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LOW-TEMPERATURE BALLOON BATTERY
PHASE II

By

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PHASE II

FINAL REPORT

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Contract NAS 5-11556

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FOREWORD

This final report covers the work performed between April 22, 1969, and November 22, 1969, under Contract NAS 5-11556, "Low-Temperature Balloon Battery - Phase II." It was prepared by the Research and Development Center of the General Electric Company in Schenectady, New York, for the National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Maryland.

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TABLE OF CONTENTS

<u>Section</u>		<u>Page</u>
	FOREWORD	i
1	SUMMARY	1
2	SPECIFIC RECOMMENDATIONS	3
3	TECHNICAL STUDIES	5
	3.1 Electrode Substrates	5
	3.2 Study of Rechargeable Mercuric-oxide Electrode Mixes	7
	3.3 Discussion on the Operation of the Positive Electrode.	14
	3.4 Construction of a Prototype Test Cell.	15
4	DESIGN CONSIDERATIONS AND PROSPECTUS.	19

LIST OF ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
1	Illustration of a Complete Cycle at Constant Current of a Mercury Cadmium Test Cell	11
2	Polarization Curve.	12
3	Polarization Curve of a Prototype Cell	17
4	Schematic Cross Section of Prototype Cell	20

LIST OF TABLES

<u>Table</u>		<u>Page</u>
1	Cycling Test Using Nickel Powder	8
2	Critical Tests for Mercury Electrodes Containing Nickel Powder at -60°C	9
3	Test Data of Pasted Electrodes Containing Silver	10
4	Determination of Optimum Silver Powder Concentration . . .	13
5	Determination of Optimum Silver Powder Concentration Results on 9th Cycle	13
6	Polarization as a Function of Current Density	14
7	Balloon Battery (First Prototype Test)	18
8	Aspect Ratio for Various Cell Materials	20
9	Comparison of Before-and-After Improvement Aspect Ratios	21

Section 1

SUMMARY

This program was directed toward developing a low-temperature rechargeable balloon battery. The effort was an extension of a Phase I investigation that singled out a mercury-cadmium system as having the best chance of meeting the battery requirements.

The development and testing of single cells revealed many unanticipated problems, but there were none that were not satisfactorily resolved.

The light-weight electrode substrates should be investigated more intensively. For the purposes of this study, nickel screens fixed to a heat-sealable plastic backing were ultimately resorted to with good results. Future developments along this line would make significant weight reduction in the system.

Silver powder was found to be the key additive in the preparation of a rechargeable mercury electrode. The data suggest the silver has a triple function, i. e., a conductor, a mercury wettable interface, and a catalytic oxidant. The use of silver appears to be crucial for the construction of a rechargeable mercuric-oxide electrode.

The result of the effort was a prototype cell one-quarter the size of that determined by the initial engineering estimates. The testing of this prototype cell made it clear that:

- (a) the full-sized cell would meet the electrical requirements of the system;
- (b) the aspect ratio (5 g/cm²) should be easily met;
- (c) the projected battery weight will be too high (i. e., 4320 grams). However, many design refinements remain to be made that are capable of bringing the battery package weight to the specified levels;
- (d) the case requirements will be easily met; and
- (e) the battery life remains to be determined.

Section 2

SPECIFIC RECOMMENDATIONS

The results of this study support the complete feasibility of an unheated low-temperature balloon battery employing a mercury-cadmium system for operation at -60°C . It is recommended that a follow-on study (Phase III) be considered to include the following program:

- I. An improved secondary cell design using light-weight heat-sealable plastics, more efficient active material compositions, better adhesives, and light substrate materials which are all currently under consideration in materials evaluation studies now being carried out.
- II. A design study of the battery and its component cells to best meet the existing or modified specifications of the system.
- III. Full-sized prototype cell fabrication and testing.
- IV. Examination of charge-control methods.
- V. Fabrication of batteries for customer evaluation and testing.

Section 3

TECHNICAL STUDIES

3.1 Electrode Substrates

As the first step in the development of the low-temperature balloon battery, electrode plate materials were studied in terms of their (a) low aspect ratio, (b) stability to potassium hydroxide, (c) ability to cycle active materials, and (d) ability to utilize the available active materials on cycling. The printed battery design described in the Phase I report NAS 5-11556 was used for a guide during the early experiments.

3.1.1 Films

A commercially available polystyrene sheet having a vapor-deposited silver layer on one face (Coating Products, 580 Sylvan Ave., Englewood Cliffs, N.J. 07638) was tested. Preliminary tests showed that the film had a resistance of 1.02 ohms/square, which is too high for practical use in that form. Taking the resistivity of silver to be 1.47×10^{-6} ohm-cm, the layer thickness was calculated as 132Å. An attempt was made to build up the thickness of the conductive layer with the active materials so as to decrease the total plate resistance without having to add inert electronic conducting materials.

All attempts to electrodeposit mercury onto the silver film failed as the mercury amalgamated with the silver causing it to agglomerate into droplets that eventually dripped off the plate. Electrical contact was quickly lost. Direct electrodeposition of cadmium from a fluoroborate bath gave fairly good coatings at times. At other times the silver-cadmium layer blistered and flaked off, leaving bare spots on the plate. One of the better plates was discharged to check the capacity of the deposited layer. The results showed an extremely high plate resistance and negligible capacity. This was anticipated as cadmium sheet is known to passivate quickly. Electrodeposition of a nickel surface on top of the silver layer was tried from a sulfate bath. The deposits were poorly adherent. An electroless nickel deposition process was resorted to which also produced unsatisfactory deposits with regard to both distribution and adherence of the nickel.

Although the attempts at producing a highly uniform and conductive nickel layer were not successful, it should not be inferred that it cannot be done. Some adjustment of the experimental conditions could have produced the desired results. At the same time, some consideration was given to vapor-depositing thick layers of a conductive material on a heat-sealable plastic substrate. Although the method is feasible, it should require a multipass arrangement so as to prevent the plastic substrate from melting. The operational variables would require study on a trial-and-error basis. The times quoted to do this when compared to the limits on this study made the method impractical. A decision was made at this point to cease work on the plating refinements and assume that a satisfactory inert metal deposit could be obtained at some future time.

3. 1. 2 Foils

Assuming that conditions could eventually be found to prepare adequate metal films on a heat-sealable plastic backing, a 5 mil nickel foil was used in lieu of the deposited metal film. Gold foil was also studied because of its desirable properties of availability in extremely thin layers (as thin as 1000Å) and its ability to be wetted by mercury via surface amalgam formation. Electrodeposition of mercury from mercuric acetate solutions in dilute acetic acid gave good surface deposits. Unfortunately, the film quickly passivated when cycling was attempted. The utilization was insignificant. The term "insignificant" will be used whenever the utilization of active materials is less than 5%. Attempts at pasting mercuric oxide onto the surface of the metal foil using Lubrizol 2240 resin (Lubrizol Corporation) and Kynar 201 resin (Pennsalt Chemical Co.) as binders gave some cyclability, but again this was insignificant from a practical standpoint.

Observations of the surface of the foil showed, in the case of the paste, a poor adherence of the active materials. The problem may lie in poor binding action, surface films on the metal substrate or the formation of a passive film on deposited mercury. Further studies were needed in understanding the nature of the interface. A decision was made to force good interfacial contact by using a screen embedded in the active materials, rather than directing effort toward determining the variables for improving the quality of the coating. This conclusion led to the investigation described below on screened substrates.

Although the studies performed up to this point were of a qualitative nature, they do point out the technical problems associated with the use of metal films on heat-sealable plastic substrates. A detailed study of methods for employing such films is necessary since their direct application as shown above indicates some definite problems. The investigation and solution of these problems were outside the scope of this contract. Should solutions become available in the future that would satisfactorily resolve the poor utilization in high internal resistance problems, films should be reconsidered.

3. 1. 3 Screens

The application of metal screens provide a well-known means toward developing workable secondary electrodes. In Phase I of this contract period, mercuric oxide-silver flake mixes were used in a pressed electrode where polyethylene-coated graphite (National Lead Co.) was used as the binder. The data secured on this electrode were used as part of the arguments demonstrating the feasibility of the low-temperature balloon battery. However, the use of pressed electrodes would make the preparation of the battery extremely difficult due to the flexibility needed for the thin-cell design.

The use of silver in the electrode mix is a problem because of its tendency to migrate on cycling. A mixture of active materials was selected for testing using nickel in place of silver as a conductive diluent.

7.0 cm² 40 mesh nickel screens with tabs pre-etched in nitric acid were used. They were initially selected so as to have an 8 ma-hr/cm² capacity as a convenient starting point. The test cell containers were made of Lucite plastic of sufficient internal volume to contain the electrode together with a cadmium counterelectrode. In the early studies, sintered cadmium plaque was used having a sufficient capacity so that there would be no possibility that the cell would become negative limiting. The specific capacity of the sinter was about 3/10 amp-hr/cm². The cells were run in a flooded condition. The cell container had the following internal dimensions: 2 1/4 inches by 2 1/2 inches by 1 inch. The cells were enclosed in a confined atmosphere during the tests in order to minimize CO₂ absorption by the electrolyte. 31% potassium hydroxide was prepared by dilution of Fisher Reagent Grade 45% KOH solution.

3.2 Study of Rechargeable Mercuric-Oxide Electrode Mixes

A preliminary screening of selected binders was pursued using a standard mix prepared by ball-milling 20.0 grams of mercuric oxide with 8.0 grams of Inco 255 nickel powder. 1.10 grams of this standard mix was ball-milled with 0.70 gram of the following materials individually: Lubrizol 2240 resin, Kynar resin, and Ganex V816 resin (GAF Corp.) Discharging cells using electrodes constructed with these materials at a 10 milliamp current showed that (a) the Kynar resin produced plates having high internal resistance and insignificant capacity, (b) the Lubrizol resin produced plates that showed a high internal resistance with a good discharge capacity, and (c) the Ganex V816 resin produced plates showing the lowest plate resistance and good discharge capacity. On the basis of this relative screening, the Ganex resin was selected as the best binder, and subsequent work was directed toward further evaluating its characteristics.

An attempt was also made to use Aquadag colloidal carbon dispersion in place of the nickel powder in the test mixes. Even when the Kynar resin was used as the binder, the mixes dispersed when placed in KOH. The use of the Aquadag dispersion was thereby eliminated from further consideration.

For the purpose of making smaller test mixtures, the standard mix mentioned earlier was reduced by a factor of 4. In that case, the best mix found on the basis of the discharge test was: 5.0 grams mercuric-oxide, 2.0 grams nickel powder, and 0.16 gram Ganex resin. A series of experiments was attempted which varied only the amount of Ganex resin added, i. e., 0.050, 0.10, 0.50, and 1.00 gram. The cell was subjected to a 10 milliamp current on charge and discharge. The cycling data were rejected as containing errors of method, but inspection of the electrodes showed that the 0.05 gram Ganex resin mix was insufficient to maintain the integrity of the paste. The others showed good integrity. As the result of this test, the 0.05 gram and 1.0 gram Ganex resin concentration levels were eliminated. Pilot tests with these electrodes seemed to show that currents of 2.0 milliamp were the maximum allowable for producing some cyclability (current density = 0.29 ma/sq cm).

Another cycling test was performed using two different mixes: 5-2 and 4-3 grams of mercuric oxide to grams of nickel powder. The latter mix was included in order to judge the effect of increased concentrations of the conductive diluent. Both 0.10 gram and 0.50 gram of Ganex resin were incorporated giving four different test mixes. The results were inconclusive with respect to the cyclability of the electrodes. That is, the electrodes oscillated between voltage cutoffs (1.5 and 0.2 volts vs cadmium/cadmium hydroxide) showing negligible capacity at a 10 milliamp charge/discharge current level. The capacities ranged from 10 to less than 1 ma-hr. One of the electrode combinations, 5-2-0.5 grams of mercuric oxide-nickel-Ganex resin, respectively, was discharged at 1.0 milliamp (0.1 ma/cm²) and showed a capacity of 0.132 amp-hr. A key observation was made here in that the discharge curve showed a large polarization early in the discharge followed by a subsequent restoration of the voltage. This large resistance, whose origin is unknown, seemed to be the reason for the poor cycling behavior at the higher current. Increasing the nickel concentration level was considered the next logical step.

A mix containing 3.5 grams mercuric oxide, 3.5 grams nickel powder, and 0.5 gram Ganex resin was prepared. Four electrodes were assembled without concern for the absolute amounts of mix applied. They were estimated to be between 0.8 to 1.0 gram of mix per electrode. The cells were designed so that two mercury electrodes surrounded a cadmium electrode. A charge voltage cutoff was set at 1.6 volts and the discharge cutoff at 0.4 volt. Two current levels were used, 7 and 4 milliamp, both charge and discharge. The experiments were run in duplicate and typical results are shown in Table 1.

Table 1
CYCLING TESTS USING NICKEL POWDER

<u>Discharge Cycle</u>	<u>Discharge Capacity (ma-hr)</u>	
	<u>7.0 ma Current</u>	<u>4.0 ma Current</u>
1	87.5	78.0
2	36.7	28.0
3	21.7	7.2
4	14.0	5.2
5	9.1	4.0
⋮	⋮	⋮
80	1.8	1.0

An identical set of tests was performed on an electrode mix containing 0.1 gram of Ganex resin instead of 0.5 gram used before. The results were substantially identical. Although the cycling results were not at this point encouraging, the minimum level of binder was established. The critical test was performed with what we considered to be the best mix: 3.5 grams mercuric oxide, 3.5 grams nickel powder, and 0.1 gram Ganex resin. The electrodes were prepared by pasting the mix onto preweighed screens and weighing the pasted electrode after drying. The test cell was placed in a Lucite container described earlier. The cadmium electrode was sandwiched between two mercury electrodes. The environment of the cell was reduced to -60°C in a Tenney environmental chamber (Tenney Engineering, Inc.) and an attempt was made to cycle the cell. The observed results are given in Table 2. The use of nickel in place of silver which was employed in the earlier Phase I test does not give a direct substitution of the conductor. The study showed that the nickel is unsatisfactory for use in the development of the battery. The integrity of the paste was however, excellent. Substituting 31% cesium hydroxide for 31% KOH had no apparent effect on the low-temperature performance. A return to the use of silver in place of nickel was considered next.

Table 2

CRITICAL TESTS FOR MERCURY ELECTRODES CONTAINING
NICKEL POWDER AT -60°C

<u>Charge-Discharge Current Density</u>	<u>Note</u>	<u>Observations</u>
1.00 ma/cm ²	Pulse current density	Immediately polarized
0.143 ma/cm ²		Immediately polarized
28.6 $\mu\text{a}/\text{cm}^2$	Estimated lower current density limit	Immediately polarized
0.43 $\mu\text{a}/\text{cm}^2$		Cycling was observed of negligible capacity

The test electrodes used in Phase I were prepared under ideal conditions; i. e., they incorporated silver flake and were pressed. However, preliminary tests on pasted structures showed that the finely divided silver flake did not wet during the pasting process, so that any attempt to prepare the paste only served to separate the silver from the mercuric oxide. Tests performed with silver flake were erratic, apparently caused by the nonwettable characteristic of the silver flake. Precipitated silver powder (Fisher Reagent Grade) was substituted for the silver flake and the wetting problem disappeared.

The first test of a mix containing 3.0 grams mercuric oxide, 1.0 gram silver, and 0.1 gram Ganex resin gave the results shown in Table 3. Assuming that the cell was positive limiting, the utilization of mercuric oxide was calculated at 23%. A constant charge and discharge curve is shown in Figure 1. A polarization of this cell in a fully charged condition after cycle 5 is shown in Figure 2. The interpretation of these curves will be given later in this report.

Table 3

TEST DATA OF PASTED ELECTRODES CONTAINING SILVER

Weight of positive electrode mix used: 0.7660 g and 0.6349 g.
 Sintered cadmium was used as the counterelectrode.
 Pellon 2505 cloth was used as the separator.
 Electrode arrangement Hg-Cd-Hg.
 Electrolyte--31% KOH.
 Temperature--ambient.
 Current--7.0 ma (CD = 0.50 ma/cm²).

<u>Cycle</u>	<u>Capacity (ma-hr)</u>
Charge 1	Formation
Discharge 1	95.0
Charge 2	61.3
Discharge 2	55.8
Charge 3	63.1
Discharge 3	57.8
Charge 4	64.4
Discharge 4	59.0
Charge 5	64.3
Terminated	

In subsequent cell tests some internal shorting was observed. Postmortem failure analysis showed that it resulted from silver migration. An RAI 2291 polyethylene separator (RAI Research Corp., Long Island City, New York) was used in place of Pellon 2505 cloth (Pellon Corp.); this separator material stopped the migration of silver.

A series of experiments was then made to determine the optimum mixture of mercuric oxide and silver. The mixtures listed in Table 4 were tested. The cells were cycled at current density of 1.0 ma/cm² using a 7.0 cm² positive electrode. The cell was positive-limiting. The following Table 5 shows the results obtained at room temperature on the ninth cycle. The last two compositions given in the Table looked most promising. Tests at -60°C showed that the 4.0-3.0-0.1 mix showed least polarization on cycling and, on that basis, it was selected as the best positive mix for low-temperature operation. The chosen mix was cycled at -60°C at various current densities and the cell voltages

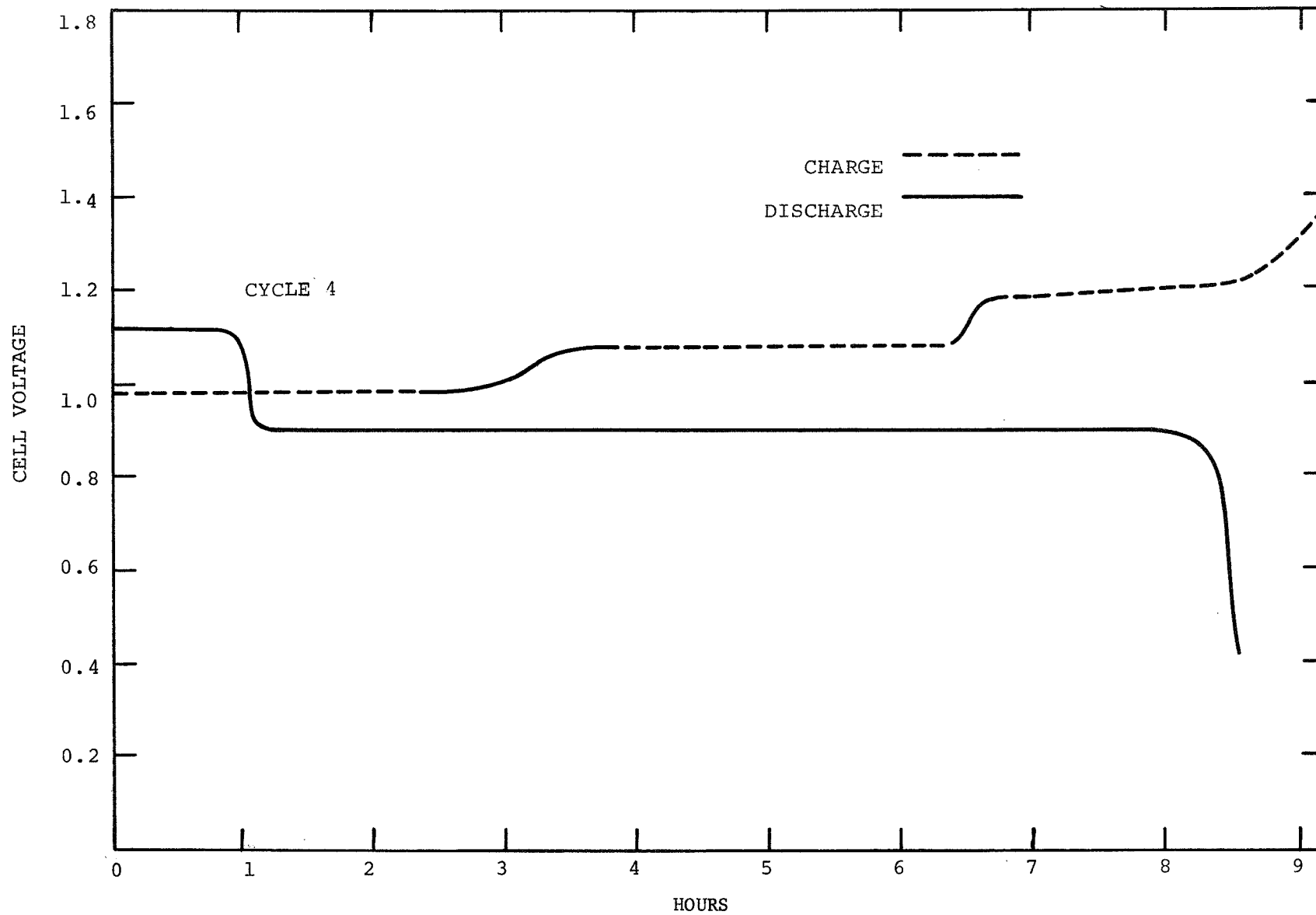


Fig. 1 Illustration of a complete cycle at constant current of a mercury cadmium test cell.

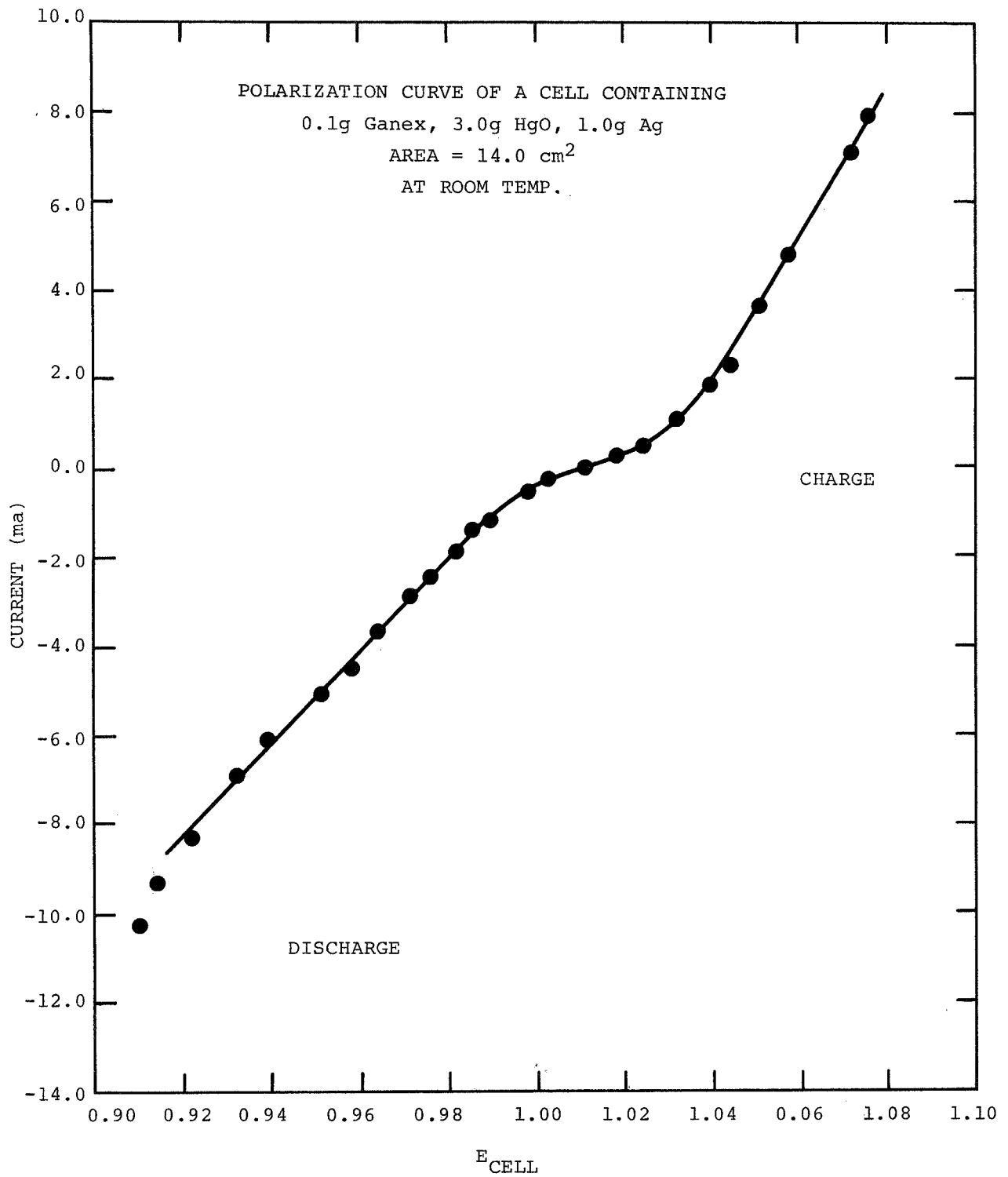


Fig.2 Polarization curve.

corresponding to the voltage maintained by the cell after the first voltage inflection were recorded (see Figure 1). The results are given in Table 6. Improvement in the power output at 1.0 ma/cm² reflects an internal heating under the continuous applied current. This mix was to be used in the next part of the work: the prototype cell development.

Table 4

DETERMINATION OF OPTIMUM SILVER POWDER CONCENTRATION

<u>Electrode No.</u>	<u>Parts HgO</u>	<u>Parts Ag (wt basis)</u>	<u>Parts Ganex Resin</u>	<u>w/o HgO</u>	<u>w/o Ag</u>
1	4.00	3.00	0.10	56.4	42.3
2	5.00	2.00	.10	70.4	28.2
3	6.00	1.00	.10	84.5	14.1
4	6.50	0.50	.10	91.5	7.0
5	6.90	.10	.10	98.2	0.14

Table 5

DETERMINATION OF OPTIMUM SILVER POWDER CONCENTRATION
RESULTS ON 9th CYCLE

<u>w/o Ag</u>	<u>Electrode Composition HgO-Ag-Ganex Resin</u>	<u>Discharge Capacity (amp-hr)</u>	<u>Theoretical Capacity (amp-hr)</u>	<u>% Utilization of HgO</u>
0.1	6.9-0.1-0.1	--	0.222	--
7.0	6.5-0.5-0.1	--	.199	--
14	6.0-1.0-0.1	.0061*	.184	32.2
28	5.0-2.0-0.1	.117	.152	77.0
42	4.0-3.0-0.1	.094	.105	89.5

*This cell was rapidly losing capacity with cycle number.

Table 6

POLARIZATION AS A FUNCTION OF CURRENT DENSITY

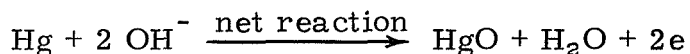
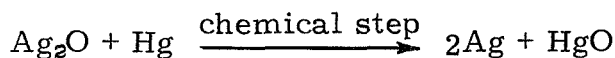
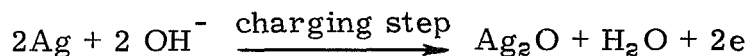
<u>I</u>	<u>Notes</u>	<u>E_{charge}</u>	<u>E_{discharge}</u>
14.3 $\mu\text{a}/\text{cm}^2$	Minimum current density by design	0.95V	0.86V
0, 143 ma/cm^2		1.43V	.66V
.50 ma/cm^2		1.80V	.46V
1.00 ma/cm^2	Pulse CD by design	(1.60V)	(.72V)

3.3 Discussion on the Operation of the Positive Electrode

The first series of cycling tests using nickel powder showed a rapid loss in capacity in the first few cycles. A postmortem on the cell showed the formation of mercury droplets. This observation is in a way similar to that observed in cadmium electrodes after they have undergone "fading." The exceptional improvement in the observed performance when silver was used in place of nickel was at first attributed to the increased tendency of silver to form amalgams as compared with nickel. The amalgam would prevent the formation of the mercury droplets in the positive electrode matrix. This is, in fact, what is observed in electrodes containing silver. Also, the tests that vary the amounts of silver in the electrode indicate that it also served as a conductive diluent.

Evidently, if this hypothesis is correct, any other materials that are highly conductive and readily form amalgams should also be effective. Two available materials, copper and gold powder, were tried. In the case of copper, the electrode cycles well at a substantially reduced voltage. The electrolyte turned a tell-tale blue indicating secondary copper electrode behavior. The gold powder was tried in a five-part mercuric oxide, two-part gold, and 0.1 part Ganex resin mix under conditions identical to those under which data described in Table 5 were obtained. In the case where 77% utilization was observed for silver, about 5% was observed for gold. Apparently, amalgamation and conduction are necessary but not sufficient for the secondary operation of the mercury electrode. A clue as to the actual situation comes from the charge and discharge curve shown in Figure 1. The high voltage early in the discharge is not due to the reduction of mercuric oxide, but corresponds in voltage to a reduction of Ag_2O . The charging curve reveals three potential arrests (at 3.3, 6.5, and about 9 hours). The early part of the charging period (3.3) hours is attributable to the oxidation of mercury. The period after 6.5 hours would correspond to the oxidation of metallic silver. The intermediate region can be attributed to the oxidation of silver amalgam whose potential of oxidation must be smaller than that of metallic silver, yet greater than that of mercury.

From an inspection of these data, it appears that more silver is oxidized on charge than is reduced on discharge. Consequently, it is proposed that the charging process involves a chemical oxidation of mercury by the silver oxide produced during the initial oxidation process. That is,



Although reasonable, further work is necessary to fully substantiate this mechanism. Evidently, silver appears unique in that its operation involves:

- (1) providing a conductive matrix;
- (2) providing a surface for amalgamation; and
- (3) providing a means for a chemical oxidation of mercury on charge.

3.4 Construction of a Prototype Test Cell

The original design of the battery called for 16 cells, each having an area of 1000 cm² so as to accommodate a 1 ma/cm² current density under the pulse load conditions. A cell having one-quarter of the area was selected for construction and testing.

At first, light-weight 100 mesh stainless steel screen was used having a strand diameter of 0.001 inch. Cells constructed with this material as the electrode substrate had a high internal resistance, i. e., 1.2 Ω at ambient temperatures. The problem was eliminated by using 40 mesh nickel screen with a 0.007-inch strand thickness.

The experimental cell was prepared as follows:

- (1) Two 40-mesh nickel screens having a strand thickness of 7 mils were cut 6.2 by 6.2 inches.
- (2) Nickel tabs 9 by 1/2 inch were cut from 5 mil sheet.
- (3) These materials were acid etched in concentrated nitric acid for about 5 seconds and then rinsed in distilled water.
- (4) Each tab was spot-welded along the edge of a screen so that one end of the tab was flush with the bottom of the screen.
- (5) An adhesive primer was applied to the portion of the tab above the screen (Pierce-Stevens E9327 primer).

- (6) Two 7.5 by 7.5-inch pieces of 5 mil PVC film were cut, and the nickel screens were affixed to them by spotting the PVC with the Pierce-Stevens adhesive.
- (7) A paste of the appropriate active materials was spread onto the screens--the composition of these materials will be given later.
- (8) The negative was formed in a 31% KOH solution at 200 ma for 15 hours; the electrode was rinsed in distilled water, and damp dried.
- (9) Separator materials 6 3/4 by 6 3/4 inches were stacked in the following series, Pellon 2505 cloth, RAI 2291 polyethylene, Pellon 2505 cloth, and were positioned between the two electrodes.
- (10) Using an impulse sealer, the entire package was heat sealed along the edges except for a single fill hole.
- (11) A hypodermic syringe was used to fill the cell with 20 cc of 31% KOH.
- (12) The fill hole was then sealed.

The final weight of a cell prepared in this way was 73 grams and its measured a-c impedance at ambient temperatures was 0.19Ω . A discharge polarization curve of the cell as obtained at ambient temperature and at -60°C is shown in Figure 3. Attempts to pulse the cell at 1 amp for 0.6 second showed that the cell voltage decreased until the end of the pulse, where it reached a value of 0.2 volt at -60°C . The polarization curve indicates that a full-sized cell of 1000 cm^2 would have no trouble maintaining this pulse.

The composition of the electrodes was as follows:

Negative

5.73 g	CdO	}	Theoretical capacity 2.4 amp-hr
0.68 g	Fe_2O_3		
.34 g	Ni (INCO 255)		
.10 g	Ganex V816 resin		

Positive

9.69 g	HgO	}	Theoretical capacity of HgO 2.4 amp-hr
7.26 g	Ag powder		
0.24 g	Ganex V816 resin		

Cycling data obtained from a cell constructed in this manner are shown in Table 7. The data were secured at room temperature at a current density of 1.12 ma/cm^2 .

At this point, work on this project was terminated.

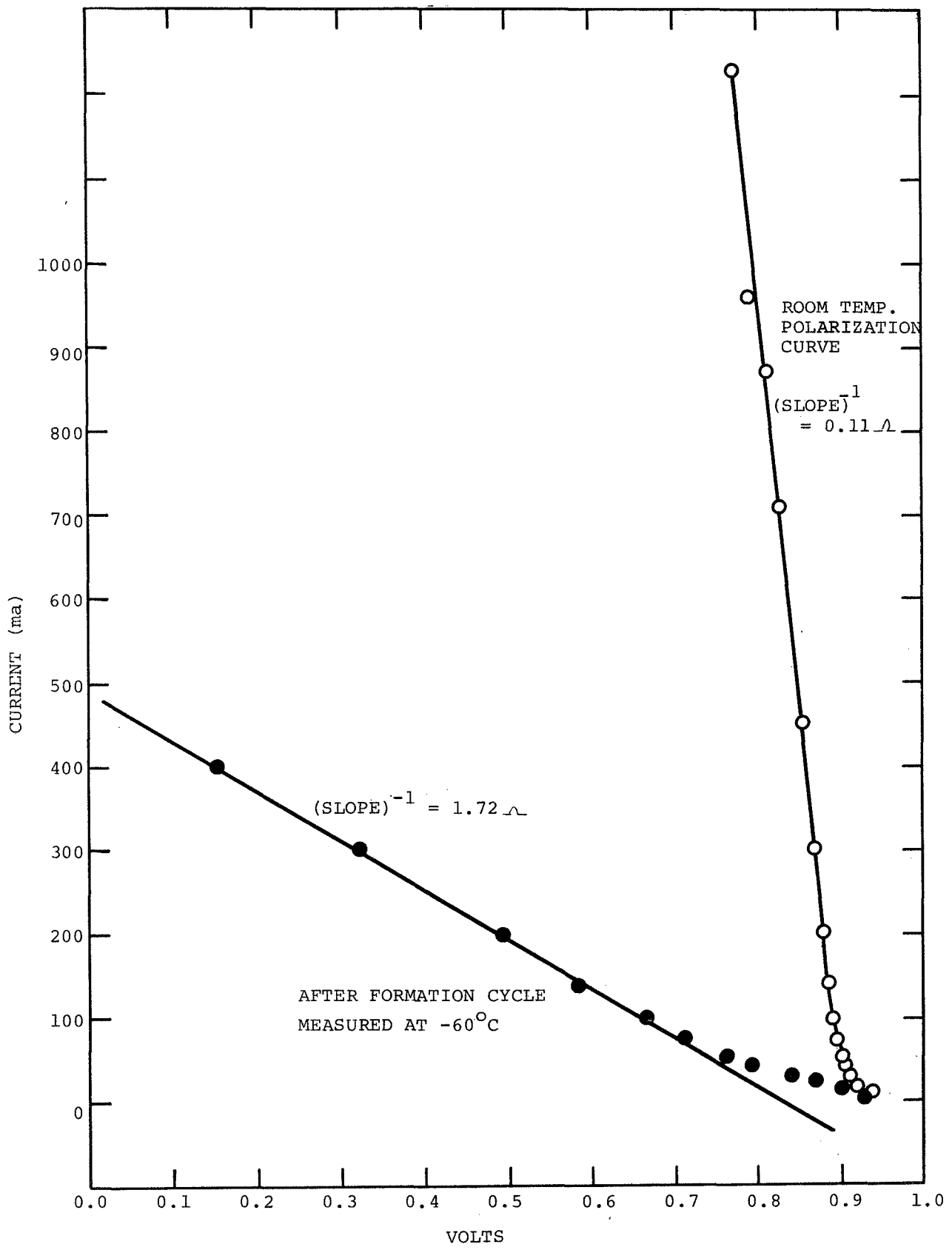


Fig.3 Polarization curve of a prototype cell.

Table 7

BALLOON BATTERY (FIRST PROTOTYPE TEST)--

Ambient temperature; 280 ma C/D; 20 ml 31% KOH used at
Electrolyte

Cycle No.	Time-Charge		Discharge		Notes
	Hours	Amp-Hr (C)	Hours	Amp-Hr (D)	
1	Adjustments made				
2	5.26 hr	1.056	3.56	0.712	Charge cut- off 1.70V
3	4.60	0.920	4.12	0.824	
4	6.98	1.954	3.15	0.882	Charge cut- off 1.80V
5	? Very long	--	4.29	1.201	
6	4.70	1.316	4.36	1.220	
7	4.70	1.316	4.38	1.226	
8	4.76	1.332	4.31	1.206	
9	4.70	1.316	4.30	1.204	
10	4.61	1.290	4.27	1.195	
11	4.49	1.257	4.04	1.131	
12	4.25	1.190	4.05	1.134	
13	4.23	1.184	4.02	1.125	
14	4.26	1.192	4.05	1.134	
15	4.18	1.170	3.97	1.111	
16	4.37	1.223	4.07	1.139	
17	4.29	1.201	4.05	1.134	
18	4.16	1.164	3.97	1.111	
19	4.07	1.139	3.90	1.092	
20	4.05	1.134	3.53	0.988	
21	3.94	1.103	3.72	1.041	
22	3.83	1.072	3.62	1.013	
23	3.75	1.050	3.52	0.985	
24	3.48	0.974	3.32	0.929	
25	3.30	0.924	3.14	0.879	
26	3.21	0.898	3.06	0.856	
27	3.11	0.871	2.99	0.837	
28	2.96	0.826	2.83	0.792	
29	2.93	0.820	2.76	0.772	
30	2.85	0.792	2.66	0.744	
31	2.70	0.756	2.52	0.705	
32	2.60	0.728	2.45	0.686	

Section 4

DESIGN CONSIDERATIONS AND PROSPECTUS

The total weight of a cell (W_T) or a battery system (nW_T) can be conveniently separated:

$$W_T = W_A + W_C + W_S$$

where W_A is the weight of the active materials, W_C is the weight of the cell case, and W_S is the weight of the support. A detailed analysis of the balloon battery design is given in the Phase I final report (NAS 5-11556), Section 4. However, it is of value to review the considerations involved in a semiquantitative way in order to indicate the critical factors determining the design of the battery.

W_A is determined by the theoretical capacity of the battery multiplied by an inefficiency factor and expressed as weight. For the prototype cell described earlier, the value was 24.0 grams. W_C contains all of the weight contributions that are a function of area. This is,

$$W_C = \frac{I}{J} \eta_C$$

where I is the pulse current, J is the current density, and η_C is the total weight aspect of the cell materials. For the prototype, $I = 1.00$ amp, so that the area of each of the electrodes is given by

$$A = \frac{1000}{J (\text{ma/cm}^2)}; \quad W_C = \frac{1000}{J} \eta_C$$

From the polarization data given in the Phase I report, J was taken as 1.00 ma/cm² as a design point so that the electrode area is 1000 cm². Using a two-electrode structure and neglecting the cell edges, the projected area of the cell is established. Further, for the sake of simplifying the exercise below, it can be assumed that the support is constructed as a band superimposed over the area of cell so that the support and cell areas are equal. That is,

$$W_S = \frac{I}{J} \eta_S$$

These approximations serve to simplify the cell weight expression

$$W_T = 24.0 + 1000\eta_C + 1000\eta_S$$

The entire structure is tentatively designated as a cylinder such that

$$\frac{I}{J} = \frac{2\pi rl}{n}$$

where r is the radius, l the length, and n the number of layers.

The cylindrical support (η_S) was not studied during this contract period. However, a nominal value can be taken as 0.050 g/cm^2 . Therefore,

$$W_T = 24.0 + 1000 (\eta_C + 0.050)$$

for a single cell. It is of value to examine the quantities composing η_C . Again, referring to the prototype cell, Figure 4 illustrates its cross section.

$$\eta_C = 2 \eta_{\text{PVC}} + 2 \eta_{\text{Ni}} + 2 \eta_{\text{PELLON}} + \eta_{\text{RAI}} + \eta_{\text{ELECTRODE}}$$

Table 8 gives the actual or averaged value of these quantities.

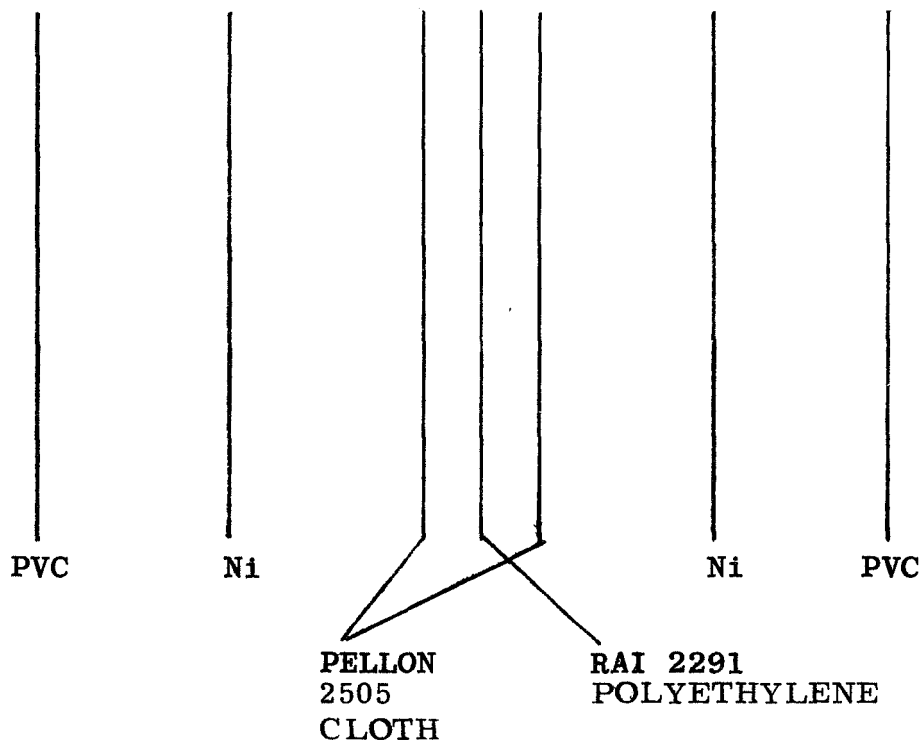


Fig. 4 Schematic cross section of prototype cell.

Table 8
ASPECT RATIO FOR VARIOUS CELL MATERIALS

<u>Material</u>	<u>Notes</u>	<u>η</u>
PVC	5 mil	0.0176
Nickel	40 mesh 0.007-inch wire	.046
Pellon 2505 cloth		.009
RAI 2291 polyethylene	1 mil	.003
Electrolyte	20 cc of 31% KOH	.100

Therefore, $\eta_C = 0.250 \text{ g/cm}^2$. Since the prototype was constructed to one-quarter size (250 cm^2), W_C equals 62.5 grams. Using the value of W_A given earlier, the weight of the cell is calculated as 86.5 grams. This can be compared with the actual cell weight determined after preparation, which was 73.0 grams. For practical purposes it is a good estimate.

What follows is an attempt to project battery weights based on the above-mentioned considerations. A revision of η_C can be made based on the actual cell weight:

$$\eta'_C = \frac{(\text{weight of actual cell} - \text{weight of active materials})}{250 \text{ cm}^2}$$

$$\eta'_C = 0.196 \text{ g/cm}^2$$

Then the weight of a full-sized battery of sixteen cells at 1000 cm^2 on a side can be estimated as:

$$W = 16 \times 24.0 + 16 \times 1000 (0.196 + 0.050)$$

$$W = 4320 \text{ grams}$$

Certain obvious improvements can be made as shown in Table 9. The improved version can similarly be shown to have an estimated weight of 2680 grams. A speculative design can be based on taking advantage of the time constant of the cell to control the cell voltage decay during the pulse. Preliminary studies have shown that the pulse is of sufficiently short duration that it could not drive the prototype cell to zero volt. In this case, if a 500 cm^2 cell were used, the total battery weight would be 1584 grams.

Table 9

COMPARISON OF BEFORE-AND-AFTER IMPROVEMENT
ASPECT RATIOS

	<u>Present</u>	<u>Improved</u>	<u>Notes</u>
Electrolyte	0.100	0.025	Starved condition (5 ml)
Pellon cloth	.018	--	None used
RAI polyethylene	.003	.006	Two layers
PVC	.035	(.017)	Substitute plastic material
	<u>0.156</u>	<u>0.038</u>	

$$\Delta\eta = 0.128$$

The engineering exercise given above serves to dramatize the prime contributors to the determination of the battery weight. For the balloon battery design they are:

- (1) current density;
- (2) amount of electrolyte used;
- (3) substrate mass; and
- (4) case material.

in a descending order of importance. By using pressed electrodes, substantially higher current densities are available (see Phase I, Final Report). Since the termination of work on this contract, thin, flexible, pressed electrodes have been prepared. Also, the amount of electrolyte is much too high in the prototype. A reduction is the obvious course of action. The electrode substrate mass could be reduced. Better and lighter cell case materials are being investigated in collateral efforts at GE.

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