B- 95	2.04	1.86	1.88	1.84	1.84	1.76	2.17	2.03	2.05	2.04	2.05	2.03	95	110
B- 96	2.07	1.79	1.78	1.75	1.75	1.65	2.18	2.00	1.94	1.95	1.94	1.95	83	95
B- 97	2.04	1.87	1.87	1.80	1.80	1.78	2.19	2.04	2.05	2.04	2.03	2.02	103	107
B- 98	2.09	1.90	1.83	1.76	1.76	1.82	2.18	2.04	2.03	1.97	2.03	2.03	112	121
B- 99	1.98	1.84	1.75	1.75	1.81	1.77	2.14	2.02	2.02	2.01	2.03	2.02	93	99
B-100	2.05	1.88	1.89	1.89	1.83	1.80	2.17	2.04	2.06	2.04	2.03	2.03	83	90
B-101	2.12	1.94	1.93	1.84	1.81	1.80	2.23	2.08	2.08	2.03	2.07	2.07	112	117
B-102	2.11	1.95	1.96	1.94	1.92	1.87	2.23	2.09	2.11	2.10	2.09	2.08	117	127
B-103	1.91	1.89	1.80	1.40	1.17	----	2.10	2.10	2.08	2.00	1.91	----	46	51
B-106	2.06	1.92	1.92	1.92	1.90	1.78	2.22	2.10	2.11	2.11	2.10	2.07	102	116
B-107	2.06	1.92	1.91	1.92	1.89	1.76	2.22	2.09	2.10	2.10	2.09	2.07	89	93
B-108	2.07	1.93	1.92	1.90	1.92	1.73	2.22	2.10	2.09	2.10	2.11	2.09	81	89
B-109	2.05	2.00	2.00	1.92	1.87	1.73	2.13	2.15	2.15	2.14	2.10	2.05	84	94
B-110	2.06	1.66	0.91	----	----	----	2.15	2.08	1.72	----	----	----	27	32
B-111	2.15	2.00	1.99	1.80	1.33	----	2.17	2.11	2.14	2.05	1.90	----	50	54
B-112	2.03	2.00	1.98	1.81	1.38	1.10	2.17	2.17	2.18	2.10	1.96	1.84	55	65
B-113	2.03	1.99	1.97	1.94	1.92	1.76	2.14	2.11	2.11	2.10	2.09	1.94	132	147
B-114	2.02	2.00	1.98	1.80	1.31	----	2.11	2.10	2.09	2.05	1.86	----	56	60
B-115	2.00	1.97	1.95	1.95	1.93	1.87	2.15	2.14	2.13	2.13	2.11	2.05	151	161

TABLE III-C
PERIODIC CELL VOLTAGES
TASK IV, Bobbin Cells

Test No.	High Load Voltage After: (Hours)						Low Load Voltage After: (Hours)						Hours to: d	
	12	24	36	48	60	72	12	24	36	48	60	72	1.5V	1.3V
IV-02	1.97	1.80	1.68	1.60	1.57	1.55	2.10	2.05	2.04	1.95	1.93	1.92	85	94
IV-03	2.04	2.00	1.90	1.58	1.03	----	2.17	2.14	2.11	2.03	1.95	----	49	52
IV-04	1.90	1.72	1.73	1.72	1.65	1.47	2.14	1.93	1.94	1.95	1.94	1.90	70	79
IV-05	2.08	1.89	1.92	1.89	1.90	1.87	2.22	2.06	2.09	2.07	2.08	2.10	82	96
IV-06	2.10	2.02	1.84	1.34	----	----	2.19	2.15	2.11	1.96	----	----	44	50
IV-07	2.05	1.90	1.90	1.89	1.88	1.83	2.22	2.08	2.09	2.09	2.09	2.08	81	101
IV-08	1.86	1.90	1.87	1.87	1.83	1.62	2.04	2.06	2.06	2.06	2.06	2.00	80	101
IV-09	1.85	1.84	1.87	1.82	1.68	1.50	2.02	2.00	2.05	2.02	2.03	1.98	74	95
IV-10	1.80	1.43*	1.71	1.65	1.60	1.58	2.07	1.97	2.02	1.98	1.93	1.91	96	103
IV-11	2.01	1.94	1.78	1.20	0.87	----	2.15	2.12	2.09	1.96	1.85	----	44	47
IV-12	1.80	1.72	1.72	1.70	1.55	1.41	2.11	1.93	1.95	1.95	1.92	1.88	67	76
IV-13	2.08	1.91	1.93	1.90	1.90	1.85	2.21	2.05	2.08	2.07	2.07	2.09	81	101
IV-14	2.09	2.01	1.81	1.30	----	----	2.19	2.14	2.10	1.96	----	----	44	48
IV-15	2.04	1.89	1.90	1.89	1.88	1.85	2.21	2.08	2.10	2.09	2.09	2.07	81	102
IV-16	1.57	1.69	1.21	----	----	----	2.03	2.04	1.92	----	----	----	26	29
IV-17	2.10	2.06	2.03	2.03	2.04	1.95	2.18	2.17	2.10	2.12	2.15	2.08	143	157
IV-18	1.79	1.56*	1.69	1.74	1.82	1.75	2.07	2.00	2.02	2.03	2.03	1.99	97	104
IV-19	2.02	1.96	1.84	1.30	----	----	2.15	2.12	2.09	1.98	----	----	46	48
IV-20	1.97	1.73	1.75	1.75	1.73	1.64	2.15	1.94	1.96	1.96	1.96	1.95	85	89
IV-21	2.09	1.91	1.93	1.90	1.91	1.85	2.22	2.06	2.08	2.07	2.08	2.10	80	94

* Poor activation at room temperature. Additional electrolyte at 28 hours.

TABLE III-C (Continued)

PERIODIC CELL VOLTAGES

TASK IV, Bobbin Cells

Test No.	High Load Voltage After: (Hours)					Low Load Voltage After: (Hours)					Hours to: d			
	12	24	36	48	60	72	12	24	36	48	60	72	1.5V	1.3V
IV-22	2.10	2.02	1.83	1.30	----	----	2.19	2.15	2.12	1.94	----	----	40	48
IV-23	2.04	1.90	1.90	1.89	1.88	1.83	2.11	2.08	2.08	2.08	2.08	2.08	84	108
IV-24	1.85	1.85	1.82	1.49	1.33	1.24	2.03	2.04	2.04	2.02	1.91	1.86	48	61
IV-25	2.07	2.02	2.00	1.97	1.93	1.83	2.15	2.13	2.11	2.09	2.08	2.03	113	143
IV-26	2.05	1.98	1.78	1.37	1.23	----	2.15	2.12	2.08	1.93	1.84	----	44	52
IV-27	1.85	1.85	1.85	1.77	1.48	----	2.09	2.07	2.08	2.05	2.00	----	60	66
IV-29	2.08	2.04	2.03	2.01	1.99	1.94	2.15	2.14	2.13	2.12	2.09	2.05	135	145
IV-30	2.13	2.08	2.05	1.87	1.29	----	2.25	2.19	2.18	2.13	2.01	----	56	60
IV-31	1.96	1.77	1.77	1.75	1.73	1.65	2.17	1.96	1.97	1.96	1.97	1.97	84	89
IV-32	2.08	1.92	1.93	1.92	1.90	1.86	2.22	2.09	2.10	2.10	2.10	2.09	84	100
IV-33	2.10	2.03	2.02	2.00	1.98	1.88	2.15	2.12	2.12	2.10	2.08	2.01	75	75
IV-34	2.04	1.96	1.70	1.32	1.16	----	2.15	2.11	2.04	1.92	1.77	----	41	50
IV-35	1.86	1.87	1.87	1.77	1.47	----	2.08	2.08	2.08	2.05	2.02	----	59	67
IV-36	1.79	1.77	1.63	0.96	----	----	2.01	1.98	2.00	1.78	----	----	39	43
IV-37	2.08	2.05	2.03	2.01	2.00	1.93	2.15	2.14	2.13	2.12	2.10	2.02	141	149
IV-38	2.13	2.08	2.04	1.88	1.26	----	2.25	2.19	2.17	2.13	2.02	----	56	59
IV-39	1.98	1.79	1.79	1.75	1.68	1.68	2.18	1.96	1.97	1.98	1.97	1.96	88	93
IV-40	2.07	1.92	1.92	1.90	1.90	1.86	2.21	2.08	2.09	2.10	2.09	2.08	87	107
IV-41	2.10	2.04	1.90	1.38**	1.50	1.27	2.21	2.17	2.14	1.97	2.02	1.92	45	51
IV-42	2.09	1.96	1.77	1.35	1.23	----	2.15	2.12	2.07	1.93	1.84	----	42	56

**Reactivated after cut-off at 45 hours.

TABLE III-C (Continued)

PERIODIC CELL VOLTAGES

TASK IV, Bobbin Cells

Test No.	High Load Voltage After: (Hours)						Low Load Voltage After: (Hours)						Hours to: d	
	12	24	36	48	60	72	12	24	36	48	60	72	1.5V	1.3V
IV-43	1.86	1.89	1.88	1.84	1.57	----	2.07	2.08	2.09	2.07	2.03	----	62	68
IV-44	1.80	1.78	1.72	1.13	----	----	2.03	2.00	2.02	1.88	----	----	42	46
IV-45	2.08	2.04	2.02	2.00	1.98	1.93	2.15	2.14	2.13	2.11	2.09	2.04	148	156
IV-46	2.12	2.08	2.04	1.85	1.26	----	2.24	2.18	2.16	2.12	2.02	----	56	59
IV-47	2.00	1.78	1.78	1.77	1.68	1.65	2.17	1.97	1.98	1.98	1.96	1.95	81	87
IV-48	2.06	1.90	1.92	1.91	1.88	1.83	2.21	2.09	2.09	2.09	2.09	2.08	85	108
IV-49	2.04	1.91	1.90	1.89	1.86	1.72	2.22	2.10	2.09	2.09	2.08	2.05	81	93
IV-50	1.77	1.78	1.48	----	----	----	2.06	2.07	2.02	----	----	----	33	39
IV-51	2.07	1.91	1.90	1.90	1.86	1.73	2.23	2.09	2.10	2.09	2.08	2.05	88	98
IV-52	2.11	2.07	2.04	1.89	1.20	----	2.25	2.20	2.16	2.13	1.97	----	55	58
IV-53	1.88	1.85	1.84	1.79	1.75	1.68	2.16	2.08	2.08	2.07	2.05	2.05	79	82
IV-55	2.05	1.98	1.78	1.09	----	----	2.17	2.14	2.10	1.95	----	----	41	44
IV-56	2.05	1.99	1.97	1.96	1.88	1.78	2.13	2.11	2.09	2.09	2.04	1.93	113	125
IV-57	2.00	1.93	1.85	1.70	1.32	----	2.18	2.13	2.12	2.08	2.06	----	52	55
IV-58	2.06	2.00	2.00	1.99	1.98	1.87	2.18	2.13	2.13	2.10	2.11	2.00	128	138

TABLE III-D

PERIODIC CELL VOLTAGES

TASK V, Bobbin Cells

Test No.	High Load Voltage After: (Hours)				Low Load Voltage After: (Hours)				Hours to: d					
	12	24	36	48	60	72	12	24	36	48	60	72	1.5V	1.3V
V-01	2.06	2.01	2.00	1.96	1.96	1.88	2.15	2.12	2.12	2.10	2.08	2.02	139	146
V-02	2.03	1.92	1.58	1.29	1.05	----	2.15	2.10	1.95	1.85	1.63	----	38	47
V-03	2.08	2.02	2.02	1.91	1.28	1.00	2.23	2.18	2.16	2.13	1.99	1.86	56	59
V-05	2.10	1.95	1.95	1.91	1.88	1.86	2.21	2.08	2.08	2.08	2.08	2.08	90	103
V-06	1.93	1.76	1.47*	1.18*	1.74	1.52	2.16	1.96	1.97	1.87	1.97	1.94	73	74
V-07	2.07	2.03	2.02	1.97	1.95	1.88	2.16	2.14	2.14	2.09	2.08	2.04	140	152
V-09	2.04	1.96	1.70	1.29	1.15	----	2.16	2.13	2.03	1.89	1.75	----	43	47
V-10	2.11	1.95	1.94	1.90	1.87	1.84	2.24	2.10	2.10	2.08	2.08	2.07	90	103
V-13	2.06	2.02	1.98	1.87	1.44	1.11	2.22	2.18	2.15	2.12	2.03	1.91	58	63
V-14	1.94	1.77	1.75	1.42**	1.73	1.34	2.16	1.96	1.97	1.97	1.97	1.90	71	72

* Light load only for several hours. Temporary load box failure. Voltage noisy. Tightened hose clamp connections.

**Light load only for several hours. Temporary load box failure. Voltage noisy. Tightened hose clamp connections.

11. APPENDIX B - CELL DESIGNS AND CONSTRUCTION METHODS

11. 1. Prismatic Cell Construction

Figure 1, page 124, 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 served as the carrier for the paste and as a cathode collector. The lead wire was soldered to the Exmet, and the joint was coated with Krylon or rubber cement.

The oxidant(s) and graphite in the desired proportions were dry blended and then mixed with a binder (1% solution of polystyrene in toluene) into a workable paste. The paste was 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 was air-dried overnight, or until the odor of toluene had disappeared. Forced drying was not applied in order to avoid shrinking and cracking of the paste.

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

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

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

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

TYPICAL PRISMATIC CELL

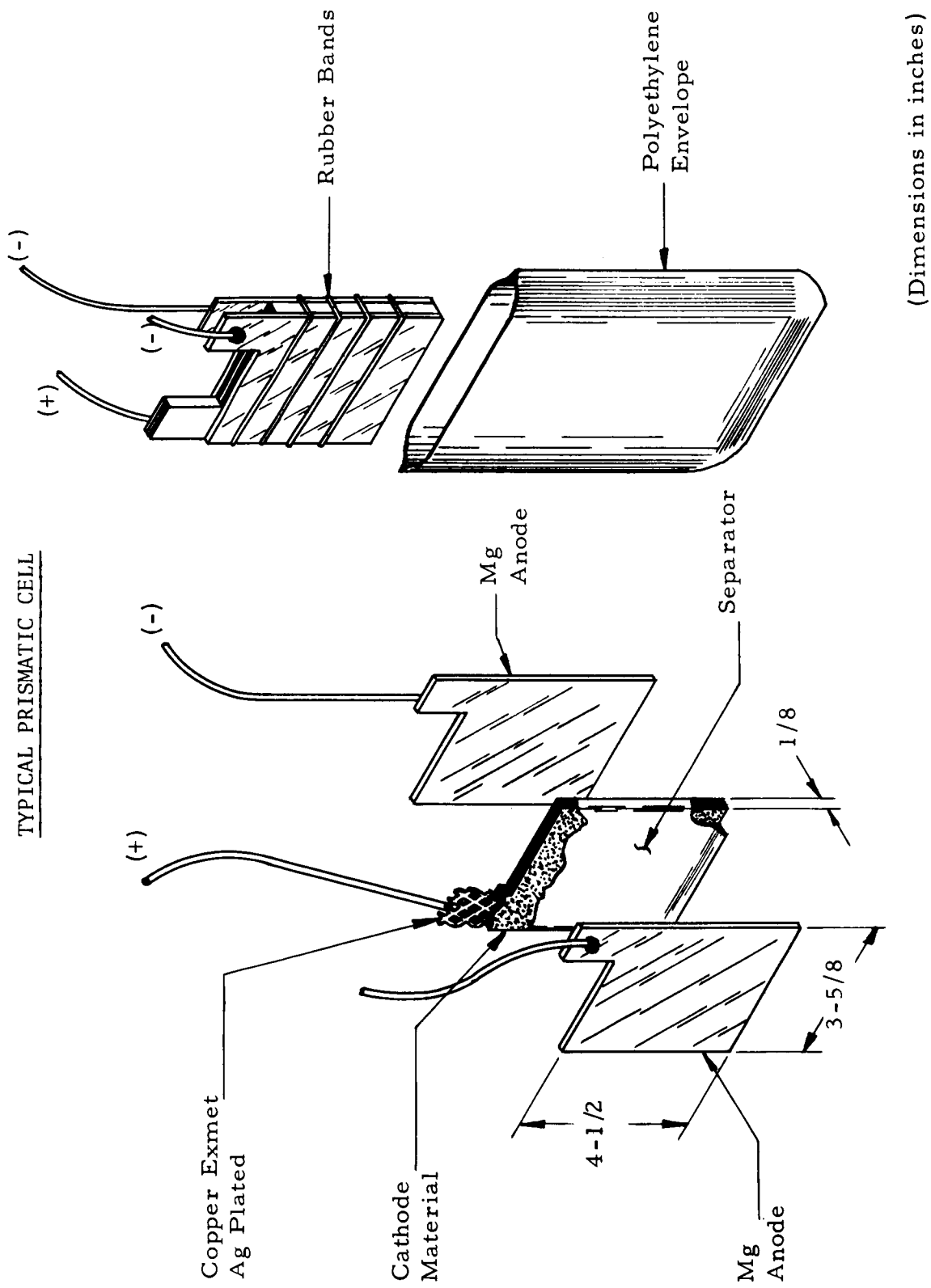


Figure 1

11. 2. Bobbin Cell Designs and Construction Methods

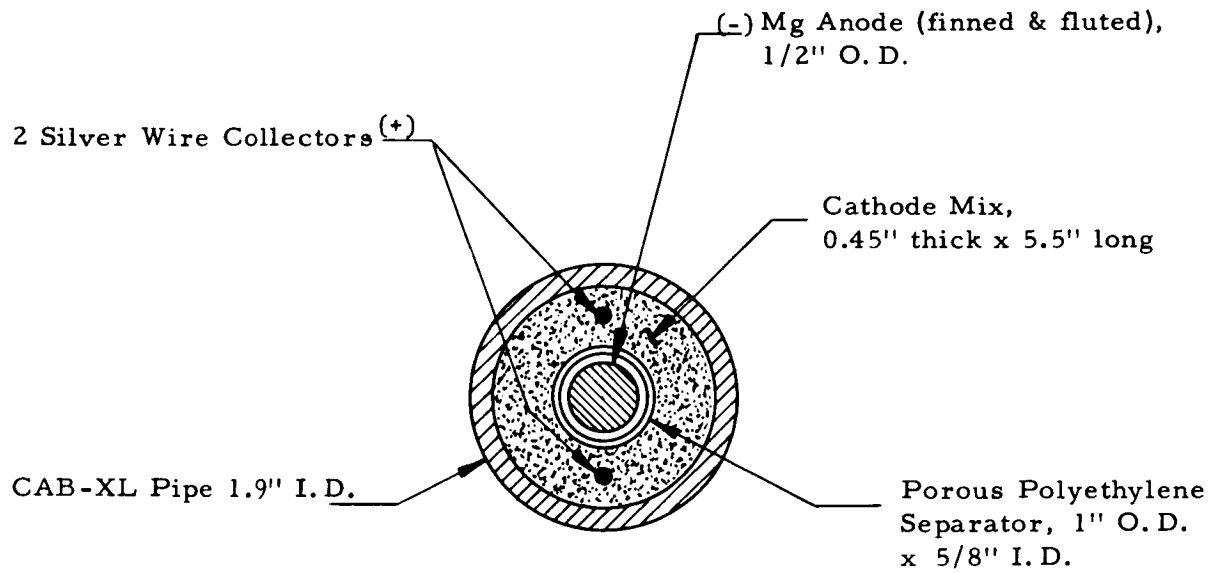
During Task I, two basic bobbin cell designs were tried:

- (1) A center cathode with an external cylindrical sheet anode, and
- (2) A central anode of various designs with an external annular ring cathode packed between the separator and the container wall.

The former design (1), Figure 8, required wire connections to both the anode and cathode and utilized the space around the anode for reserve electrolyte. Since our testing vehicle was a conductive plastic, the latter design (2) allowed the cathode connection to be made externally to the outside wall of the container. Space for reserve electrolyte was provided in the center of the cell around the anode.

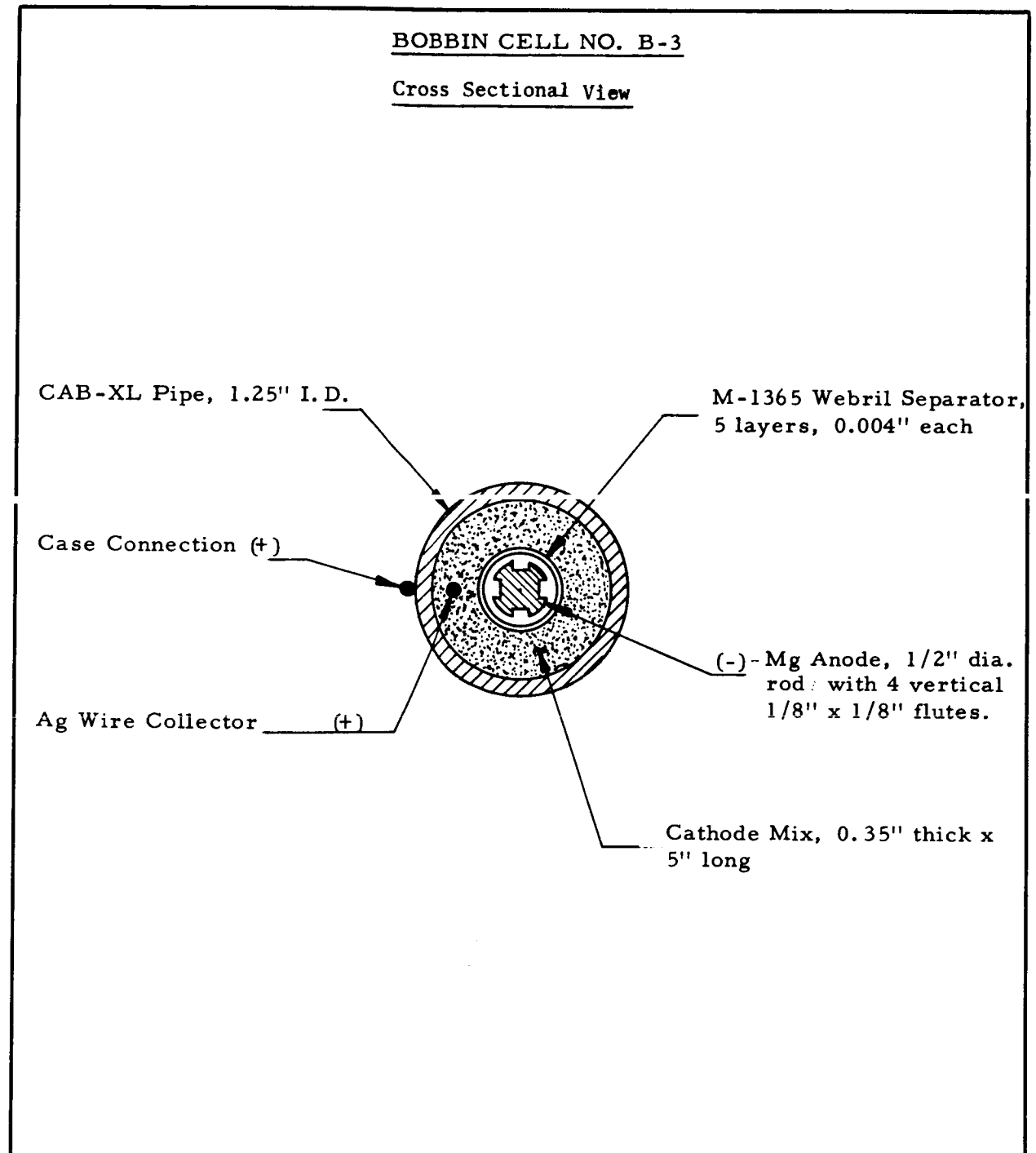
Figures 2 thru 8, pages 126 - 132, show cross sectional views of the configurations that were tried in the preliminary design stages.

The design that was adopted and approved by the Project Manager for the remainder of Task I. A. and B. is illustrated in Figures 9, 10 and 11, pages 134 - 136. This basic configuration was used throughout the contract period for most of the experimental bobbin cells which were left open to the atmosphere. The assembly procedure is given on page 133.

BOBBIN CELLS NOS. B-1 and B-2Cross Sectional View

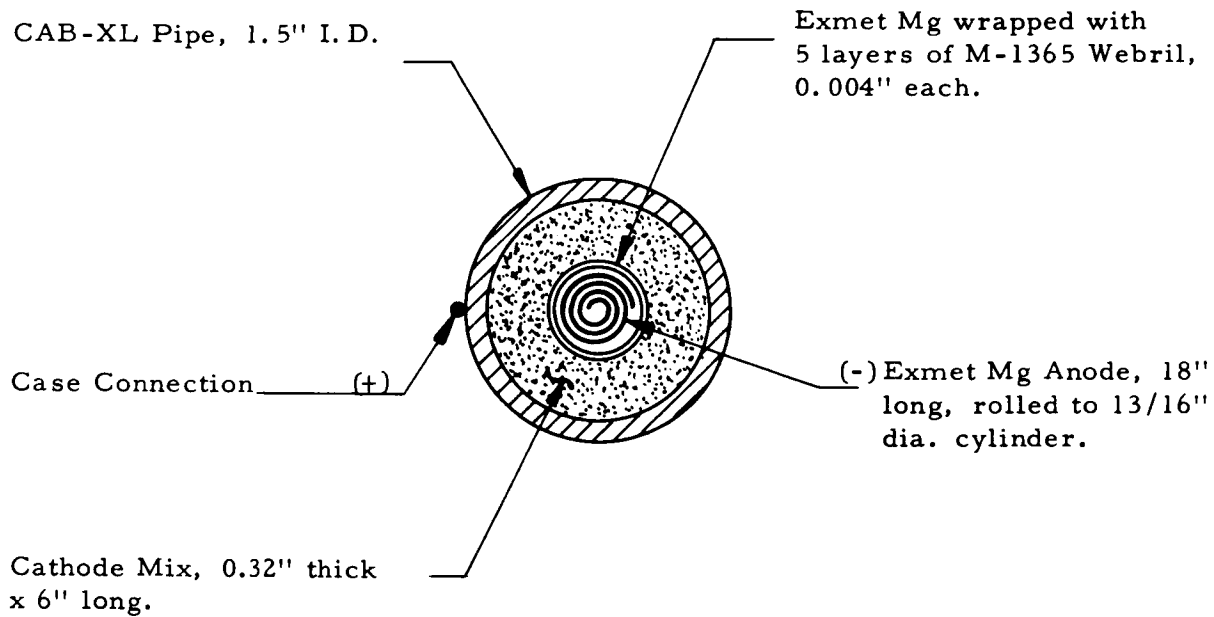
FORM FM-100

Figure 2

BOBBIN CELL NO. B-3Cross Sectional View

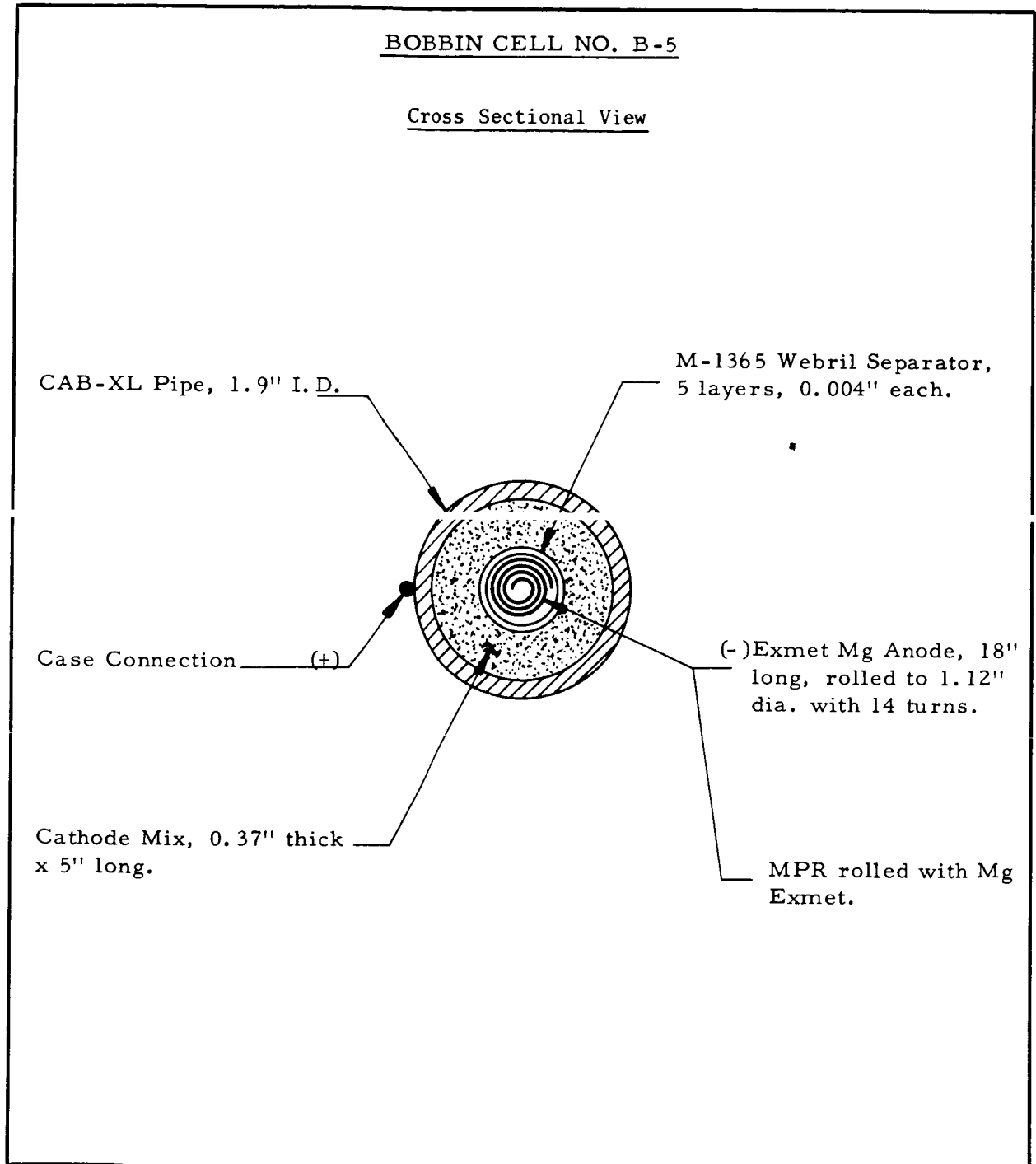
FORM FM-100

Figure 3

BOBBIN CELL NO. B-4Cross Sectional View

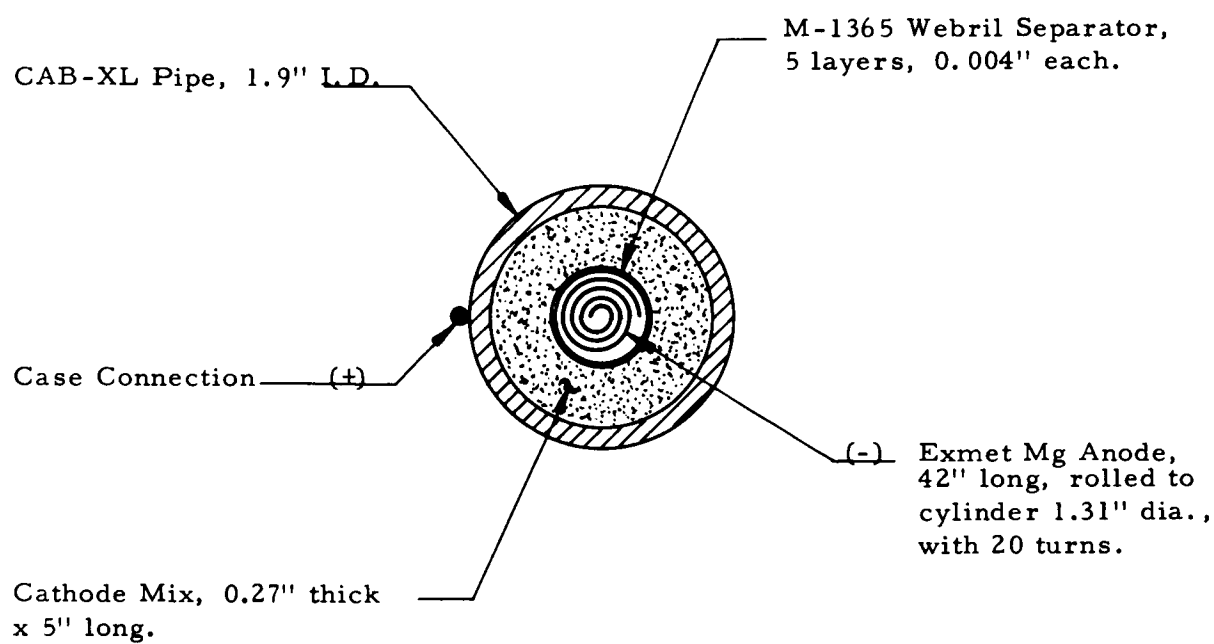
FORM FM-100

Figure 4

BOBBIN CELL NO. B-5Cross Sectional View

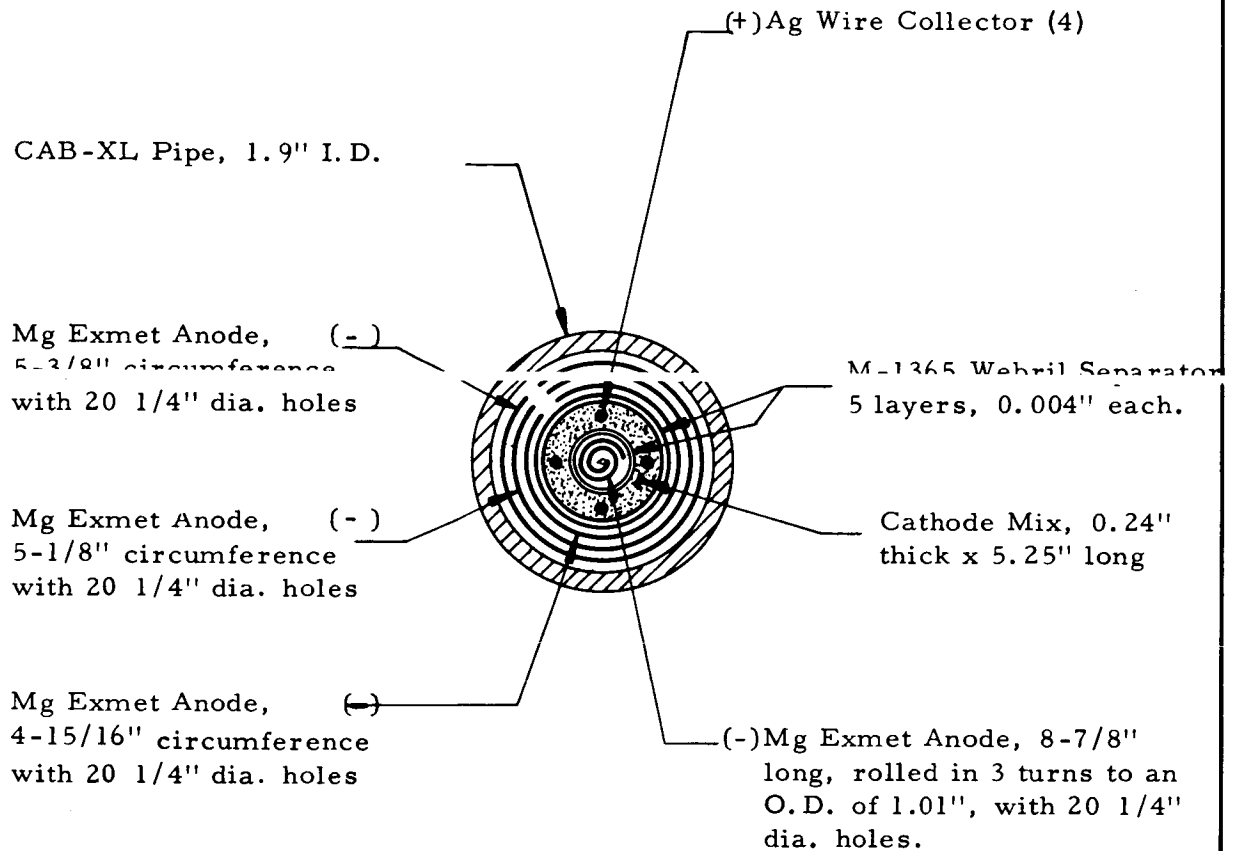
FORM FM-100

Figure 5

BOBBIN CELL NO. B-6Cross Sectional View

FORM FM-100

Figure 6

BOBBIN CELL NO. B-7Cross Sectional View

FORM FM-100

Figure 7

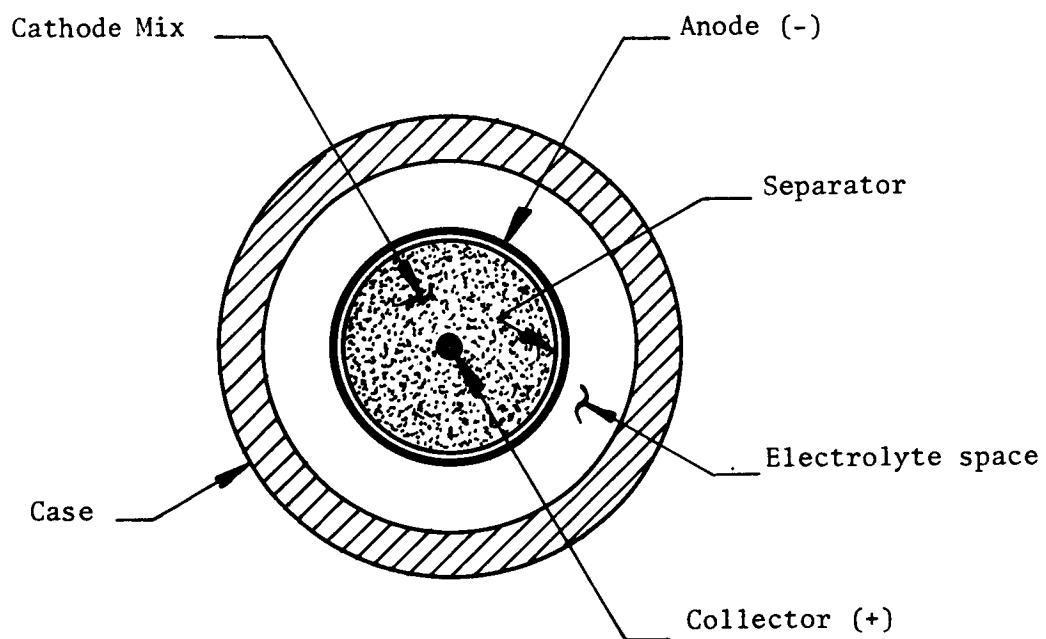
BOBBIN CELL NO. B-11Cross Sectional View

FIGURE 8

11. 2. (a) Task I. B., Cell Assembly Procedure

Refer to Figures 9, 10 and 11, pages 134 - 136.

1. Five (5) layers of M-1365 Webril separator fabric were wrapped around a 1-1/4 inch diameter mandrel. The fabric was folded over at the bottom to form a cylindrical cup, and all seams were sealed with acetone.
2. The anode was fabricated as shown in Figure 11, page 136.
3. A metal plug was pressed into the bottom of the plastic case.
4. The separator cup with mandrel in place was placed in the center of the case, and the cathode mixture was packed between the separator and the wall of the case in ten equal increments with a piston which fitted the annular space. Each increment was packed to occupy 1/10 of the total cathode volume.
5. The mandrel was then removed from the separator cup and was replaced by the anode with its negative connection.
6. The positive connection was made by soldering a wire to several adjustable bands attached to the outside of the conductive plastic case. Seven bands were used on full-sized cells; four, on the half-sized ones.

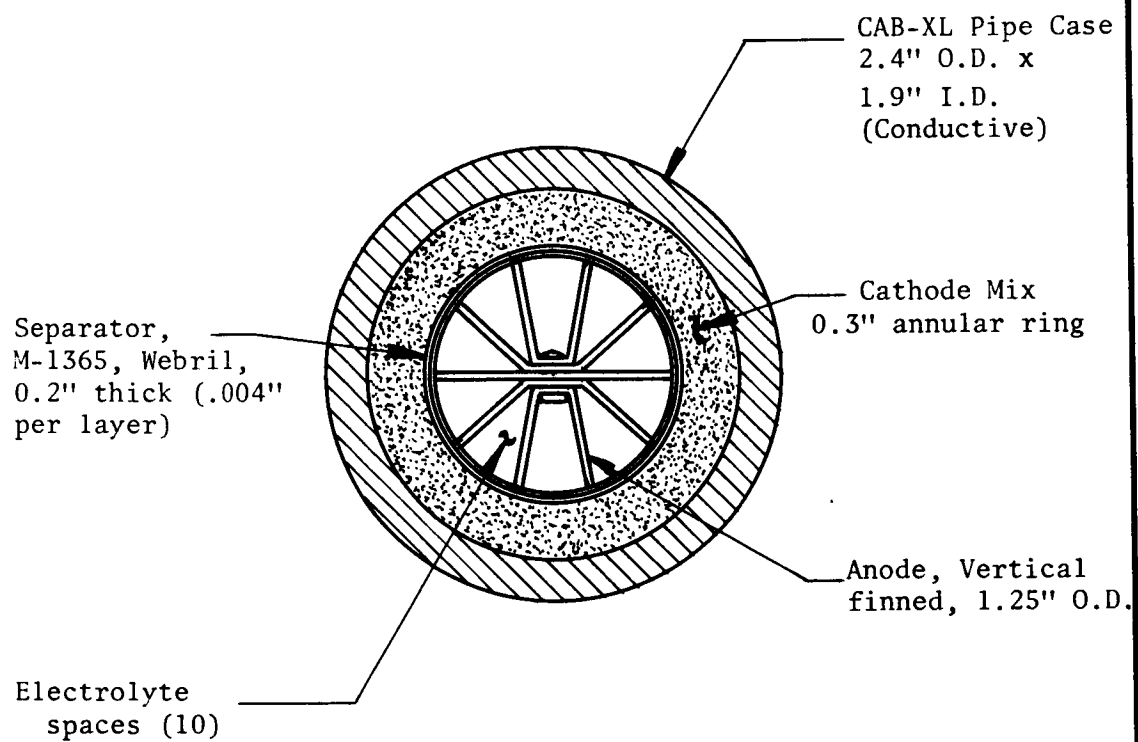
TYPICAL CELL CROSS SECTIONCELL B-15 THROUGH TASK III. A.

FIGURE 9

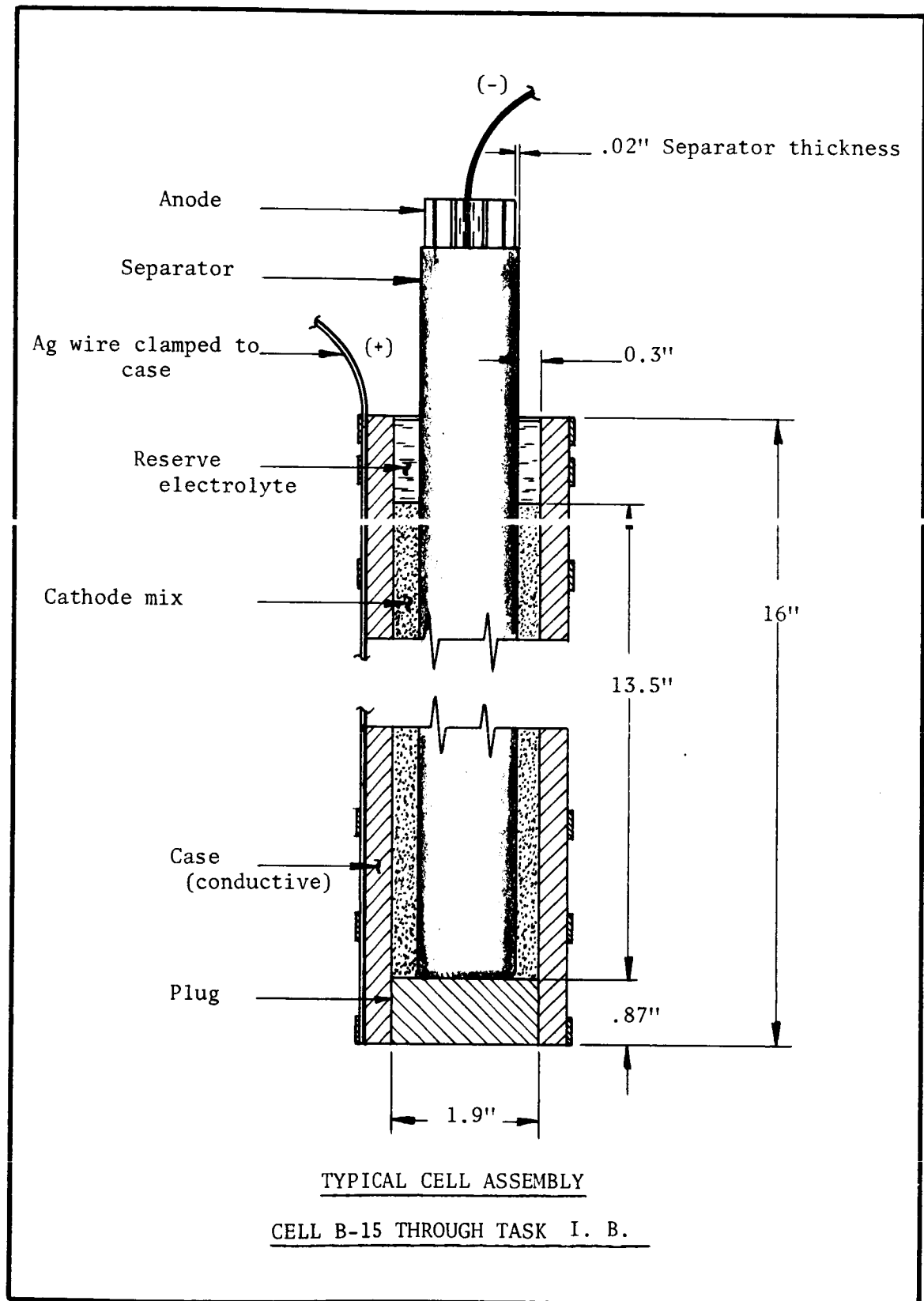


FIGURE 10

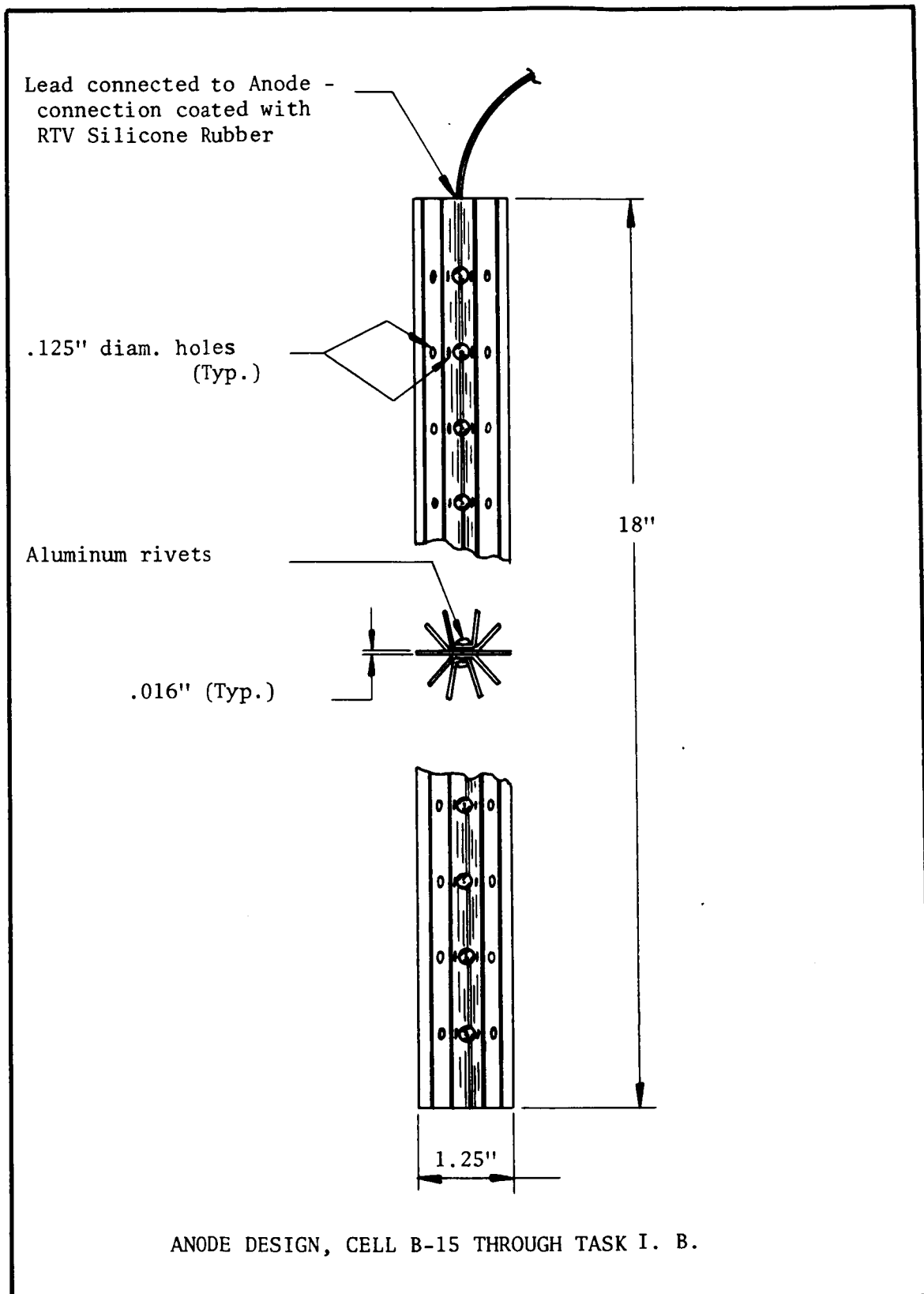


FIGURE 11

11. 2. (b) Task II, Design

A cell was designed in hardware to withstand the ammonia pressures and to conform to the requirements of the environmental testing which was later applied to a group of Task IV cells.

This cell was a refined version of the Task I experimental cell with a top as well as a bottom closure.

The cell assembly is shown in Figure 12, page 139. The Cell Assembly Procedure follows in part (c).

11. 2. (c) Task II, Task III Mockup and Task III. A. Cell Assembly Procedure

Refer to Figure 12, page 139, for numbers in parentheses, and to the Parts and Materials List, page 147.

1. The bottom metal plug (3) (silicone primed) was pressed into position in the plastic case (1), and disc (19) was inserted.
2. The hole in the bottom plug was stoppered, and then a silicone encapsulant (18) was poured onto the plug to a depth of 1/4 inch. After a 16 hour curing period, the stopper was removed.
3. Five layers of M-1365 Webril separator fabric (8) were 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) were inserted. Then the separator was folded over at the bottom and sealed, after which a second disc (15) was placed over the end. This separator cup, with arbor in place, was inserted in the case.
4. The cathode mixture (7) was packed between the separator and the case in ten equal increments with a hollow cylindrical piston. Each increment was packed to occupy 1/10 of the total cathode volume.
5. The arbor was replaced by the anode (6), the bottom 1/4 inch diameter extension of which was insulated with a nylon sleeve (17).
6. A 1/4 inch layer of silicone rubber (14) was poured on top of the cathode mix and allowed to cure.

7. This was followed by a polypropylene space ring (13).
8. The top plug (2), with an insulating disc (12), was pressed into place.
9. Nine stainless steel adjustable bands (10) were placed on the case and tightened. The two end ones helped to hold the plugs in place. The others, to which a silver wire (11) had been soldered, served as the 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, were then inserted and tightened. The threads were sealed with Teflon tape.
11. The finished cell was carefully tested for leaks under pressure. If free from leaks, it was evacuated for at least 16 hours to remove moisture and was then ready for activation. However, if the cell were to be placed in storage for future discharge, the unit was back-filled with one atmosphere of argon gas and then sealed.

11. 2. (d) Task III. B. and Task IV Redesign

The Task II design was modified as detailed below. Item No. 6 applies to Task IV cells only.

1. The plugs were lengthened and the interference ring was moved forward to provide stability.
2. The air space below the anode bottom protrusion remained, but the insulator disc was lowered to the bottom of the hole. The diameter of the hole was reduced and acted as a centering device for the Mg anode.
3. The silicone primer on the aluminum plug and the polypropylene disc below the separator were omitted. The separator was potted into the silicone rubber, providing a seal around the anode protrusion.
4. The fabricated anode, formerly made from sheet and rod stock, was replaced by the extruded magnesium. The top extension on the extruded Mg anode was lengthened to accommodate the thicker end plugs. The distance between the plugs inside the case remained the same.
5. The two adjustable bands which helped to hold the end plugs in place, were replaced by machined (press fit) aluminum retainer rings.
6. The current collector assembly described on page 138, item No. 9, was modified. The soldered connections were eliminated, and the silver wire was wrapped around the top and bottom clamps with the wire passing between the case and the clamp twice. The silver wire passed under all other clamps once.

The Method of Cell Closure with the improved plug design, a cross-section of the cell and the Cell Assembly drawing are shown in Figures 13, 14 and 15, pages 141, 142, and 143.

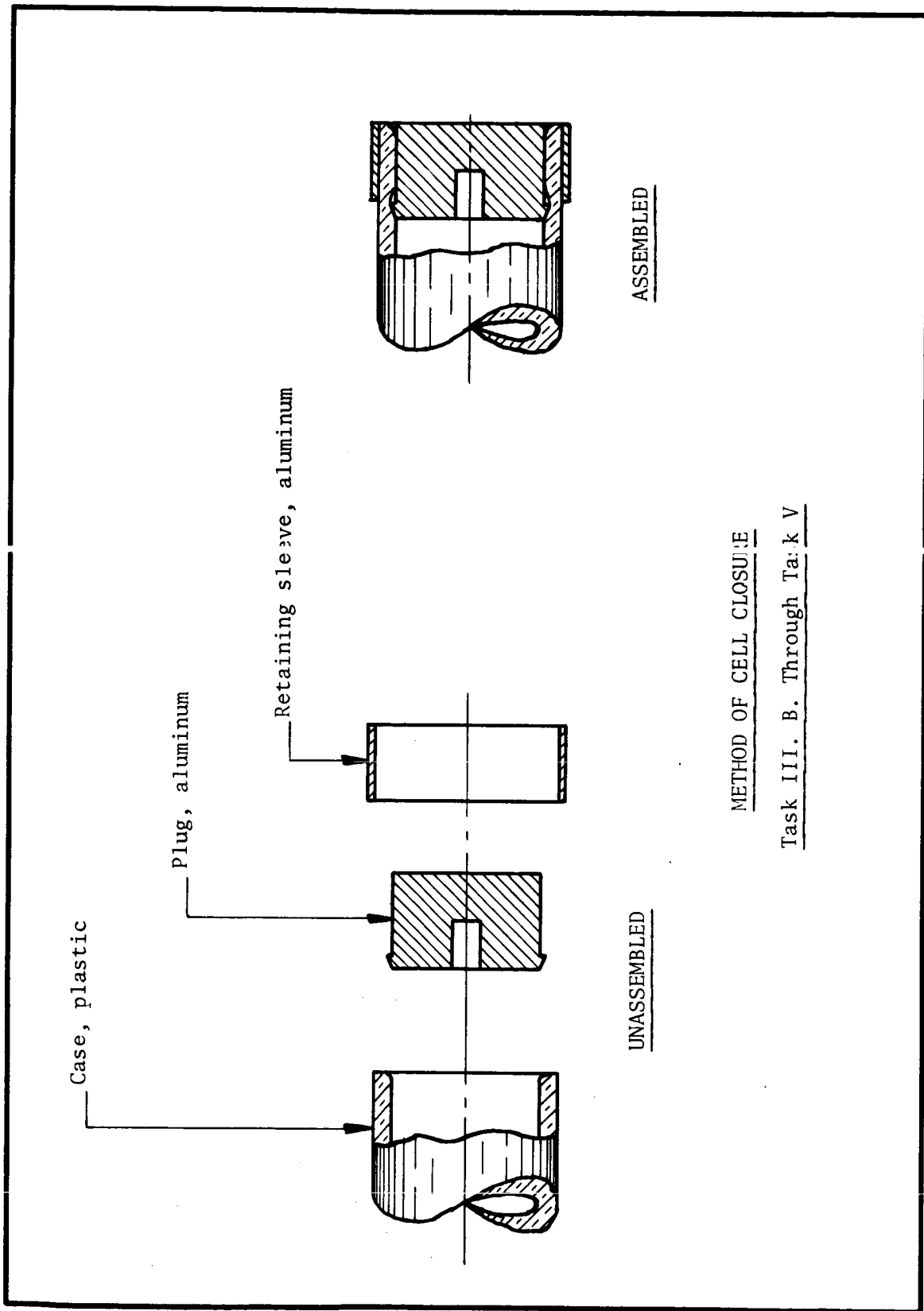


FIGURE 13

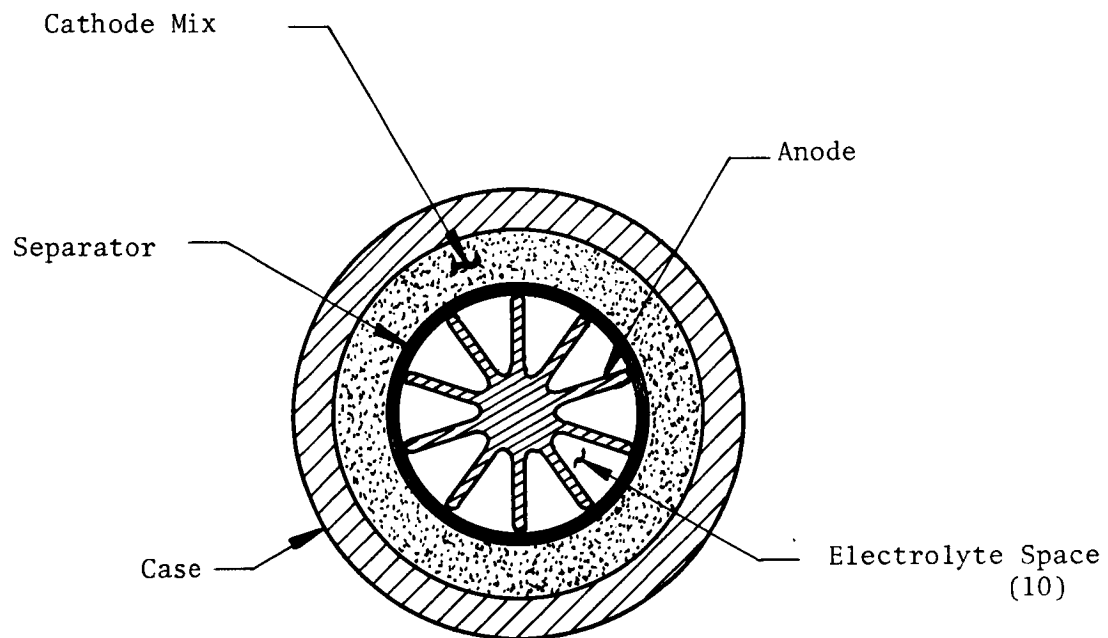
TYPICAL CELL CROSS SECTIONTask III. B. Through Task V

FIGURE 14

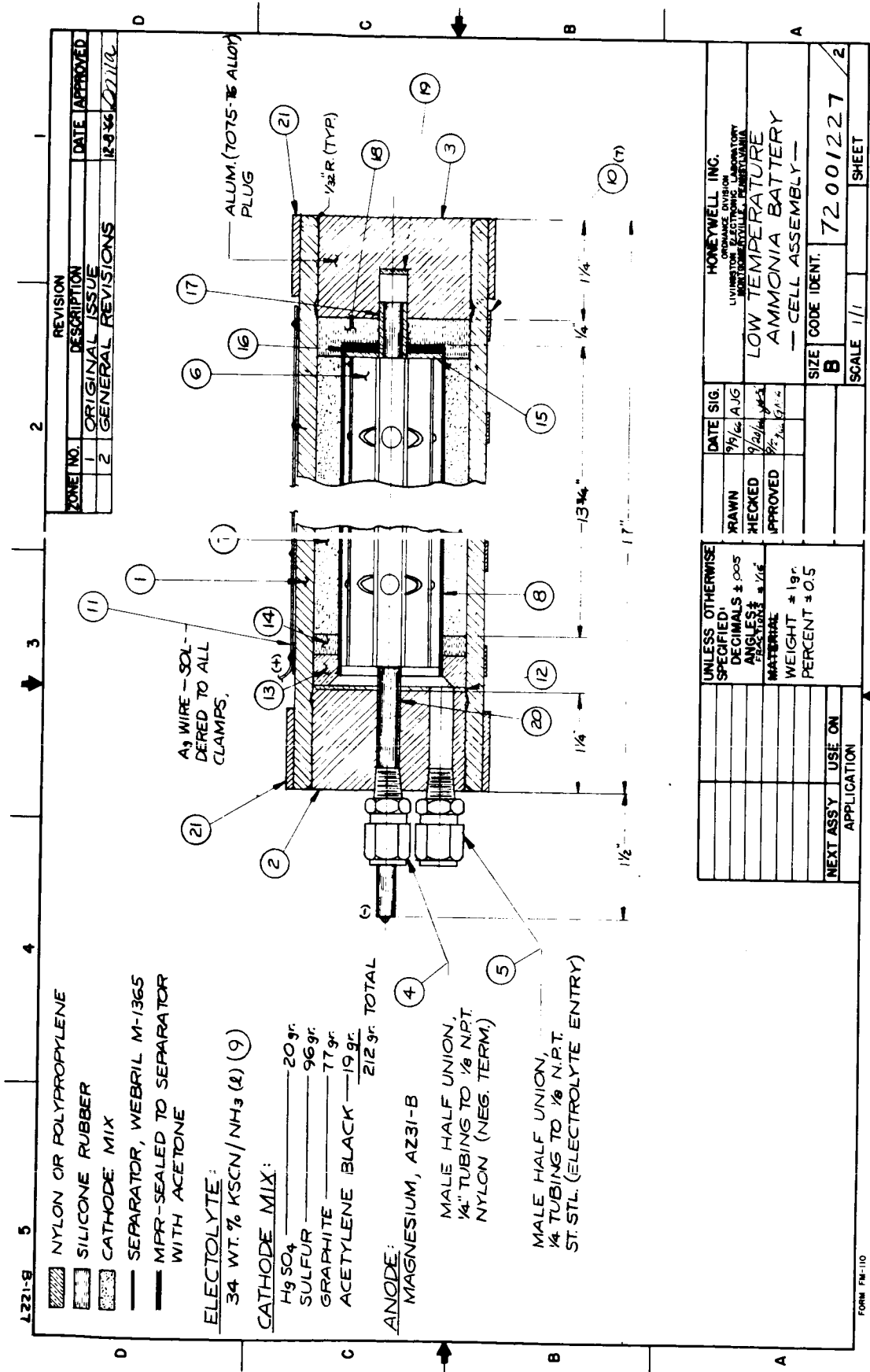


Figure 15

11. 2. (e) Task V Cell Assembly Procedure

The numbers in parentheses in the following procedure appear in the cell assembly drawing, Figure 16, page 146, and are identified in the Parts and Materials List on pages 147 - 149.

1. The metal bottom plug (3) was pressed into position in the plastic case (1), and a plastic disc (19) was inserted in the hole of the plug.
2. Five layers of non-woven separator fabric (8) were wrapped around a 1-1/4 inch diameter arbor forming a right cylinder. In the bottom end, a polypropylene disc (15) and a microporous rubber disc (16) were inserted. Then the separator was folded over and cemented at the bottom and along the longitudinal seam with acetone. The top edge was temporarily attached to the arbor with masking tape.
3. A premixed quantity (17g base + 1.7g catalyst) of silicone rubber encapsulant (18) was poured into the bottom of the case.
4. Before the silicone rubber cured, the arbor and the separator were placed in the case with the extension of the arbor occupying the hole in the bottom plug.

The length of the arbor extension was such as to hold the bottom of the separator 1/4 inch away from the surface of the plug and raise the encapsulant level to 3/8 of an inch along the outer edge. A curing period of at least 16 hours was allotted.

5. The cathode mixture (7) was packed between the separator and the wall of the case in ten equal increments, using a hollow cylindrical piston. Each increment was made to occupy 1/10 of the cathode volume.
6. The arbor was then removed from the separator cylinder and replaced by the anode (6), the bottom extension of which had been insulated with a nylon sleeve (17) and the top extension with a length of heat shrinkable tubing (20).
7. A premixed quantity (10g base + 1g catalyst) of silicone rubber encapsulant (14) was poured on top of the cathode mix forming a seal 1/4 inch in thickness.
8. Before the silicone rubber encapsulant set, a plastic spacer ring (13) was inserted on top of the rubber. Then a plastic spacer collar (12) was placed on top of the ring after which the encapsulant was allowed to cure for at least 16 hours.

9. The metal top plug (2) was pressed into place with the use of an arbor press.
10. The two metal end rings (21) were pressed on flush with the ends of the plastic case.
11. A stainless steel male half union (5), as the electrolyte fill port, and a nylon male half union (4), to insulate the anode extension from the metal plug and case, were then inserted and tightened, the pipe threads being sealed with Teflon tape.
12. A positive connection to the cell case was made with a silver wire (11) and three stainless steel bands (10) having adjusting screws. A silver wire was wrapped twice around the cell case beneath each of three bands which were spaced 4-5/8 inches apart starting at a point 4-1/8 inches from the bottom of the case. Four additional stainless steel bands were placed in between the current collector bands to provide extra case strength at the higher pressures encountered above the boiling point of the ammonia electrolyte.
13. The completed cell was pressure-tested for leaks and then evacuated for at least 16 hours to remove moisture. If the cell were to be activated with electrolyte for electrical discharge, the vacuum was maintained. However, if the cell were to be placed in storage for future discharge, the unit was back-filled with one atmosphere of argon gas and then sealed.

Figure 16

11. 2. (f) PARTS AND MATERIALS LIST

CONTRACT: NAS 3-8503 - DATE: December 13, 1967

<u>Part No.</u>	<u>Item Description/Supplier</u>
1	Case - CAB-XL, 2" I.P.S. sch. 80, carbon-filled cross-linked polyethylene pipe; Cabot Corp., Louisville, Ky.
2	Plug, top - Aluminum alloy 7075-T6; Metal Supply Co., Philadelphia, Pa.
3	Plug, bottom - Aluminum alloy 7075-T6; Metal Supply Co., Philadelphia, Pa.
4	Insulator - Swagelok nylon male connector, 1/4" tubing to 1/8" N.P.T. (with Gyrolok 1/4" ferrules); Crawford Fitting Co., Solon, Ohio. - Gyrolok ferrules; Hoke, Inc., Creskill, N. J.
5	Fill Port - Swagelok stainless steel male connector, 1/4" tubing to 1/8" N.P.T. (with Gyrolok 1/4" ferrules); Crawford Fitting Co., Solon, Ohio. - Gyrolok ferrules; Hoke, Inc., Creskill, N. J.
6	Anode - Extruded magnesium, alloy AZ31-B; White Metal Rolling & Stamping Corp., Brooklyn, N. Y.
7	Cathode - Dry packed powder consisting of: a. Mercuric Sulfate - A. R. Grade; Mallinckrodt Chemical Works, St. Louis, Mo. b. Sulfur - Sublimed; Matheson, Coleman & Bell, Norwood, Ohio. 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.

<u>Part No.</u>	<u>Item Description/Supplier</u>
8	Separator - Webril M-1365, acetate-cotton non-woven fabric, 5 layers x 4 mils/layer; Kendall Co., Walpole, Mass.
9	Electrolyte - 34 percent potassium thiocyanate in liquid ammonia a. KSCN - Reagent B & A Code 2144; Allied Chemical Co., New York, N. Y. b. NH₃ - Anhydrous; National Ammonia Co., Philadelphia, Pa.
10	Clamps (7) - Stainless steel, size #32; Ideal Corp., Brooklyn, N. Y.
11	Collector - #20 AWG sterling silver wire, annealed; T.B. Hagstoz & Sons, Philadelphia, Pa.
12	Insulator disc - (as used in Tasks II through IV) 1.94" diam. x 40 mil sheet, polypropylene; Spacer Collar - (as used in Task V) 1.94" O.D. x 1.68" I.D. x 1.25" h. polypropylene; Commercial Plastics & Supply Corp. of Penna., Philadelphia, Pa.
13	Spacer Ring - Polypropylene, 1.94" O.D. x 1.32" I.D. x 0.12" h.; Commercial Plastics & Supply Corp. of Penna., Philadelphia, Pa.
14	Seal - Silicone rubber, RTV 3110; Dow Corning Corp., Midland, Mich.
15	Disc - Polypropylene, 1.25" O.D. x 0.39" I.D. x 40 mil sheet; Commercial Plastics & Supply Corp. of Penna., Philadelphia, Pa.
16	Disc - Microporous rubber, 1.25" O.D. x 0.39" I.D. x 40 mil sheet; American Hard Rubber Co., Butler, N. J.
17	Insulator Sleeve - Nylon, 0.37" O.D. x 0.25" I.D. x 0.75" long; Commercial Plastics & Supply Corp. of Penna., Philadelphia, Pa.

<u>Part No.</u>	<u>Item Description/Supplier</u>
18	Shock Absorber - Silicone rubber RTV 3110; Dow Corning Corp., Midland, Mich.
19	Disc - Polypropylene, 0.39" diam. x 40 mil sheet; Commerical Plastics & Supply Corp. of Penna., Philadelphia, Pa.
20	Insulator Sleeve - Polyvinylchloride, heat shrinkable tubing, 3/8" expanded x 3/16" recovered x 2.25" long; Frank Markle & Sons, Norristown, Pa.
21	Retainer Rings (2) - Aluminum alloy 6061-T6, 2.50" O.D. x 2.33" I.D. x 1" long; Metal Supply Co., Philadelphia, Pa.

11. 2. (g) Preparation of 34 Percent KSCN/Ammonia Electrolyte

Materials and Equipment Needed:

1. KSCN: potassium thiocyanate; B & A Reagent Grade or equivalent.
2. NH₃: anhydrous liquid ammonia; preferably refrigerated below -35°C. Ammonia vapor or an inert gas such as argon may be used to pressurize the container for transfer of the liquid from a closed system to any other receptacle.
3. Container: (1500 ml capacity) for electrolyte preparation, storage and handling. A wide mouth polyethylene bottle is preferred over glass for reasons of safety. Available from A. H. Thomas Co., Cat. No. 2207-G.
4. Exhaust fume hood: to allow NH₃ fumes to escape during preparation of the electrolyte.
5. Safety equipment: a face shield and gloves for protection of face and hands.
6. Balance, such as Ohaus, A. H. Thomas Co., Cat. No. 1945-B.

Preparation of 1 Kilogram of Electrolyte:

1. Weigh out 340 grams of dry KSCN and place in a suitable container of known tare weight. Allow to remain on balance.
2. Slowly add cold liquid NH₃ to the salt, stirring constantly with a glass rod to prevent formation of phase layers within the solution and to prevent boiling over of the electrolyte.
3. Periodic weight checks are made until 660 grams of ammonia have been added for a total net weight of 1000 grams. The NH₃ weight should be in excess of 5 to 10 grams but not under; this allows for some loss of NH₃ which normally occurs during handling.

4. The container may be lightly capped (such as by means of a cap screwed on only part way) and the electrolyte stored in a refrigerated area below -33°C , preferably -50°C . Do not allow the electrolyte to warm up above -33°C .

CAUTION: The electrolyte should not be stored in the presence of carbon dioxide as contamination of the electrolyte will occur.

NOTE: One kilogram of this electrolyte has a volume of about 1140 cc at -73°C and about 1220 cc at room temperature. This expansion factor (about 7%) should always be considered when storing the electrolyte in containers at cold temperature or in pressure vessels at temperatures above the boiling point. For containers that are filled cold, there should be at least 30% free space allowed for expansion and a safety factor.

Test Report No. M429-7810No. of Pages 24**Report of Test on****LIQUID AMMONIA BATTERIES****ENVIRONMENTAL TESTS**

for

HONEYWELL, INC.**Associated Testing Laboratories, Inc.**

Wayne, New Jersey

Date May 11, 1967

	Prepared	Checked	Approved
By	J. Perzel	J. Valentine	T. Dowd
Signed	<i>J. Perzel</i>	<i>J. Valentine</i>	<i>T. Dowd</i>
Date	<i>5-12-67</i>	<i>5-15-67</i>	<i>5-15-67</i>

T A B L E O F C O N T E N T S

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vibration Test	6
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Shock Test	18
Acoustic Noise Test	19
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Administrative Data

1.0 Purpose of Test:

To subject the submitted Liquid Ammonia Batteries to environmental tests in accordance with the referenced document.

2.0 Manufacturer:

Honeywell, Inc.
Livingston Electronic Laboratories
Route 309
Montgomeryville, Pennsylvania
18936

3.0 Manufacturer's Type or Model No.:

S/N 02, 05, 08, 12, 15, 19, 22,
27, 30, 34, 37, 40, 44 and 47

4.0 Drawing, Specification or Exhibit:

National Aeronautics and Space
Administration Change Order
dated January 11, 1967

5.0 Quantity of Items Tested:

14

6.0 Security Classification of Items:

Unclassified

7.0 Date Test Completed:

March 21, 1967

8.0 Test Conducted By: **Associated Testing Laboratories, Inc.**

9.0 Disposition of Specimens:

Returned to
Honeywell, Inc.

10.0 Abstract:

There was no evidence of physical damage to the Liquid Ammonia Batteries as a result of the environmental tests. In addition, the resistance value exhibited by the Batteries throughout the test program was infinity.

Report No. M429-7810

Page 1

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