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NATIONAL CARBON COMPANY
DIVISION OF UNION CARBIDE AND CARBON CORP.
FINAL QUARTERLY PROGRESS REPORT - NO.4
October 5, 1953 to January 4, 1954
on
DEVELOPMENT OF A
LOW TEMPERATURE LECLANCHE BATTERY
CONTRACT NO. DA-36-039-sc-42611
SIGNAL CORPS. PROJECT NO.31-2022A
DEPT. OF THE ARMY PROJECT NO. 3-18-03-021

Submitted by

W B Lloyd
William B. Lloyd
Project Director

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PART II - RESUME' AND SUMMARY OF CONTRACT DEVELOPMENT

ABSTRACT

This final report consists of two parts. Part I is a detail of the fourth and final quarter activities. Part II is a final resume' and summary of all development work since the inception of the contract.

In Part I the work plan for the fourth and final quarter is discussed. The pilot line used for the manufacture of the FL-5 flat cells, used in the "B_1" and "B_2" sections of the BA-2270/U battery is described in detail.

Salient points concerning the FL-2 flat cells used as the "C" section and the "AA" size round cells used in the "A" section are also presented. The BA-2270/U battery assembly used for the final batteries of this contract is described.

Round cell voltage and amperage patterns on shelf as well as the fresh and delayed services on these cells are tabulated and discussed. The flat cell shelf and delayed service picture is also presented.

In Part II is given a resume' transcript of the development findings that resulted from this contractual work. The development work of this contract is presented in the resume' in classifications that represent the main lines of endeavor. The report terminates with a final summary.

PURPOSE

The purpose of this project is to search for and evaluate production feasible means of improving the low temperature characteristics of the Leclanche batteries.

The Signal Corps Technical Requirements for this work are as follows:

1. This technical requirement covers the requirements for investigations leading to the improvement of the low temperature characteristics of the Leclanche battery.

a. Basic studies are to be conducted on the constituent parts of the Leclanche electrochemical system to determine the characteristics that affect low temperature operation.

b. Cells suitable for incorporation in the "A" and "B" sections of battery BA-2270/U are to be designed and developed incorporating the results of the above studies and the results of the investigations conducted under Signal Corps Contract No. DA-36-039-sc-7 having or approaching the following characteristics:

(1) -40°F. Battery

(a) Operation down to -40°F. with a minimum capacity at -40°F. not less than 70 per cent of full capacity at 70°F.

(b) The cells shall be capable of being stored at 113°F., 30 per cent R.H. for a minimum period of 90 days, at 70°F. for a minimum period of one (1) year and also at temperatures down to -80°F. for a period of one (1) year with a maximum loss in capacity not greater than 10 per cent of the original capacity as measured at 70°F.

(c) The design of the cells and their process of meanufacture shall be commercially feasible for large scale production.

(2) -65°F. Battery

(a) Operation down to -65°F. with a minimum capacity at -65°F. not less than 50 per cent of full capacity at 70°F.

(b) The cells shall be capable of being stored at 113°F. 30 per cent R.H. for a minimum period of 90 days, at 70°F. for a minimum period of one (1) year and also at temperatures down to -80°F. for a period of one (1) year with a maximum loss in capacity not greater than 10 per cent of the original capacity as measured at 70°F.

(c) The design of the cells and their process of manufacture shall be commercially feasible for large scale production.

c. Other pertinent investigations as directed by the Contracting Officer or his technical representative.

PART I

DETAIL OF FOURTH QUARTER

October 5, 1953 to January 4, 1954

PROGRAM OF FOURTH AND FINAL QUARTER

At the start of this final quarter, the status of the development efforts of this contractual work was discussed in detail with members of the Signal Corps Engineering Laboratories. It was decided that the work during this final quarter was to be directed toward the manufacture of 300 sample BA-2270/U batteries. The "A" section of this battery was to consist of 33 "AA" size cells equipped with a mechanical seal and containing the very wet depolarizing mixes required for improved low temperature functionability. The separator material for all of these cells was specified to be National Carbon Company's MB-1 paper-coated film separator stock.

The "B_1" section of the battery was to consist of four 15-cell stacks of FL-5 size cells of HE-266 construction. These cells contain the rigid frame support for the very wet depolarizing mixes.

This frame type construction, as a means of containing the extremely wet mixes required for low temperature functionability, was developed under Signal Corps Contract No. DA-36-039-sc-7. In this original work, pure film separator material was considered to have some advantage over the MB-1 paper-backed film separator stock. As this construction has been further improved in the work on this subject contract, pure film separator stock has been maintained. This stock is not commercially available nor is it considered currently commercially practicable for mass production methods. It was, however, the purpose of this contractual work, to define the best possible constructional features for low temperature application in the time and monetary limitations of the contractual work. For these reasons, pure film separator stock has been used in all of the flat cells of this development. The material has all been made on laboratory equipment.

The "B_2" section of the BA-2270/U battery has been specified as two 17-cell stacks of FL-5 size cells in a construction identical with that of the "B_1" section.

For the "C" section of this battery, three FL-2 size cells have been used. These were made on regular "Mini-Max" flat cell equipment using, of course, the appropriate depolarizing mix and electrolyte content for these low temperature batteries.

This contract called for the manufacture of 300 sample batteries at the completion of the work. In the light of the experimental data available, it appeared desirable to manufacture part of these batteries with lithium chloride base electrolyte and the other part with calcium chloride base electrolyte. Representatives of the Signal Corps Engineering Laboratories requested that 150 batteries be provided with each electrolyte system. The lithium chloride electrolyte chosen was LTE-7. For the 150 batteries with the calcium chloride base electrolyte, LTE-121 was chosen.

<u>Depolarizing Mix</u>

The depolarizer used on all experimental lots in this development work and also for the 300 batteries made at the end of this contract was Western Electrochemical's electrolytic ore from Lot 244. This ore has been used in a 7:1 ratio with acetylene black. In those mixes wherein calcium chloride electrolyte (LTE-121) was used, a solution volume between 65 and 70 per cent was maintained. For the depolarizing mix containing lithium chloride electrolyte (LTE-7), a solution volume of 70 to 75 per cent was maintained. The acetylene black, zinc chloride, and ammonium chloride have all been of standard battery quality.

The FL-5 Flat Cell Manufacture

All of the FL-5 size flat cells were manufactured on pilot line equipment. In Plate I is shown a cross-sectional view of the low temperature HE-266 flat cells with preformed blanket. This construction was used in the manufacture of the FL-5 cells made at the end of this contract.

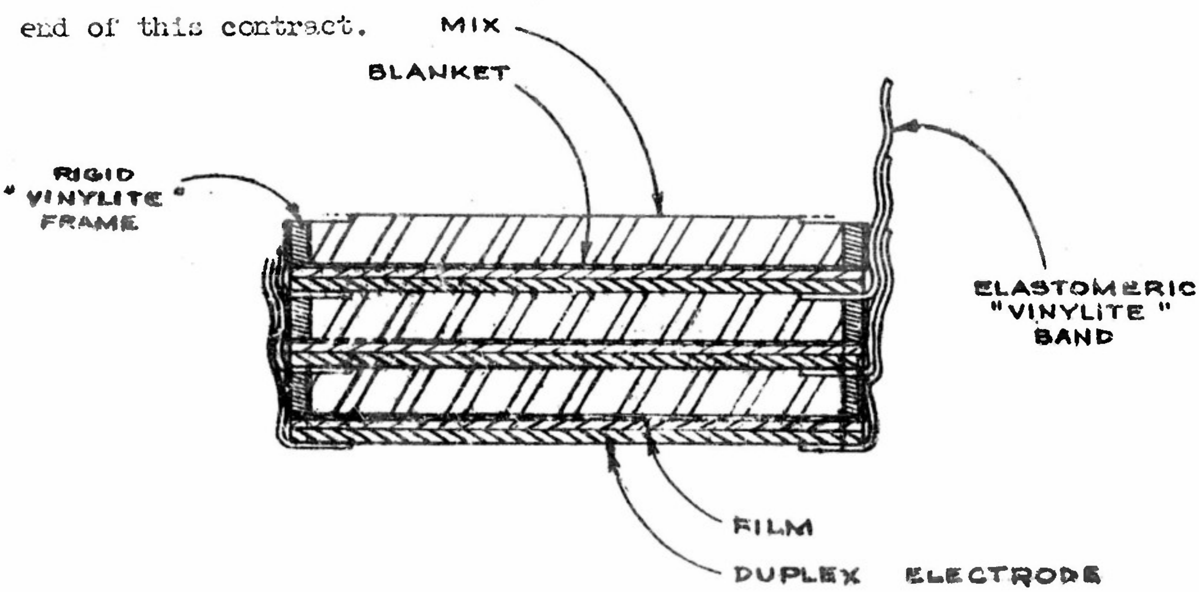

PLATE I LOW TEMPERATURE HE-266 FLAT CELL WITH PREFORMED BLANKET.

The elastomeric "Vinylite" bands and the duplex electrodes are standard production items. The depolarizing mix and separator stock have been previously discussed. The pure film separator stock was prepared for use on the pilot line, by blanking the material out so that after presoaking in electrolyte, the film would extend just beyond the outer periphery of the duplex zinc electrode. For the blanket stock, a very pure 4 mil paper was used. This paper was blanked out and preformed to a cup shape with the lips of the cup extending just to the top of the rigid "Vinylite" frame that contains the depolarizing mix. The blanket positioning is shown in Plate 1.

Further preparatory work with the preformed blanket before actual assembly operations on the pilot line involved the sealing of the rigid "Vinylite" frame to the cup-shaped blanket. Adhesive was applied to the bottom surface of the rigid plastic frame. This frame was then accurately positioned in the preformed blanket. It was then ready for use on the pilot line operation.

Plate 2 is a view of the first step in the pilot line. This plate shows a series of basket fixtures positioned on their metal frame. A piece of plastic is slid under the basket fixtures and this assembly is then placed in the positioning blocks as shown in the forepart of the plate.

The preformed blankets with the rigid "Vinylite" frames sealed therein are then placed in the basket fixtures so that they

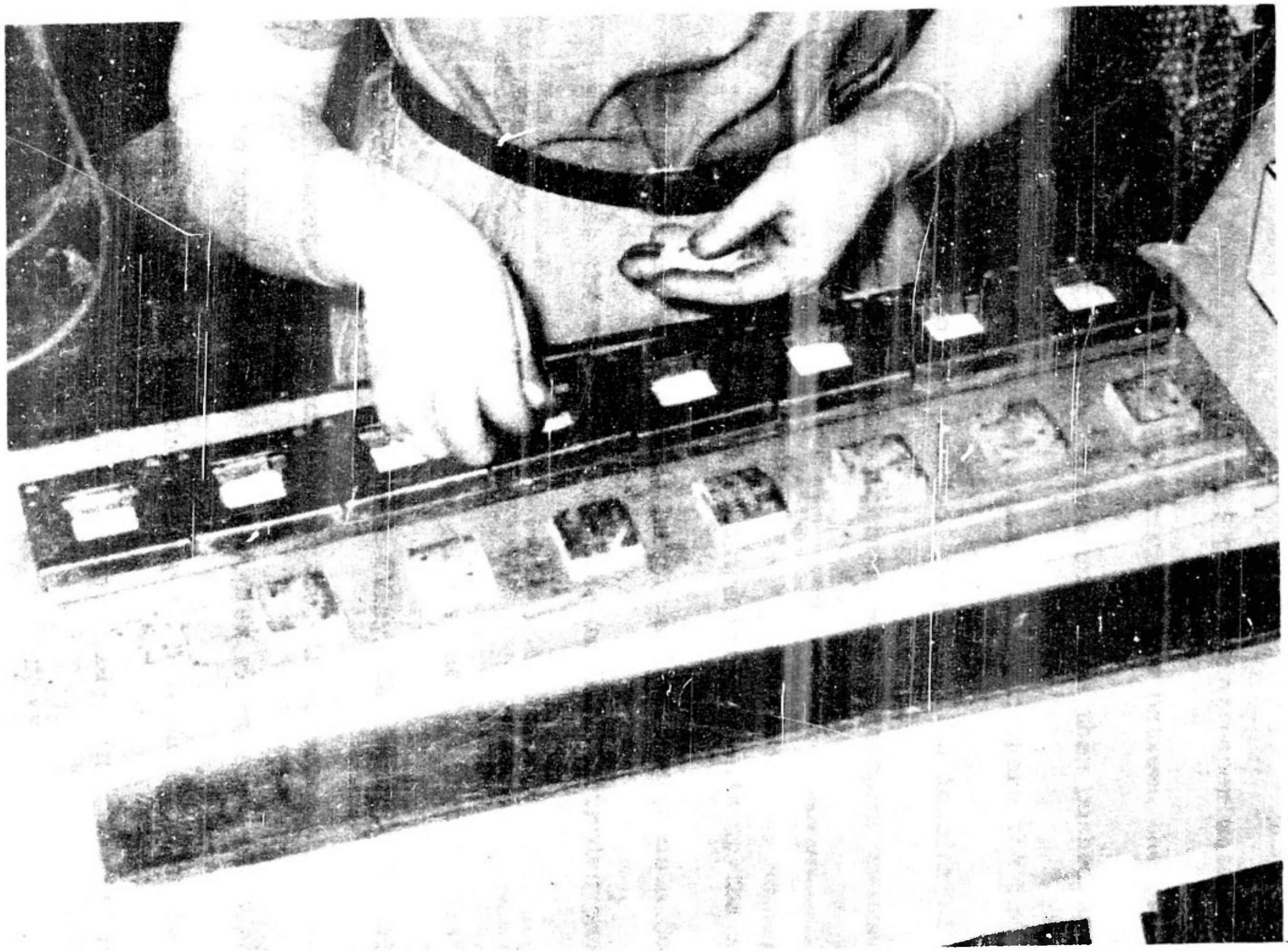

Plate 2 - Blanket and Frame Positioning

come to rest on the positioning blocks. A piece of parting paper containing a center hole for mix insertion is then laid on top of the rigid frames within the preformed blanket.

These units are then ready for mix insertion which is shown on Plate 3. In this operation, very wet depolarizing mix is inserted through the hole in the parting paper until it completely fills the space within the rigid frame between the preformed blanket and the parting paper. These units are then pushed still in their handling racks down the assembly line to where the individual cells are developed to the point of receiving the depolarizing mix.

The first step in this cell developing assembly line is to form the elastomeric vinyl bands into cups. This operation is shown in Plate 4. It is noted that the band extends up the side of the basket fixture the desired height and also extends a portion of the way across the bottom so that the duplex electrodes can be sealed thereto.

Plate 5 is a view of the machine used to seal the duplex electrodes to the elastomeric "Vinylite" bands. In this operation the basket fixture containing the elastomeric "Vinylite" band stretched into proper shape and with a duplex electrode laid therein, is placed individually in this unit where a heat-sealed joint is effected.

At this point on the assembly line, the units from the mix filling machine are brought in. A presoaked film is positioned in

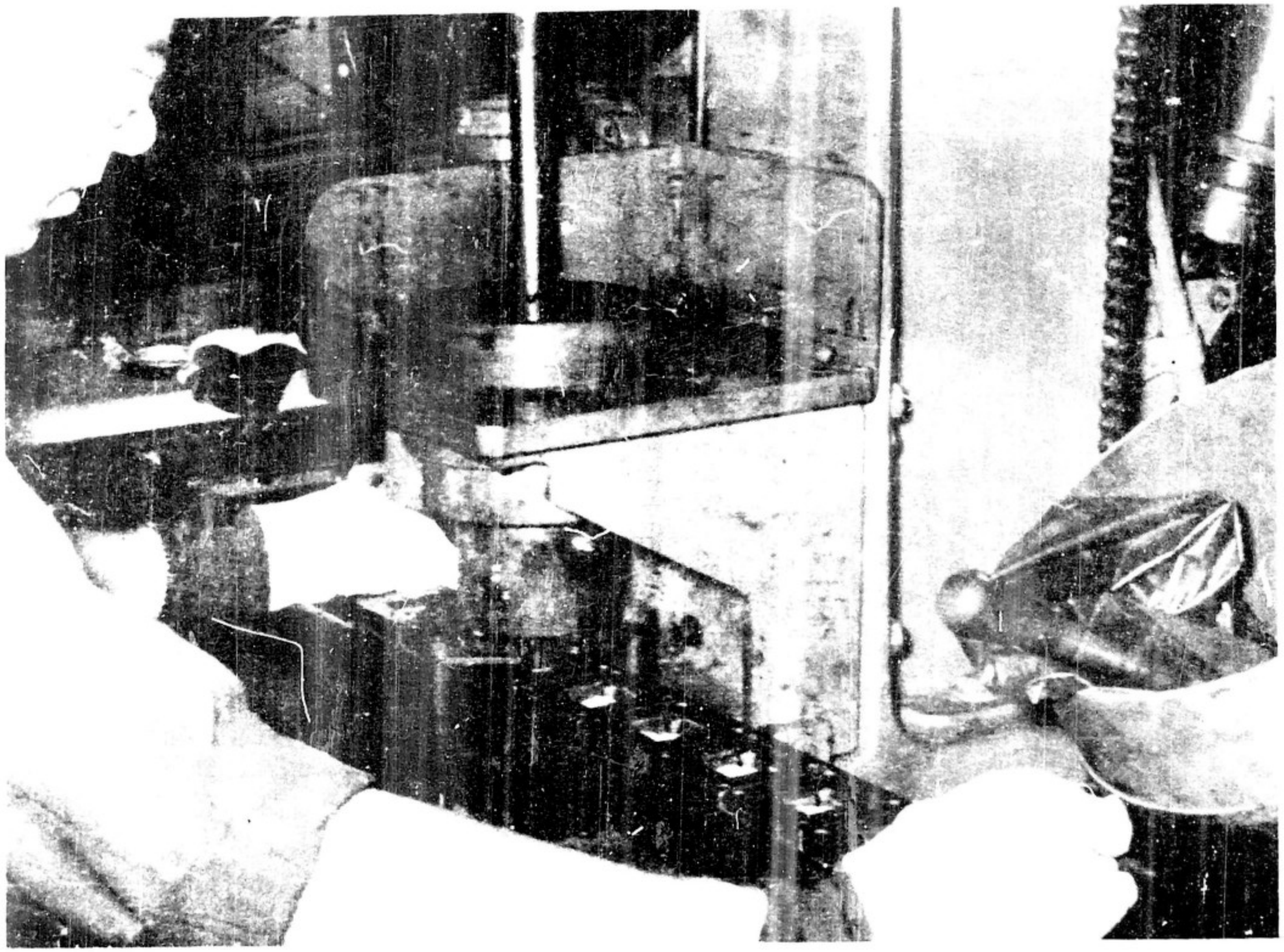

Plate 3 - Depolarizer Mix Filling

Plate 4 - Formation of "Vinylite" Cups

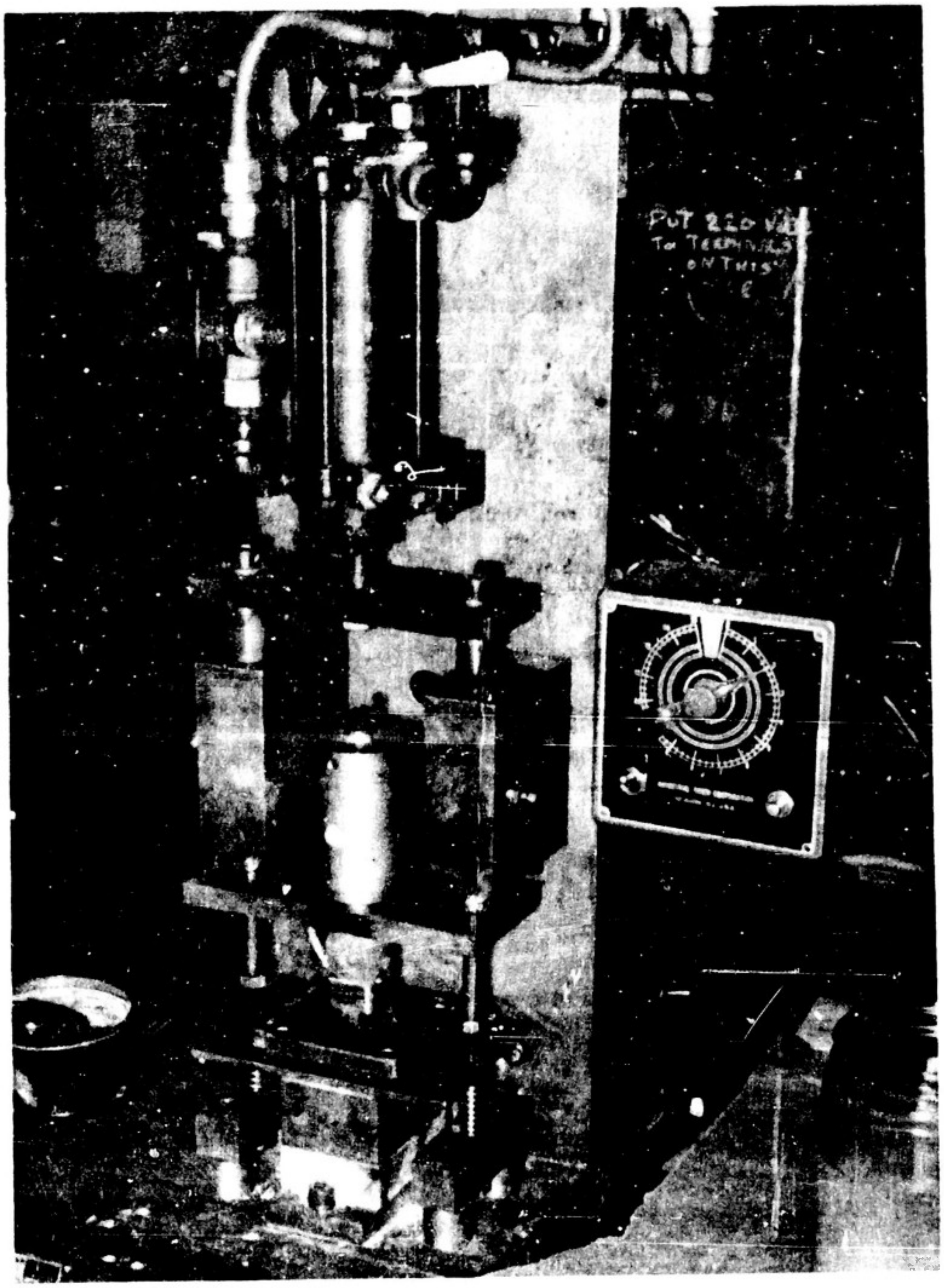

Plate 5 - Duplex Electrode Sealing Unit

each cell, then as is illustrated in Plate 6, the blanket-rigid frame-mix assembly is ejected from the basket fixtures. The parting paper is then removed from the top surface. These units are then placed on top of the presoaked film to complete the individual cells.

Plate 7 shows these individual cells on the pilot line. They are stacked by telescoping one inside the other and placed in the racks at the top of the picture. Plate 8 shows the two dipping racks used for these assemblies. The assemblies are removed from the stacking racks shown in Plate 7 and placed in the dipping racks shown on the right side of Plate 8, and immersed in molten low temperature wax. This shrinks the elastomeric "Vinylite" bands tightly around the cells as shown in Plate 1, and provides the whole external surface with a protective coating of wax.

After the assemblies have had time to cool from this first wax applying operation, special low temperature rubber bands are positioned around the stacks. They are then placed in the dipping rack in Plate 9 and again dipped in molten special low temperature wax. Assemblies are then ready for their normal aging period prior to testing and assembly into batteries.

Plate 6 - Unit Cell Assembly

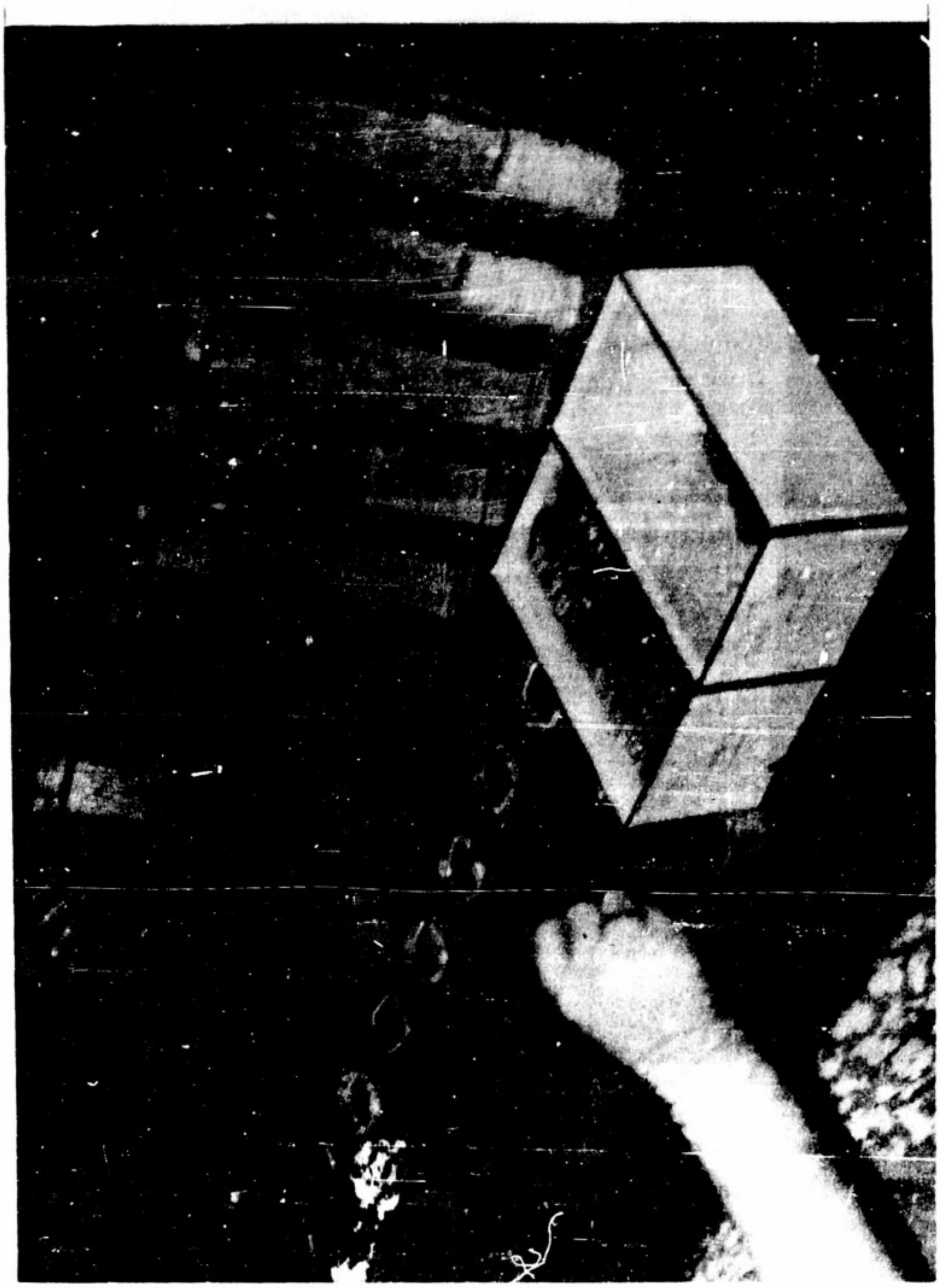

Plate 7 - Individual Cells Ready for Stacking

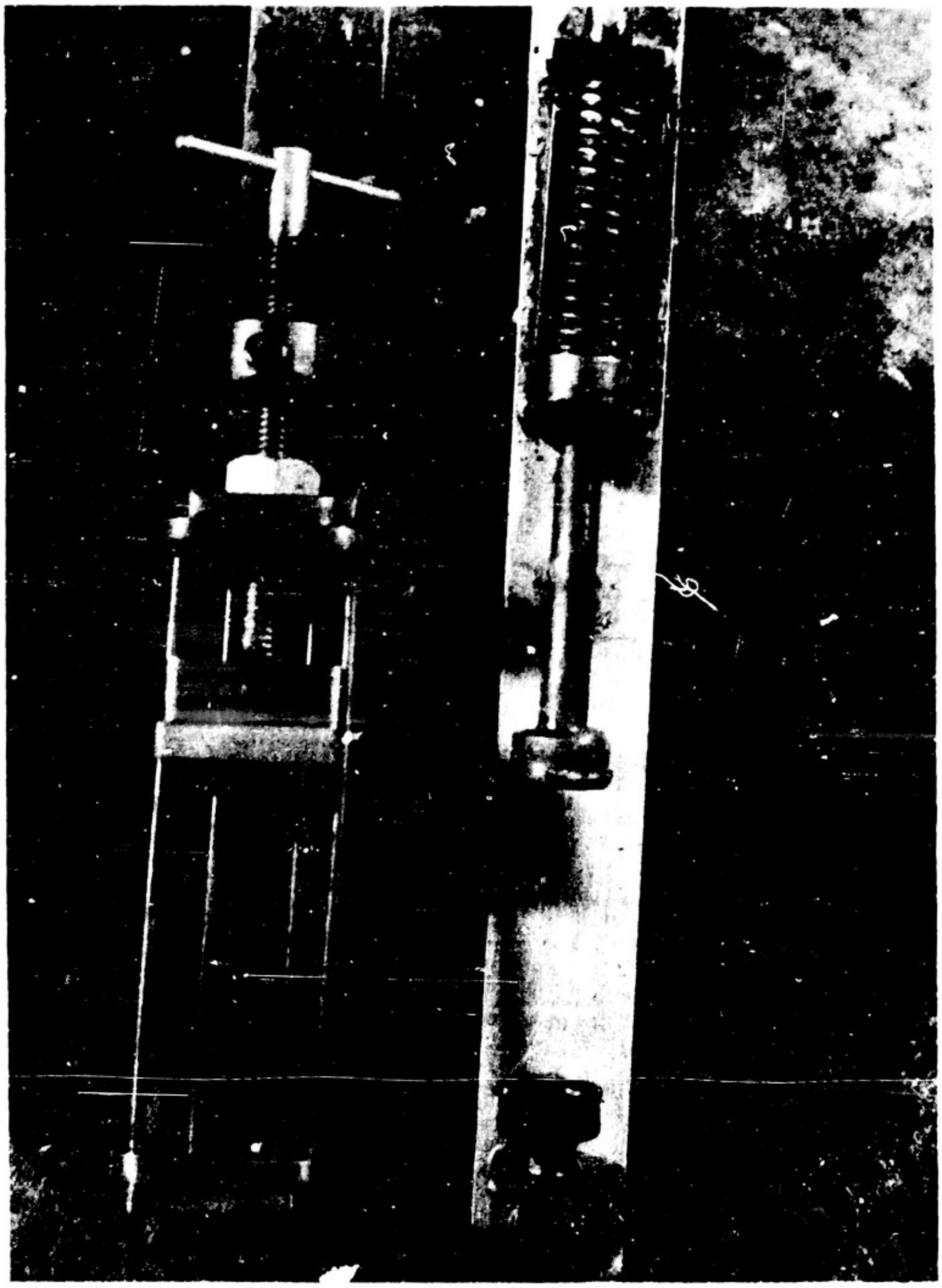

Plate 8 - Dipping Racks

Plate 9 - Final Dipping Rack

FL-2 Flat Cell Manufacture

Three FL-2 flat cells are used in series as the "C" section of the BA-2270/U battery. These cells are manufactured on regular production equipment. The depolarizing mixes used contained Western Electrochemical's electrolytic ore from Lot 244. This ore was used in a 7:1 ratio with acetylene black. One hundred fifty of the 3-cell units were made with calcium chloride LTE-121 electrolyte and the other 150 units made with lithium chloride LTE-7 electrolyte. The only difference between this depolarizing mix and that used for the "A", "B_1" and "B_2" sections of the battery is in the quantity of electrolyte used. With these very small cells of conventional construction, it was necessary to cut back slightly on the final solution volume in order that the mix would be manageable on regular production equipment. It was not considered necessary to provide this "C" section with as wet a depolarizing mix as is necessary for the "A", "B_1" and "B_2" sections for it is expected to maintain potential only.

"AA" Round Cell Manufacture

The "AA" size round cells were manufactured on regular production equipment. The new mix injector capable of handling appreciably wetter depolarizing mixes was not yet installed on the production line. The depolarizer mix filling was, therefore, done on a unit off the production line. The mix filled cells were then again placed on the production line and finished.

At the beginning of this contract work, the "AA" size cells were made with a poured seal. This is not an uncommon practice when the Leclanche cells are to be used in pack batteries. Shelf and delayed service on these cells made with the poured seal, however, showed evidences of poor keeping qualities on shelf for these cells of low temperature formulation. It was agreed, however, with representatives of the Signal Corps Engineering Laboratories that the "AA" cells for these final production samples would be made with a mechanical seal. Data thus far indicate that improved keeping qualities will be attained on these low temperature cells with the mechanical seal.

BA-2270/U Battery Assembly

Plate 10 is a side view of the BA-2270/U battery assembly that has been used for the 500 batteries provided at the end of this contract. It will be seen that the 33 parallel connected "AA" size cells are contained in three segments. The bottom segment contains 14 cells. The top segment closest to the terminal contains 9 cells and the third segment contains 10 cells. The two battery stacks of FL-5 size cells in the bottom center of the picture function as the "B_2" section of the battery. On the left side of the picture, there are four 15-cell stacks of FL-5 size cells to serve as the "B_1" section of the battery. The three FL-2 cell stack that serves as the "C" section of the battery can be seen in the end of the terminal pad.

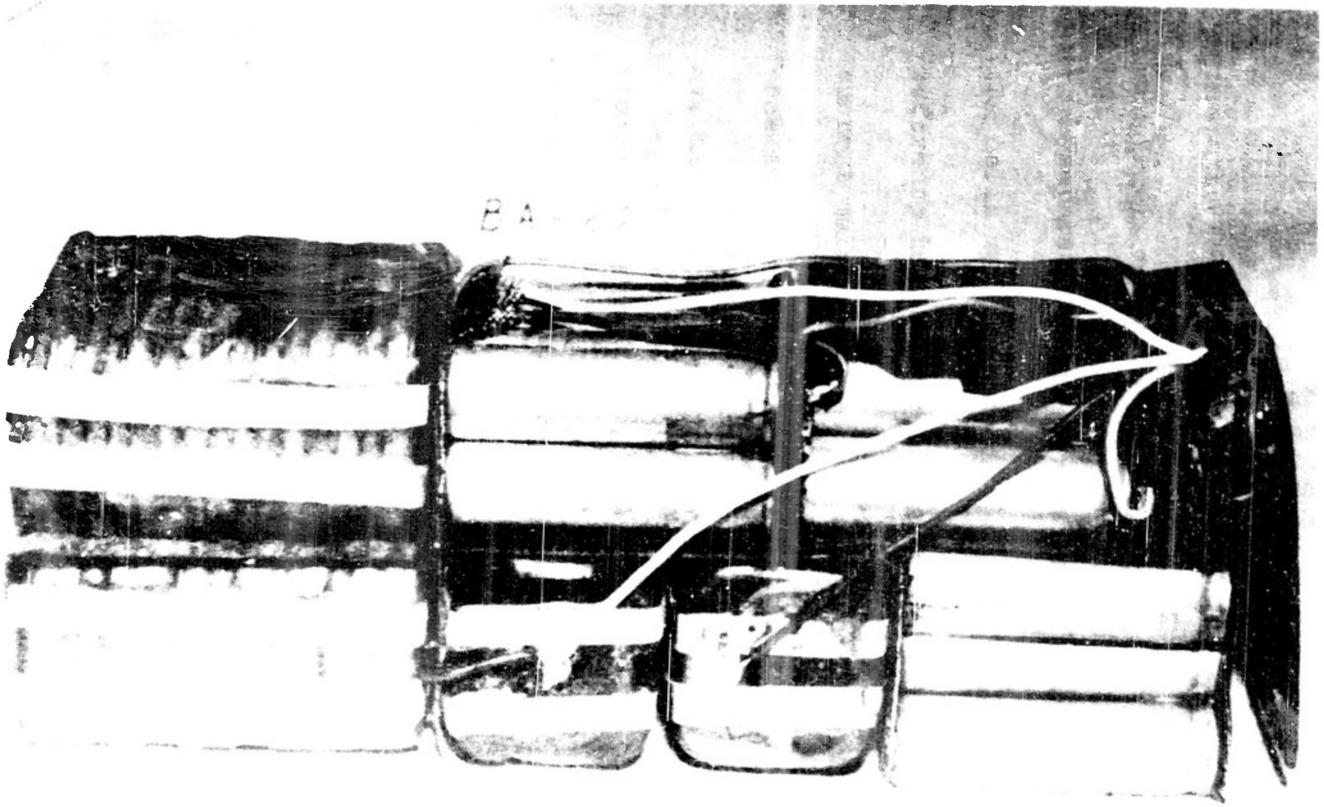

Plate 10 - BA-2270/U Component Assembly

The battery as presented in Plate 10 is ready for insertion in a BA-2270/U outer nest. After insertion in the nest, the battery is potted with low temperature wax.

Round Cell Voltage and Amperage Patterns on Shelf

In Table 3 of Quarterly Progress Report No. 3, fresh, 3 and 6 months voltage and amperage patterns are presented for one "AA" size construction. This construction consisted of LTE-121 electrolyte, MB-1 separator stock, 25 per cent water in the depolarizing mix and the cells were closed by means of a poured seal. It may be seen by reference to this table that these lots of cells averaged 72 per cent current maintenance at 3 months and about 50 per cent current maintenance at 6 months. Voltage and amperage patterns on shelf are now available on several lots of cells which differ from the above-mentioned lots only in that pure film was used as the separator material in the place of the MB-1 separator stock. These data are presented in Table 1 attached. It is seen that lots made with the pure film separator stock averaged 74 per cent current maintenance at 3 months and about 50 per cent at 6 months current maintenance. These data are in the same order of magnitude as those referred to above for the MB-1 separator lots. The type of separator is, therefore, not a variable as far as current maintenance expectancy is concerned.

The next potential variable that will be compared with regard to possible effect on service maintenance expectancy is round cells with 20 per cent additional electrolyte content. These results are represented in Table 2 attached. The cells of Table 2 contain LTE-121 electrolyte, MB-1 separator stock, 30 per cent water in the depolarizing mix and the cells were finished with a poured seal. The average current maintenance at 3 months of 76 per cent and the average current maintenance at 6 months of about 50 per cent are in the same range as the lots of cells with 25 per cent water in the depolarizing mix, both with MB-1 separator stock and pure separator stock. It is evident, therefore, that the inclusion of additional electrolyte in the cell system is not a panacea for delayed shelf voltage and amperage character.

There was a possibility, of course, that pure film separator stock in "AA" size cells containing increased electrolyte content, by combination of the two factors, might provide an improvement for delayed shelf maintenance. Table 3 attached presents the results of five lots of cells of this construction. It is seen from these data that this combination does not provide the cells with improved keeping qualities.

It was resolved from the afore-mentioned information that inadequacy of seal of the poured seal units was solely responsible for the drop-off in voltage and amperage on shelf storage. The "AA" size round cells were therefore made with a mechanical seal which is a more perfect seal against moisture loss.

In Table 4 attached, the fresh and 4 month voltage and amperage patterns of "AA" size cells made with MB-1 separator stock, 20 per cent additional electrolyte in the depolarizing mix system and with a mechanical seal are presented. In this table the three lithium chloride electrolyte systems, that have been considered throughout this report, are included. One large lot of cells containing LTE-121 calcium chloride electrolyte is also included. The current maintenance after 4 months storage on all of these lots, it will be noted from the table, ranged from a low of 92 per cent to 100 per cent. This range is considered quite acceptable for these low temperature cells.

Round Cell Fresh and Delayed Services

It will be seen by reference to Tables 3, 4, 5 and 6 in the third Quarterly Progress Report of this contractual work that the 3 month delay services on the round cell sections of the BA-2270/U battery, on the whole, did not present an especially good service maintenance pattern when compared to the corresponding fresh tests. There was an indication, however, that delayed service expectancy was enhanced by higher depolarizing mix solution volumes. It was also mentioned in this same report that examination of these cells after shelf storage and also after delayed service showed evidences that an adequate seal had not been maintained on these cells. To improve this situation, the construction was altered to include a mechanical seal. In Table 5 attached are presented fresh and 4 months delay service data on the "A" section of the BA-2270/U batteries consisting of "AA" size round cells with the mechanical seal. The construction includes the MB-1 separator stock, LTE-7 electrolyte and 35 per cent water in the depolarizing mix.

At a current density of 16.2 milliamperes per square inch for the 2 minute period, three lots of cells containing the LTE-7 lithium chloride electrolyte averaged 1.7 hours on fresh test. These same lots of cells when tested at 70°F. provided 22 hours of service on fresh test.

In the bottom section of Table 5 is presented the 4 month delay service on these same lots of cells. The average of 1.5 hours service is most encouraging and in a quite acceptable range. Compared to the 1.7 hours fresh service, it is evident that very good service maintenance has been obtained.

The cells just discussed from Table 5 were of LTE-7 electrolyte formulation, and so contained no ammonium chloride in the depolarizing mix system. Cells of Table 6 attached were made with LTE-192 electrolyte. In this lithium chloride electrolyte system, the depolarizing mix calculates to about 4 per cent ammonium chloride content. With the exception of the change in depolarizing mix to LTE-192 lithium chloride electrolyte, the cells in Table 6 were made identical to those described in Table 5. Fresh -40° service on these cells averaged 2.0 hours and the fresh 70° service, 30 hours. The fresh -40° service is probably in the same range as obtained with LTE-7 electrolyte. The 70° service is in a somewhat higher bracket as is expected of cells containing ammonium chloride.

In the lower portion of Table 6, the 4 month delay service at -40°F. is given. The average of 1.0 hour of service is somewhat below expectancy.

Table 7 provides data on the cells made at the same time and with the same construction as used in Tables 5 and 6 except that the LTE-158 lithium chloride electrolyte was used in the depolarizing mix. It can be seen that these lots averaged 1.6 hours on the fresh -40° test and 27 hours on the fresh 70° test. An average of 1.5 hours service at -40°F. after 4 month delay is shown in the bottom portion of the table and represents very good service maintenance.

Cells made with the same constructions as described in Tables 5, 6 and 7 except with calcium chloride LTE-121 electrolyte in the depolarizing mix are summarized in Table 8. Fresh service was run at two current densities. At an anode current density of 19.6 milliamperes per square inch for the 2 minutes, service at -40°F. averaged 2.1 hours and the fresh 70° service, 28 hours. At an anode current density of 16.2 milliamperes per square inch for 2 minutes, the fresh -40°F. service averaged 2.7 hours and the fresh 70° service 36 hours. The 4 month delayed service at the bottom of Table 8 is from cells discharged at a current density of 16.2 milliamperes per square inch for the 2 minute period. These averaged 1.8 hours at -40°F. This represents a considerable reduction from the 2.7 hours obtained on the -40°F. fresh test, however, it will be noted that the service of 1.8 hours is still in excess of that obtained on any of the three lithium chloride lots already described.

In Table 20 of the third Quarterly Progress Report of this contractual work, services were shown for four lots of "AA" size round cells containing a paste separator system. These comparisons included the LTE-192 lithium chloride electrolyte system and the LTE-7 lithium chloride electrolyte system. In Table 9 of this report, the corresponding fresh services for the LTE-5 calcium chloride system and the LTE-158 lithium chloride system of pasted separator construction are presented to complete this picture. These additional data do not alter conclusions that have already been reached that the MB-1 separator system is superior to the pasted separator system for the BA-2270/U battery low temperature application.

Flat Cell Voltage and Amperage Patterns on Shelf

In Table 10 a considerable number of voltage and amperage patterns of FL-5 size cells of the HE-266 frame type construction are reported. It can be seen from the mass of data of cells containing the lithium chloride LTE-7 electrolyte that the 3 month current maintenance on many of the lots was quite good. However, there are in the table a few lots that are definitely below expectancy. Similar conclusions result from a consideration of the current maintenances at 5 months. These data on the LTE-7 lithium chloride electrolyte system may be compared with the two results shown in the table for the LTE-158 lithium chloride system at 3 months. These lots appear to be in the same current maintenance range as those for the LTE-7 electrolyte. One lot of cells containing LTE-192 lithium chloride electrolyte is also estimated to be in the same range as far as current maintenance is concerned from the one figure shown at 5 months.

Flat Cell Delayed Services

In the attached Table 11 are summarized the 3 month delay service results from flat cells containing LTE-7 electrolyte. These cells were stored at room temperature for 3 months and then tested. The construction was HE-266 and the depolarizing mix and separator system contained 36 per cent water. One section of a BA-2270/U battery provided 1.3 hours average service at -40°F. after this 3 month delay period. Corresponding cells discharged at 70°F. averaged 17.3 hours. The B_2 sections discharged in conjunction with these B_1 sections averaged 1.5 hours service at -40°F. after 3 month delay and 22 hours at 70°F.

A few lots of cells of the same construction have reached 4, 5 and 8 month delay periods and the service on these lots are summarized in Table 12. These longer delay periods, it will be noted from Table 12, delivered at -40°F. somewhat lower and more variable services. These lots were made early in the contract work and do not contain certain changes that have been made in the structural features such as the inclusion of the preformed blanket. Since making these cells, it is also felt that the assembly technique was further perfected as the pilot line operators gained more experience on the job. It is expected, therefore, from latter lots made under this contract that better long delay service will prevail than is indicated in Table 12.

CONCLUSIONS:

It is concluded that:

1. The delayed service level of "AA" size round cells has been achieved with a good service maintenance. This has been accomplished by the use of a mechanical seal whereby the cell could be adequately sealed against moisture loss.

2. Very good voltage and amperage patterns have been attained after 4 months shelf on "AA" cells with a mechanical seal.

3. Good 4 month delayed service at -40°F. has been attained in "AA" size round cells with both calcium chloride and lithium chloride electrolyte.

4. Good 3 month delayed service has been attained on FL-5 size flat cells of the HE-266 frame type construction.

5. A good voltage and amperage pattern has been attained on most of the FL-5 size flat cells on shelf for 3 and 5 mos.

6. The current maintenance of FL-5 size flat cells with the 3 lithium chloride electrolytes LTE-7, LTE-192 and LTE-158 appear to be about equivalent.

PERSONNEL

The work on this contract is under the administrative supervision of Mr. F. W. Duggan as head of the Edgewater Development Laboratory. The list of personnel actively engaged in this contract during the second quarter is as follows:

	Per Cent of Time During Quarter Charged to Project
William B. Lloyd - Senior Development Engineer Project Director	50%
John V. Franquemont - Development Engineer	100%
Edward J. Zeitz - Development Engineer	100%
Tony J. Dauria - Senior Laboratory Assistant	100%
John Poticny - Laboratory Assistant	100%
James R. Morell - Laboratory Assistant	100%
Robert Prok - Laboratory Assistant	100%
Donald Stieber - Laboratory Assistant	60%
Steve Duraney - Laboratory Assistant	100%
Kay Gaul - Pilot Line Operator	100%
Helen Gall - Pilot Line Operator	100%
Betty Doyle - Pilot Line Operator	100%
Doris Green - Pilot Line Operator	100%
Verna Pewanick - Pilot Line Operator	75%
Marge Sedlock - Pilot Line Operator	25%

APPENDIX

ELECTROLYTE CODE AND FORMULATIONS INDEX

LTE No.	% $CaCl_2$	% LiCl	% $ZnCl_2$	% NH_4CL	% H_2O
7	-	25	5	-	70
192	-	15	8	10	67
158	-	15	12	8	65
121	17	-	19	7	57

Table 1

Fresh, 3 and 6 Months Voltage and Amperage Pattern
Construction: "AA" Size Cells with LTE-121 Electrolyte -
Pure Film Separator - 25% Water in Mix - Poured Seal

No. Cells	14 Days Avg. Volts	14 Days Avg. Amps	3 Mos. Avg. Volts	3 Mos. Avg. Amps	3 Months % Current Maint.	6 Mos. Avg. Volts	6 Mos. Avg. Amps	6 Months % Current Maint.
245	1.69	4.8	1.57	2.8	58.	1.56	2.2	46.
348	1.68	5.8	1.57	4.0	69.	1.56	3.2	55.
273	1.60	3.4	1.56	2.8	82.	-	-	-
157	1.66	3.2	1.59	2.6	81.	1.57	1.6	50.
40	1.68	5.2	1.58	4.2	81.	-	-	-

Table 2

Fresh, 3 and 6 Months Voltage and Amperage Pattern
Construction: "AA" Size Cells with LTE-121 Electrolyte -
MB-1 Separator - 30% Water in Mix - Poured Seal

6 Months						%
Voltage			Amperage			Current
Avg.	Min.	Max.	Avg.	Min.	Max.	Maint.
1.55	1.54	1.55	1.7	1.6	2.8	41
1.54	1.52	1.54	2.0	1.6	3.4	48
1.55	1.54	1.56	1.8	1.6	2.8	41
1.56	1.55	1.59	2.0	1.6	3.2	57
1.56	1.55	1.58	2.6	1.6	3.6	72

Table 3

Fresh, 3 and 6 Months Voltage and Amperage Pattern
Construction: "AA" Size Cells with LTE-121 Electrolyte -
Pure Film Separator - 30% Water in Mix - Poured Seal

No. Cells	14 Days Avg.		3 Mos. Avg.		3 Months % Current Maint.	6 Mos. Avg.		3 Months % Current Maint.
	Volts	Amps	Volts	Amps		Volts	Amps	
41	1.69	5.4	1.58	4.2	78	1.56	3.4	63
41	1.71	5.4	1.58	4.4	82	1.54	1.6	30
100	1.63	5.0	1.56	2.4	41			
100	1.65	4.8	1.56	2.8	58			
100	1.65	5.2	1.56	3.8	73			

Table 4

Fresh and 4 Months Voltage and Amperage Pattern
Construction: "AA" Size Cells with Electrolyte as Indicated -
MB-1 Separator - 20% Additional Electrolyte in Mix - Mechanical Seal

Electrolyte	No. Cells	14 Days Avg.		4 Months Avg.		% Current Maintenance
		Volts	Amps	Volts	Amps	
LTE-7	502	1.76	4.2	1.68	4.0	95
LTE-7	140	1.76	4.6	1.71	4.5	98
LTE-158	448	1.72	4.0	1.68	3.7	93
LTE-158	144	1.72	3.8	1.69	3.6	95
LTE-192	155	1.73	4.0	1.66	3.7	93
LTE-192	509	1.74	4.8	1.68	4.4	92
LTE-121	223	1.73	4.4	1.69	4.4	100
LTE-121	508	1.72	4.4	1.66	4.2	96

Table 5

"A" Section BA-2270/U - Fresh and Delayed Services - Round Cells
Construction: MB-1 Separator - LTE-7 Electrolyte - 35% Water in Mix - Mechanical Seal

With Anode Current Density of: 16.2 ma/in² for 2 minutes
(34 "AA" Size Cells) 8.1 ma/in² for 18 minutes

Fresh Service

Hours at 70°F.		Hours at -40°F.	
Avg.	Individual Component Results by Trials	Avg.	Individual Component Results by Trials
21.7	21.0, 19.9, 22.5 22.5, 21.0, 21.0 23.7, 22.3	1.7	1.8, 1.8, 1.9, 2.0 1.3, 1.3, 1.4, 1.3 1.5, 1.5, 1.6

4 Months Delayed Service

Hours at -40°F.	
Avg.	Individual Component Results by Trials
1.5	1.3, 1.4, 1.4 1.5, 1.5, 1.6

Table 6

"A" Section BA-2270/U - Fresh and Delayed Services - Round Cells
Construction: MB-1 Separator - LTE-192 Electrolyte - 30% Water in Mix - Mechanical Seal

With Anode Current Density of: 16.2 ma/in² for 2 minutes
(34 "AA" Size Cells) 8.1 " " 18 "

Fresh Service

Hours at 70°F. Avg.	Individual Component Results by Trials	Hours at -40°F. Avg.	Individual Component Results by Trials
	23.8, 30.4, 30.7, 32.8		1.4, 1.5, 1.6, 1.6
29.7	28.0, 30.2, 30.3, 31.0	2.0	2.4, 2.5
	30.2, 28.4, 30.5, 30.4		2.0, 2.2, 2.3, 2.3

4 Months Delayed Service

Hours at -40°F. Avg.	Individual Component Results by Trials
1.0	.7, .8, .9, 1.0, 1.3

Table 7

"A" Section BA-2270/U - Fresh and Delayed Services - Round Cells
Construction: MB-1 Separator - LTE-158 Electrolyte - 30% Water in Mix - Mechanical Seal

With Anode Current Density of: 16.2 ma/in^2 for 2 minutes
(34 "AA" Size Cells) 8.1 " " 18 "

Fresh Service

Hours at 70°F.		Hours at -40°F.	
Avg.	Individual Component Results by Trials	Avg.	Individual Component Results by Trials
27.0	25.6, 25.6, 26.0 27.2, 25.2, 27.8, 27.8 29.4	1.6	1.4, 1.5, 1.6, 1.7 1.6, 1.6, 1.6, 1.6

4 Months Delayed Service

Hours at -40°F.	
Avg.	Individual Component Results by Trials
1.5	1.4, 1.4, 1.4 1.7, 1.7

Table 8

"A" Section BA-2270/U - Fresh and 4 Months Service - Round Cells
Construction: M8-1 Separator - LTE-121 Electrolyte - 30% Water in Mix - Mechanical Seal

With Anode Current Density of: 16.6 ma/in² for 2 minutes

With Anode Current Density of:	19.6	ma/in^2	for	2	minutes
(28 "AA" Size Cells)	9.8	"	"	18	"

Fresh Service

Hours at 70°F.		Hours at -40°F.	
Avg.	Individual Component Results by Trials	Avg.	Individual Component Results by Trials
27.8	27.6, 27.7, 26.9, 28.8	2.1	2.2, 2.0, 1.9, 2.2

With Anode Current Density of:	16.2	ma/in^2	for	2	minutes
(34 "AA" Size Cells)	8.1	"	"	18	"

Fresh Service

Hours at 70°F.		Hours at -40°F.	
Avg.	Individual Component Results by Trials	Avg.	Individual Component Results by Trials
36.4	37.0, 36.7, 35.4, 36.6	2.7	2.7, 3.0, 2.5, 2.5

4 Months Delayed Service

Hours at -40°F.	
Avg.	Individual Component Results by Trials
1.8	1.8, 1.8, 1.9

Table 9

"A" Section BA-2270/U - Fresh Service - Round Cells
Construction: Paste Separator - Electrolyte as Indicated - 25% Water in Mix and Separator System - Poured Seal

With Anode Current Density of: 19.6 ma/in^2 for 2 minutes
(28 "AA" Size Cells) 9.8 " " 18 "

LTE-5 Electrolyte - Wrapped Bobbin Construction

Hours at 70°F.		Hours at -40°F.	
Avg.	Individual Component Results by Trials	Avg.	Individual Component Results by Trials
18.9	18.9, 18.9	1.3	1.3, 1.3

LTE-158 Electrolyte - Wrapped Bobbin Construction

Hours at 70°F.		Hours at -40°F.	
Avg.	Individual Component Results by Trials	Avg.	Individual Component Results by Trials
20.0	19.6, 20.3	1.2	1.1, 1.2

Table 10

Fresh, 3 and 5 Months Voltage and Amperage Patterns

Construction: "HE-266" with Electrolyte as Indicated - 36% Water in Mix and Separator System

LTE No. of Elect.	No. Cells in Stack	% H_2O in Mix	No. Tests	Average Voltage			Average Amperage			Current Maintenance	
				14 Days	3 Mos.	5 Mos.	14 Days	3 Mos.	5 Mos.	3 Mos.	5 Mos.
7	15	30	7	26.3	24.0	23.7	0.86	0.83	0.82	96	95
7	15	30	12	26.8	23.3	22.4	0.83	0.62	0.48	75	57
7	15	30	5	25.7	24.1	23.3	0.74	0.81	0.67	109	89
7	15	36	5	25.7	24.6	23.3	1.5	1.4	1.3	93	87
7	15	36	5	25.5	23.5	23.8	1.6	1.5	1.2	94	75
7	1,	36	5	25.7	24.6	24.1	1.6	1.5	1.4	94	88
7	15	36	5	26.1	24.1		1.5	1.5		100	
7	15	36	4	25.7	23.2		1.9	1.		84	
7	15	36	6	25.5	23.8	22.8	1.7	1.5	0.8	88	47
7	15	36	11	25.7	25.0	24.6	1.9	1.8	1.8	95	95
7	15	36	5	26.4	24.8		2.0	1.9		95	
7	15	36	10	26.3	25.1		1.8	1.8		100	
7	15	36	30	26.4	25.1		1.7	1.7		100	
7	15	36	8	26.3		24.5	2.0		1.9	95	
7	17	36	15	29.8		27.8	2.0		1.9	95	
7	17	36	4	29.9	27.7		1.8	1.7		94	
158	15	36	13	24.3	23.6		1.5	1.4		93	
158	15	36	8	25.8		24.2	2.0		2.0		100
158	17	36	4	26.4	25.9		1.6	1.5		94	
192	15	36	6	25.7		24.1	2.4	2.2			92

Table 11

Flat Cells

3 Months Delayed Service Results (Storage at Room Temp.)
Construction: "HE-266", LTE-7 Electrolyte, 36% Water in Mix and Separator System

With Anode Current Density of: 20.9 ma/in² for 2 minutes
(60 FL-5 Size Cells) 5.3 " " 18 "

"B_1" Section

Hours at 70°F. Avg.	Individual Component Results by Trials	Hours at -40°F. Avg.	Individual Component Results by Trials
	16.8, 13.1		.83, .67, 1.0
17.3	21.7		1.33, 1.0
	19.7, 15.0	1.3	1.33, 1.67, 1.33, 1.33
			1.67, 1.67
			1.3, 1.67
			1.0, 1.33

With Anode Current Density of: 31.0 ma/in² for 2 minutes
(34 FL-5 Size Cells) 0 " " 18 "

"B_2" Section

Hours at 70°F. Avg.	Individual Component Results by Trials	Hours at -40°F. Avg.	Individual Component Results by Trials
	20.6, 15.1		0.67, 1.0
22	27.8		1.67, 1.67
	25.8, 20.8	1.5	2.0, 2.0
			1.67, 1.67
			1.33, 1.67

Table 12

Flat Cells
4, 5 and 8 months Delayed Service Results
Construction: "HE-266", LTE-7 Electrolyte - 30% Water in
Mix and Separator System

With Anode Current Density of: 20.9 ma/in^2 for 2 minutes
(60 FL-5 Size Cells) 5.3 " " 18 "

"B_1" Section

4 Months Delay		5 Months Delay		8 Months Delay	
Hours at 40°F.		Hours at -40°F.		Hours at -40°F.	
Avg.	Individual Component Results by Trials	Avg.	Individual Component Results by Trials	Avg.	Individual Component Results by Trials
.2	.33 .02, .02, .02 .67	.67	.33, .67 .02 1.0, 1.33	.67	.33 .67 .33 1.33, 1.0, 0.33

With Anode Current Density of: 31.0 ma/in^2 for 2 minutes
(34 FL-5 Size Cells) 0 " " 18 "

"B_2" Section

4 Months Delay		5 Months Delay		8 Months Delay	
Hours at 40°F.		Hours at -40°F.		Hours at -40°F.	
Avg.	Individual Component Results by Trials	Avg.	Individual Component Results by Trials	Avg.	Individual Component Results by Trials
.6	.33 .02 .02 .67, 2.0	.8	.02, .02 1.33, 1.67 2.0, 0	.7	.67

PART II

RESUME' AND SUMMARY OF CONTRACT DEVELOPMENT

DISCUSSION OF THE GENERAL PROGRAM

This contractual work was initiated by a review of the literature on the low temperature Leclanche batteries. From the literature and a general background knowledge of Leclanche battery manufacture, a resume' was presented in Report No. 1 of the myriad of individual component factors that could potentially affect low temperature functionability.

From the many sets of circumstances and problems individually discussed for each of the components required for a BA-2270/U battery, a few were chosen for further pursual in this contractual work. The factors chosen for further investigation and perfection were considered to hold most promise for the advancement of the low temperature battery manufacturing art.

The experimental considerations that have been further explored and clarified in this work are as follows:

Comparison of Calcium Chloride and Lithium Chloride Base Electrolytes

Clarification of Depolarizing Mix Wetness Desired

A Comparison of Separator Stocks

The Importance of Low Anode Current Density for Low Temperature Functionability and The Advantage of a Balanced Anode Current Density for the Various Sections of the Battery

Round Cells vs. Flat Cells for Series Connected Sections

Comparison of Calcium Chloride and
<u>Lithium Chloride Base Electrolytes</u>

Considerable work has been done during the past several years on a variety of electrolyte systems for potential application in low temperature batteries. Much of this information has been made available by work under Signal Corps direction. From these investigations, the lithium chloride and calcium chloride electrolyte systems stand out as most promising.

The low temperature batteries containing lithium chloride fall essentially into three categories. The first category consists only of lithium chloride-zinc chloride-water. The second category differs in that it contains 10 per cent ammonium chloride in the electrolyte system which calculates to 3 to 4 per cent ammonium chloride in the depolarizing mix system (LTE-192). The third category contains even more ammonium chloride. In addition to the 8 per cent ammonium chloride contained in the electrolyte syste, ammonium chloride is added to the depolarizing mix so that a total ammonium chloride content in the depolarizing mix system amounts to about 16 per cent (LTE-158).

The most promising calcium chloride low temperature electrolytes are considered to be LTE-5 and LTE-121. These differ one from the other in the relative content of calcium chloride and zinc chloride. The LTE-5 electrolyte system is normally preferred for use in a pasted cell construction and the LTE-121 electrolyte system is preferred for use in the MB-1 paper-backed film separator system.

It was a part of this contractual work to comparatively consider the above electrolyte systems with regard to their functionability with several separator stocks.

In the Appendices attached are presented the shelf and service data on all the important variables of this contract work. From these data certain lots may be exerpt for a direct electrolyte comparison both at -40°F. and 70°F. These data are presented in the tables that follow.

Table 1 below makes an electrolyte comparison at normal depolarizing mix wetness. At this mix wetness, lithium chloride (LTE-7) provided 1.2 hours at -40°F. and calcium chloride (LTE-121) 0.8 hour at -40°F. In this comparison the advantage is with the LTE-7 electrolyte. However, both services are considered low. It is noted that the advantage is reversed when 70°F. is considered.

Table 1

Round Cells
Electrolyte Comparison at Normal Depolarizing Mix Wetness

Appendix Table and Item No.		Hours Fresh Service	
		-40°F.	70°F.
1-12	Lithium Chloride (LTE-7)	1.2	24
1-2	Calcium Chloride (LTE-121)	0.8	29

In Table 2 this same comparison is made with 20 per cent additional electrolyte added to the cell system. The averages in this table are from items 8 and 14 in the attached Appendix 1 and have the same anode current density and separator system as the comparison in Table 1. It is seen that the lithium chloride LTE-7 average is 1.9 hours at -40°F. compared to 2 hours at -40°F. for the calcium chloride (LTE-121). In this instance LTE-121 electrolyte holds a slight edge at -40°F. and a somewhat more pronounced edge at 70°F. with 31 hours as compared to 25 hours for the lithium chloride electrolyte.

In the second section of Table 2, the same data are presented at a higher anode density and here again there appears to be a moderate advantage for LTE-121 electrolyte over the LTE-7 electrolyte.

Table 2

Round Cells
Electrolyte Comparison with 20% Additional
Electrolyte Added to Cell System

Appendix and Item No.		Hours Fresh Service -40°F.	70°F.
1-14	Lithium Chloride (LTE-7)	1.9	25
1-8	Calcium Chloride (LTE-121)	2.0	31
	At Higher Anode Current Density		
1-15	Lithium Chloride (LTE-7)	1.1	17
1-19	Calcium Chloride (LTE-121)	1.2	23

The data in Table 3 are from lots made at the end of the contractual work. These lots, like those in Table 2 also contain 20 per cent additional electrolyte. However, in these cases the additional electrolyte was not added by post assembly methods but was contained in the depolarizing mix as used in the cell assembly operations. The experimental lots of Table 3 also contain mechanical seal in place of the poured seal used on the previous lots. In this table -40°F. service for the LTE-7, LTE-192, and LTE-158 lithium chloride electrolyte systems averaged 1.7 hours, 2 hours and 1.6 hours respectively. The -40°F. service for calcium chloride electrolyte LTE-121 was 2.7 hours. The advantage in this comparison is for the calcium chloride electrolyte. The corresponding services at 70°F. are 21 hours, 30 hours, and 27 hours for the LTE-7, LTE-192 and LTE-158 lithium chloride electrolytes respectively and 36 hours for the calcium chloride electrolyte LTE-121. Here again the better fresh service is with the calcium chloride electrolyte.

Table 3

Round Cells
Electrolyte Comparison with 20% Additional
Electrolyte Contained in Cell System

Appendix and Item No.		Hours Fresh Service -40°F.	Hours Fresh Service 70°F.
1-27	Lithium Chloride (LTE-7)	1.7	21
1-28	Lithium Chloride (LTE-192)	2.0	30
1-29	Lithium Chloride (LTE-158)	1.6	27
1-26	Calcium Chloride (LTE-121)	2.7	36

All of the comparisons in Tables 1, 2 and 3 have been with MB-1 paper-coated film separator stock. In Table 4 below the various electrolytes are compared in a pasted separator system.

The -40°F. service for the lithium chloride base electrolytes in their order of increasing ammonium chloride content are 2 hours, 1.2 hours, and 1.2 hours respectively. Calcium chloride base electrolyte LTE-5 in this same comparison gave 1.3 hours. In this comparison LTE-7 electrolyte holds the advantage with the LTE-5 in second place. At 70°F. the corresponding services are 17 hours, 14 hours and 20 hours for the three lithium chloride electrolytes and 19 hours for the calcium chloride electrolyte. At this temperature LTE-158 was best with the LTE-5 a close second.

Table 4

Round Cells
Electrolyte Comparison with Paste Separator System

Appendix and Item No.		Hours Fresh Service -40°F.	Hours Fresh Service 70°F.
1-22	Lithium Chloride (LTE-7)	2.0	17
1-21	" " (LTE-192)	1.2	14
1-24	" " (LTE-158)	1.2	20
1-23	Calcium Chloride (LTE-5)	1.3	19

The comparisons of the calcium chloride and lithium chloride base electrolytes thus far have been with round cells. Now to make this same comparison in flat cells with the same type of construction. In Table 5 these data are presented. Consider first the alternating continuous "B_1" drain. The three lithium chloride electrolytes in their increasing order of ammonium chloride content have averaged 1.6 hours, 4.3 hours and 3.0 hours at -40°F. and 19 hours, 29 hours and 37 hours at 70°F. The LTE-121 calcium chloride electrolyte on the other hand averaged 2.8 hours at -40°F. and 30 hours at 70°F. In this comparison it should be pointed out that by far the majority of the experimental tests run have been with LTE-7 electrolyte. With the other electrolytes, only preliminary data are presented. Until further substantiation of service expectancy are made available, therefore, the conclusion that can be made is that both lithium chloride and calcium chloride base electrolytes provide "B_1" section flat cell service in a good low temperature expectancy range that may possibly be in the same statistical universe.

In the second portion of Table 5, flat cells of the same FL-5 size frame type construction are compared with regard to electrolyte on the intermittent "B_2" drain of the BA-2270 battery. These intermittent results like the alternating continuous drain of the "B_1" section show a good low temperature service expectancy range and like the previously mentioned "B_1" section require further substantiation to determine whether or not all the results are in the same statistical universe.

Table 5

Flat Cells
Electrolyte Comparison with 20% Additional Electrolyte Contained in Cell System

Appendix and Item No.		Hours Fresh Service -40°F.	Hours Fresh Service 70°F.
	("B_1" Section)		
4-5	Lithium Chloride (LTE-7)	1.6	19
4-8	" " (LTE-192)	4.3	29
4-7	" " (LTE-158)	3.0	37
4-9	Calcium Chloride (LTE-121)	2.8	30
	("B_2" Section)		
4-13	Lithium Chloride (LTE-7)	2.2	22
4-16	" " (LTE-192)	5.1	39
4-15	" " (LTE-158)	3.3	44
4-17	Calcium Chloride (LTE-121)	3.5	43

Considering all of the tabular comparisons just made between calcium chloride and lithium chloride base electrolytes, it is concluded that insofar as fresh service is concerned, both at -40°F. and 70°F. that calcium chloride base electrolytes are at least on a par with the lithium chloride base electrolytes.

The electrolyte comparison data presented thus far have been on fresh services. The delayed service data that are available will now be considered for the various electrolytes. In Table 6 the available round cell delayed service data are presented.

Table 6

Round Cells
Delayed Service - Electrolyte Comparison

Appendix and Item No.		Age in Mos. at Time of Test	Hrs. Delayed Service at -40°F.
2-10	Lithium Chloride LTE-7	4	1.5
2-11	" " LTE-192	4	1.0
2-12	" " LTE-158	4	1.5
2-13	Calcium Chloride LTE-121	4	1.8

The 4 month delayed service as shown in this table are for round cells that have been made with a mechanical seal. There is contained in Appendix 2 additional delayed service data on round cells with a poured seal. It will be noted that these services are on the low side. This has been attributed to the inadequacies of the poured seal used.

The 4 month delayed services shown in Table 6 are in a very acceptable service range. The averages do not include a sufficient mass of data to draw conclusions of whether one electrolyte is slightly better than the other at this stage of delayed service. It is fully expected that either type of electrolyte can provide reasonably good delayed service character providing structural shortcomings do not develop within the cells and that the cells are adequately sealed against moisture loss.

In Table 7 an electrolyte comparison of the amperage patterns after 3 months storage is reported.

Table 7

Round Cells
Amperage Patterns - Electrolyte Comparison
(All cells made with mechanical seal)

Appendix and Item No.		14 Days Avg.Amps	3 Mos. Avg.Amps	3 Mos. Current Maint. in %
3-6	Lithium Chloride (LTE-7)	4.4	4.3	97
3-8	" " (LTE-192)	4.4	4.2	96
3-7	" " (LTE-158)	3.9	3.7	95
3-9	Calcium Chloride (LTE-121)	4.4	4.2	96

It is seen from this table that all three of the lithium chloride electrolytes and the calcium chloride electrolyte have maintained very excellent current maintenance after 3 months on shelf. If this order of current maintenance is maintained with additional aging on shelf, the long delay services should be quite acceptable.

The available flat cell delay services are presented in Table 8.

Table 8

Flat Cells
Delayed Service - Electrolyte Comparison

Appendix and Item No.		Age in Mos. at Time of Test	Hrs. Delayed Service at -40°F.
	("B_1" Section)		
5-1	Lithium Chloride (LTE-7)	3	1.3
5-3	" " (LTE-7)	5	.7
5-5	" " (LTE-192)	5	1.7
5-7	" " (LTE-158)	5	1.2
5-9	Calcium Chloride (LTE-121)	2	3.0
	("B_2" Section)		
5-10	Lithium Chloride (LTE-7)	3	1.5
5-12	" " (LTE-7)	5	.8
5-14	" " (LTE-192)	5	2.0
5-16	" " (LTE-158)	5	1.8
5-18	Calcium Chloride (LTE-121)	2	3.5

The hours delayed service at -40°F. of this table represent the averages of only a few lots. It is seen that at 3 months the lithium chloride LTE-7 electrolyte system provided 1.5 hours at -40°F. At 5 months, this same system provided .8 hour. This difference may indicate the normal spread in service expectancy from random sampling rather than actual depreciation of service from the additional 2 mos. on shelf. It is tentatively concluded, therefore, that all three lithium chloride electrolytes LTE-7, LTE-192 and LTE-158 are capable of maintaining reasonably good service after storage periods on shelf. Attention is called in this regard to Table 25 in Quarterly Progress Report No. 3 wherein it is shown that this same construction provided a service maintenance of 78 per cent after 6 month delay. These results were obtained on the BA-2038/U service test.

Table 9 compares the amperage patterns of the HE-266 constructed flat cells of FL-5 size.

Table 9

Flat Cells
Amperage Patterns - Electrolyte Comparison

Appendix and Item No.		14 Days Avg. Amps	Avg. Amps	Current Maint. in %
6-2	Lithium Chloride (LTE-7)	1.7	1.6	94
6-3	" " (LTE-7)	1.8	1.7	94
6-4	" " (LTE-158)	1.5	1.4	93
6-5	" " (LTE-158)	1.6	1.5	94

The average current maintenance of 94 per cent after 3 mos. storage for the LTE-7 lithium chloride electrolyte lots represent the average of 115 stacks from 13 lots. The 95 per cent current maintenance figure at 3 months for the LTE-158 lithium chloride lot is an average of two experimental trials totalling 17 stacks. These 3 month current maintenance figures are deemed to be fairly good for this type of construction.

From a summary consideration of these delayed service and shelf data, it is concluded that any one of the three lithium chloride electrolytes (LTE-7, LTE-192 or LTE-158) or the calcium chloride electrolyte LTE-121 can be made into either round cells or flat cells to provide good 3 month delayed service and shelf character. It is probable that longer delayed service would also be in an acceptable range.

Clarification of Depolarizing Mix Wetness Desired

There have been definite evidences from previous experiments that electrolyte solution volumes well above those normally attainable are, in specific circumstances, especially advantageous for low temperature functionability. This problem of the depolarizing mix wetness desired for low temperature functionability has been further clarified by this development effort. It has been shown that at very light anode current densities, conventionally made cells of normal depolarizing mix wetness have performed entirely satisfactory at low temperatures. For example, it is reported in Table 14 of Quarterly Progress

Report No. 2 that conventional "Mini-Max" batteries containing LTE-121 electrolyte and with 24 per cent water in the mix gave on an average of 40 hours service at -40°F. on a 1.54 milliampere per square inch continuous drain (BA-2041 test). This compares to a minimum requirement in JAN-B-18A of 14 hours. These same batteries, however, when tested as a "B_1" section of the BA-2270/U battery with an anode current density of 21.5 for the 2 minute period provided only .5 hour at -40°F. The point that is established by these and allied data is that at very low anode current densities, a normal solution volume in conventional cells is capable of performing entirely satisfactory at -40°F. At relatively high anode current densities, however, conventional made batteries with normal solution volumes have very low -40°F. service capacities.

The question that presents itself is, "What can be accomplished in regard to depolarizing mix wetness to improve -40° service at high anode current densities?" The first attempt was to add additional electrolyte to the formed mix slug as it was positioned in the cell. In Table 10 it is seen that "AA" cells containing calcium chloride electrolyte and MB-1 separator, and operated at 16.2 anode current density for a 2 minute period provided 1.1 hours at -40°F. and 30 hours at 70°F. when normal solution volume was used. When 20 per cent additional electrolyte was added to the depolarizing mix slugs, the corresponding services were 1.7 hours at -40°F. The -40°F.

fresh service was, therefore, improved by better than 50 per cent by adding 20 per cent additional electrolyte to the cell system.

It was propitously determined that one of National Carbon Company's new mix filling devices was capable of handling depolarizing mix that contained 20 per cent additional electrolyte. The results of cells made with this new filling device are presented as the third item of Table 10 and exhibit a -40°F. service of 2.7 hours and a 70°F. service of 36 hours. This represents a pronounced improvement over the normal solution volume service of 1.1 hours at -40°F.

In the second portion of Table 10, the same comparison between normal solution volume and 20 per cent additional solution volume are presented for a higher anode current density. Results show 0.8 hours vs. 2.0 hours at the -40°F. level.

Table 10

Round Cells
Calcium Chloride Electrolyte (LTE-121), MB-1 Separator

Appendix and Item No.		Hours Fresh Service -40°F.	Hours Fresh Service 70°F.
	(16.2 anode current density for 2 minute period)		
1-1	Normal Solution Volume (25% H_2O)	1.1	30
1-7	20% Add'l " " (30% H_2O)	1.7	-
1-26	" " " " (" ")	2.7	36
	(17.6 anode current density for 2 minute period)		
1-2	Normal Solution Volume (25% H_2O)	0.8	29
1-8	20% Add'l " " (30% H_2O)	2.0	31

In Table 11 an additional comparison is made between normal and 20 per cent additional solution volume at three anode current densities. The cells in this table were made with pure film separators in place of the normally used MB-1 separator stock. Here again it is shown that at all three anode current densities, the cells containing additional electrolyte have provided the best -40°F. service.

Table 11

Round Cells
Calcium Chloride Electrolyte (LTE-121) Pure Film Separators

Appendix and Item No.		Hours Fresh Service -40°F.	Hours Fresh Service 70°F.
	(16.2 anode current density for 2 minute period)		
1-4	Normal Solution Volume (25% H_2O)	1.5	35
1-9	20% Add'l " " (30% H_2O)	2.6	33
	(17.6 anode current density for 2 minute period)		
1-5	Normal Solution Volume (25% H_2O)	1.2	26
1-10	20% Add'l " " (30% H_2O)	1.6	27
	(19.6 anode current density for 2 minute period)		
1-6	Normal Solution Volume (25% H_2O)	1.3	26
1-11	20% Add'l " " (30% H_2O)	1.9	26

The comparisons that have just been made in Tables 10 and 11 have been with round cells containing calcium chloride electrolyte. In Table 12 a similar comparison is made on flat cells with lithium chloride electrolyte (LTE-7). These flat cells contain pure film separators. It is seen from the table that at an anode current density of 20.9 milliamperes for the 2 minute period, a normal solution volume provides 0.4 hour at -40° and 12 hours at 70°F. With 20 per cent additional solution volume, the same cell system provides 1.6 hours at -40°F. and 19 hours at 70°F.

Here again a very definite advantage is indicated for increased solution volume as an assist for low temperature functionability.

Cells from these same lots operated on the intermittent "B_2" section with an anode current density drain of 31 milliamperes for the 2 minute period shows an even more pronounced effect for solution volume. At -40°F. cells containing normal solution volume did not deliver any service and cells with 20 per cent additional solution volume delivered 2.2 hours of service. At 70°F. the corresponding figures were 13 hours and 22 hours respectively.

Table 12

Flat Cells
Lithium Chloride Electrolyte (LTE-7) Pure Film Separators

Appendix and Item No.		Hours Fresh Service -40°F.	Hours Fresh Service 70°F.
	(20.9 anode current density for 2 minute period)		
4-4	Normal Solution Volume (30% H_2O)	.4	12
4-5	20% Add'l " " (36% H_2O)	1.6	19
	(31.0 anode current density for 2 minute period)		
4-12	Normal Solution Volume (30% H_2O)	0	13
4-13	20% Add'l " " (36% H_2O)	2.2	22

These data indicate that for both round cells and flat cells, calcium chloride and lithium chloride electrolyte, and regular MB-1 paper-backed film and pure film separator stock all provide appreciably more service at -40°F. when additional electrolyte is available in the cell system.

A Comparison of Separator Stocks

The definite advantages of National Carbon's MB-1 separator stock over the conventional pure paste wall separator system has been well established for many battery discharge schedules intended to operate at normal temperatures. In order to establish this comparative pattern between separators at -40°F. and with low temperature electrolytes, a development program was set up as part of this contractual work. In Table 13 a pure paste wall separator system is compared to the MB-1 separator system in round cells containing calcium chloride electrolyte. Here it is noted that the paste separator system provided 1.3 hours at -40°F. and 19 hours at 70°F. This may be compared to the MB-1 separator system with 2.1 hours at -40°F. and 28 hours at 70°F.

Table 13

Round Cells
Calcium Chloride Paste vs. MB-1 Separator Systems

Appendix and Item No.		Hours Fresh Service -40°F.	70°F.
1-23	Paste Separator	1.3	19
1-25	MB-1 Film Separator	2.1	28

In Table 14 paste and MB-1 separators are compared in a lithium chloride electrolyte cell. It is noted that these comparisons include LTE-7, LTE-192 and LTE-158 electrolytes. In every case the MB-1 film is considered to be equivalent or slightly better than the paste separator system at -40°F. and appreciably better at 70°F.

Table 14

Round Cells
Lithium Chloride Electrolyte - vs. MB-1 Separator Systems

Appendix and Item No.		Hours Fresh Service -40°F.	Hours Fresh Service 70°F.
1-22	Lithium Chloride (LTE-7) Paste Sep.	2.0	17
1-27	" " " MB-1 Film	1.7	21
1-21	" " (LTE-192) Paste	1.2	14
1-28	" " " MB-1	2.0	30
1-24	" " (LTE-158) Paste	1.2	20
1-29	" " " MB-1	1.6	27

It is not considered that there are a sufficient mass of data in the above comparisons to definitely state that the MB-1 separator stock is superior to the paste separator on fresh service at -40°F. It is quite possible that both the paste and MB-1 separator systems provide service at -40°F. in the same order of magnitude. From these and allied data, it is quite evident, however, that the MB-1 separator provides appreciably better service at 70°F. on fresh test.

Now to critically consider the MB-1 stock. This is a paper-backed film separator. The question arises, "Would a pure film separator stock provide any appreciable assist in low temperature functionability?" In Table 15 the MB-1 separator stock is compared with pure film separator in a calcium chloride electrolyte system containing normal solution volume (25% water).

Table 15

Round Cells
Calcium Chloride Electrolyte and MB-1 vs. Pure Film with Normal Solution Volume (25% H_2O)

Appendix and Item No.		Hours Fresh Service -40°F.	70°F.
	(16.2 ma/in^2 anode current density for 2 minute period)		
1-1	MB-1 Separator	1.1	30
1-4	Pure Film Separator	1.5	35
	(17.6 ma/in^2 anode current density for 2 minute period)		
1-2	MB-1 Separator	.8	29
1-5	Pure Film Separator	1.2	26

At the two anode current densities shown in this table, pure film appears to hold a finite advantage over the MB-1 stock. Pure film, however, is not currently a practical production item and it will be shown in Table 16 that the apparent advantage for pure film at normal solution volumes is appreciably mitigated by the use of depolarizer mixes containing 20 per cent additional electrolyte.

Table 16

Round Cells
Calcium Chloride Electrolyte with 20%
Additional Electrolyte in Cell System

Appendix and Item No.		Hours Fresh Service -40°F.	70°F.
	(16.2 ma/in² anode current density for 2 minute period)		
1-7	MB-1 Separator	1.7	-
1-9	Pure Film Separator	2.6	33
1-25	MB-1 Separator	2.7	36
	(17.6 ma/in² anode current density for 2 minute period)		
1-8	MB-1 Separator	2.0	31
1-10	Pure Film	1.6	27
	(19.6 ma/in² anode current density for 2 minute period)		
1-11	Pure Film	1.9	26
1-25	MB-1 Separator	2.1	28

In Table 16 the average results shown for the MB-1 separator lots that precede pure film lots represent cells made by the addition of electrolyte to the formed depolarizing mix. This method of manufacture also applies to all of the pure film separator lots. The MB-1 separator lots that succeed the pure film lots are from cells wherein the depolarizing mix contained the additional electrolyte. From a perusal of these data at the three current densities, it appears that at this higher solution volume, pure film and MB-1 separator stock are in the same statistical universe.

The Importance of Low Anode Current Density for Low Temperature Functionability and a Balanced Anode Current Density for the Various Sections of the Battery

Many times in normal battery manufacture, a disproportionation in the various components of a battery not only can be tolerated but many times is advantageous. This point can be expressed another way by saying that in normal temperature batteries, there are many instances wherein the anode current density is not the service limiting factor. In low temperature batteries designed for heavy drain applications such as the BA-2270/U, the anode current density is an important factor. In Quarterly Progress Report No. 2 of Contract DA-36-039-sc-30284, an interesting observation on this subject was pointed out. When low temperature round cells are operated on continuous drains at 70°F. which range from 2 milliamperes per square inch to 28 milliamperes per square inch of anode area, the service obtained is almost directly proportional to the depolarizing mix availability. When these batteries were discharged at -40°F., the service obtained was also almost directly proportional to the depolarizing mix availability at 2 milliamperes per square inch of anode area. At 28 milliamperes per square inch of anode area, the depolarizing mix availability became much less an important factor and the services appeared to be approaching a constant value that was independent of the quantity of depolarizing mix available (above an obvious minimum requirement). Since the BA-2270 battery operates in the upper bracket of the above discussed anode current density range, the obtaining of as low an anode current density as possible and a balance between sections of the battery seems axiomatic.

Data in Table 17 indicate that service at -40°F. falls off more precipitously with increased anode current density than is the case at 70°F. These data are further indication of why the anode current density should be kept as low as possible and balanced between the sections of the battery for best low temperature functionability.

Table 17

Round Cells
Effect of Current Density on Service at -40°F.

Appendix and Item No.		Hours Fresh Service -40°F.	Hours Fresh Service 70°F.
1-1	16.2 ma/in^2 of anode area	1.1	30
1-2	17.6 " " " "	0.8	29
1-3	23.0 " " " "	0.4	20

Round Cells vs. Flat Cells
for Series Connected Sections

In the manufacture of batteries for normal temperature applications, flat cells are used to advantage for series connected sections for the series connections are automatically made as the stacks are built up. When round cells are used for series connected sections, on the other hand, the expensive and time consuming operations of nesting, insulating and series soldering are involved. Effort was therefore directed right from the start of this contractual work to provide satisfactory flat cell components for the "B_1" and "B_2" sections of the BA-2270 battery. Round cell series connected sections were, of course, also made for a direct comparison. In Table 18 these comparisons are made. The first item of this table involves a series connected round cell for the "B_1" section. These cells contain LTE-121 electrolyte with what has been referred to as a normal solution volume throughout this report. The fresh service of .7 hour at -40°F. and 35 hours at 70°F. is better than the second item which represents flat cells of the conventional "Mini-Max" construction of normal depolarizing mix wetness and containing the same LTE-121 electrolyte. Round cell results are also better than the flat cells of frame type construction containing LTE-7 electrolyte and with normal mix wetness. In the last item of Table 18, flat cells of frame type construction with 20 per cent additional electrolyte of LTE-7 formulation provided -40°F. service of 1.6 hours which more closely approached the target figure of 2 hours at -40°F.

Table 18

Round Cells vs Flat Cells for Series Connected Sections

Appendix and Item No.		Hours Fresh Service -40° F.	70° F.
4-1	Round cells with 20.6 anode current density for 2 minute period (LTE-121)	0.7	35
4-3	Flat cells ("Mini-Max") 21.5 anode current density for 2 minute period (LTE-121)	0.5	24
4-4	Flat cells (frame type) 20.9 anode current density for 2 minute period with some relative solution volume (LTE-7)	0.4	12
4-5	Flat cells (frame type) 20.9 anode current density for 2 minute period with 20% additional electrolyte (LTE-7)	1.6	19

From the summary analysis that follows, it was concluded that the best effort BA-2270/U battery would result from FL-5 size flat cells of the frame type construction in the "B_1" and "B_2" sections of the battery and parallel connected "AA" size round cells in the "A" section.

First in this analysis, consider an all round cell construction for the BA-2270/U battery. The closest commercial size cell, for which equipment is available, that would provide a tolerable anode current density for the "B_1" section within the space allotment of the BA-2270/U battery was the "AA" size round cell. A study of these cells in this series connected "B_1" section would, of course, be required. It was further determined that 30 "AAA" cells should function satisfactorily current density-wise and fit into the space allotment of the BA-2270/U battery as the "B_2" section. In the remaining available space, 28 "AA" size cells could be parallel connected as the "A" section. This would mean that the "A" section would be operating at 20.8 milliamperes per square inch for 2 minutes and 10.4 milliamperes per square inch for 18 minutes. Data indicated that at this current density, it was not likely that much in excess of one hour service at -40°F. could be expected.

If on the other hand, four 15-cell stacks of FL-5 cells were used as the "B_1" section and two 17-cell stacks of FL-5 cells for the "B_2" section, these units could be expected to deliver about 1.6 hours service at -40°F. The remaining space within the BA-2270/U battery would then accommodate 33 "AA" size cells connected in parallel as the "A" section. This number of cells in parallel would lower the anode current density to a point where 1.6 hours service at -40°F. could be expected.

It seemed, therefore, most propitious from a service balance standpoint as well as the economy and ease of construction to direct contractual effort toward the perfection of flat cell "B_1" and "B_2" sections and round cell "A" section. The BA-2270/U batteries were made according to this pattern for the final batteries required to be submitted under this contract. The manufacturing methods used are described in detail in the Fourth Quarter section of this final report.

SUMMARY:

From the literature and a general background knowledge of Leclanche battery manufacture, the component factors that could potentially affect low temperature functionability were critically analyzed. Several of these factors were chosen for further investigation and perfection. These chosen development directions are summarized below.

The problem of the choice of electrolyte for low temperature cells was considered in need of further comparison and resolution. This comparison has been made on cells of the same construction with such factors as depolarizing stock, depolarizing mix solution volume, and separator stocks held constant as nearly as is possible.

Lithium chloride electrolyte systems both with and without ammonium chloride contents were compared to a calcium chloride electrolyte system with a small amount of ammonium chloride. These comparisons were made with three separator systems, MB-1 paper-backed film, pure film and the conventional paste separator construction. Two ranges of depolarizing mix wetness were also included as a part of this investigation. In addition to the above investigations using round cells, flat cells were also critically compared in both the lithium and calcium chloride electrolyte systems.

From the experimental evidences gathered in these comparisons calcium chloride electrolyte (LTE-121) is at least on a par with

lithium chloride electrolytes LTE-192 and LTE-158 on fresh, 3 and 4 months delayed services at both 70°F. and -40°F. The calcium chloride electrolyte (LTE-121) is also considered to be at least on a par with the lithium chloride (LTE-7) electrolyte at -40°F. fresh and delayed service. The fresh and delayed services of LTE-121 electrolyte appears superior to that of LTE-7 on the fresh and delayed 70°F. services.

A further point developed from the delayed service electrolyte comparisons is that any one of the three lithium chloride electrolytes considered or the calcium chloride electrolyte can be utilized in either round or flat cells to provide good 3 month delayed service and shelf character. It is probable that longer delayed services will also be in an acceptable range.

The second major subject of investigation was to obtain experimental clarification of the depolarizing mix wetness desired. Here again several constructions of both round and flat cells were compared. Both MB-1 and pure film separator stocks were compared in the lithium chloride and calcium chloride electrolyte systems. With these separator systems and electrolytes, the depolarizing mix was compared at normal production wetness with a mix containing 20 per cent more electrolyte. The experimental data indicated a definite advantage both with regard to service and shelf for the higher electrolyte content. This advantage applied to all of the electrolytes evaluated.

A comparative study of several separator stocks for low temperature applications was the third category of investigation. National Carbon Company MB-1 separator stock was firmly established with respect to normal temperature functionability. At very low discharge temperatures further experimental evidence was desired. This stock was, therefore, compared to paste wall separators and with a film like that used in the MB-1 stock without the paper backing. There appeared, from the trials made, an advantage service-wise for the pure film over the MB-1 stock. At the higher depolarizing mix solution volumes, this difference was appreciably mitigated and both film separators appeared to be in the same statistical universe. The MB-1 separator system gave -40°F. services at least equivalent to the paste wall separator system. At 70°F. the MB-1 separator system was definitely superior.

The importance of low anode current density for low temperature functionability and a balanced anode current density for the various sections of the battery was illustrated by the data accumulated. Service falls off more precipitously at -40°F. with changes in anode current density than occurs at 70°F.

Round cells vs. flat cells for the series connected "B_1" and "B_2" sections were comparatively resolved from a space requirement, ease of manufacturing, probable cost and, of course, determining the level of service that could be provided by each. On all counts, the series connected sections of flat cells held a definite advantage. The FL-5 size flat cell of rigid frame type construction was, therefore, further perfected during the course of this contract.

The contract was completed by the provision of 150 sample BA-2270/U batteries of each of two low temperature electrolyte systems. The lithium chloride electrolyte system used in the final batteries was LTE-7. The calcium chloride electrolyte system used for the remaining 150 sample batteries was LTE-121.

The component structure of the batteries delivered at the end of this contract was:

"A" section	33 "AA" size cells
"B_1" "	60 FL-5 " "
"B_2" "	34 FL-5 " "
"C" "	3 FL-2 " "

Appendix 1

Low Temperature Round Cells - Fresh Service

"AA" Size

Item No.	Anode Cur.Dens. 2 Minute Period	LTE No. of Electr.	Type of Separators MB-1	Type of Separators Pure Film	% Water in Mix	Type of Seal Poured	Type of Seal Mech.	Fresh Service in Hours -40°F. Avg.	-40°F. Min.	-40°F. Max.	70°F. Avg.	70°F. Min.	70°F. Max.
1	16.2	121	x		25	x		1.1	0.7	1.9	30	25	35
2	17.6	"	x		"	x		0.8	0.7	1.2	29	23	34
3	23.0	"	x		"	x		0.4	0.4	0.4	20	20	21
4	16.2	"		x	"	x		1.6	0.8	2.0	35	30	40
5	17.6	"		x	"	x		1.2	0.7	1.9	26	25	30
6	19.6	"		x	"	x		1.3	0.8	1.8	26	25	28
7	16.2	"	x		30	x		1.7	1.5	1.8			
8	17.6	"	x		"	x		2.0	1.5	2.5	31	29	33
9	16.2	"		x	"	x		2.6	2.2	2.9	34	30	37
10	17.6	"		x	"	x		1.6	0.9	2.3	27	26	28
11	19.6	"		x	"	x		1.9	1.5	3.2	26	23	28
12	17.6	7	x		30	x		1.2	0.8	1.5	24	23	25
13	19.6	"	x		"	x		0.9	0.7	1.4	19	14	27
14	17.6	"	x		35	x		1.9	1.6	2.3	25	24	27
15	19.6	"	x		"	x		1.1	0.9	1.3	17	10	20
16	17.6	"		x	30	x		1.8			24		
17	17.6	"		x	35	x		2.3			25		
18	16.2	158	x		23	x					27	27	28
19	19.6	"	x		"	x		1.2	1.0	1.4	23	19	26
20	23.0	"	x		"	x					14	13	14
21	19.6	192		Paste	25	x		1.2			14		
22	19.6	7		Paste	"	x		2.0			17		
23	19.6	5		Paste	"	x		1.3			19		
24	19.6	158		Paste	"	x		1.2			20		
25	19.6	121	x		30		x	2.1	1.9	2.2	28	27	29
26	16.2	"	x		"		x	2.7			36		
27	16.2	7	x		35		x	1.7			21		
28	16.2	192	x		30		x	2.0			30		
29	16.2	158	x		30		x	1.6			27		

Appendix 2

Low Temperature Round Cells - 3 Months Delayed Service

"AA" Size

Item No.	Anode Cur.Dens. 2 Minute Period	LTE No. of Electr.	Type of Separators MB-1	Type of Separators Pure Film	% Water in Mix	Type of Seal Poured	Type of Seal Mech.	3 Months Service in Hours -40°F. Avg.	-40°F. Min.	-40°F. Max.	70°F. Avg.	70°F. Min.	70°F. Max.
1	16.2	121	x		25	x		0.2	0.0	0.4	22	20	25
2	19.6	"	x		"	x		0.3	0.0	0.6	19	13	22
3	20.7	"	x		"	x		0.6	0.3	1.3	17	15	20
4	16.2	"		x	"	x		0.7	0.3	1.2	25		
5	20.7	"		x	"	x		0.8	0.0	1.8	22	17	25
6	16.2	"	x		30	x		1.0	-	-	-	-	-
7	19.6	"	x		"	x		0.8	0.5	1.0	18	14	22
8	20.7	"	x		"	x		0.4	0.1	1.0	19	11	23
9	20.7	"		x	"	x		1.1	0.5	1.6	23	16	25
10		7	x		35		x	* 1.5	-	-			
11		192	x		30		x	* 1.0	-	-			
12		158	x		30		x	* 1.5	-	-			
13		121	x		30		x	* 1.8	-	-			

* 4 months delayed

Appendix 3

Voltage and Amperage Patterns on Low Temperature Round Cells

"AA" Size

Item No.	LTE No. of Electr.	No. of Lots	Type of Separators MB-1	Type of Separators Pure Film	% Water in Mix	Type of Seal Poured	Type of Seal Mech.	14 Days Avg. Volts	14 Days Avg. Amps	3 Mos. Avg. Volts	3 Mos. Avg. Amps	3 Mos. Current Maint. in %
1	121	12	x		25	x		1.63	3.6	1.57	2.6	72
2	121	9	x		30	x		1.67	3.9	1.58	3.0	76
3	7	4	x		30	x		1.73	3.6	1.59	2.9	81
4	121	5		x	25	x		1.66	4.5	1.57	3.3	74
5	121	5		x	30	x		1.66	5.2	1.57	3.5	66
6	7	2	x		35		x	1.76	4.4	1.70	4.3	97
7	158	2	x		30		x	1.72	3.9	1.68	3.7	95
8	192	3	x		30		x	1.73	4.4	1.68	4.2	96
9	121	1	x		30		x	1.72	4.4	1.66	4.2	96

Appendix 4

Low Temperature Flat Cells - Fresh Service

FL-5 Size

Item No.	Type of Constr. R.C.	M.M.	HE-266	% Water in System	Anode Cur.Dens. 2 Minute Period	LTE No. of Electr.	Fresh Service in Hours -40°F. Avg.	-40°F. Min.	-40°F. Max.	70°F. Avg.	70°F. Min.	70°F. Max.	
1	x			25	20.6	121	0.8	0.4	1.4	36	21	42	"B_1" Section
2	x			"	22.5	"	0.6	0.2	0.8	36	28	41	
3		x		24	21.5	"	0.5	0.0	0.7	24	23	25	
4			x	30	20.9	7	0.4	0.4	0.4	13	-	-	
5			x	36	"	"	1.6	1.0	2.3	19	10	23	
* 6			x	"	"	"	2.6	1.7	3.0				
7			x	32	"	158	3.0	2.3	3.7	38	31	44	
8			x	36	"	192	4.3	-	-	29	-	-	
9			x	32	"	121	2.8	-	-	30	-	-	
10		x		24	48.1	121	0.3	0.0	0.3	27	26	29	"B_2" Section
11		x		"	"	"	0.5	0.0	1.4	41	34	55	
12			x	30	31.0	7	0.0	-	-	13	-	-	
13			x	36	"	"	2.2	1.3	2.7	23	13	32	
* 14			x	"	"	"	3.2	2.3	3.7	-	-	-	
15			x	32	"	158	3.3	2.7	3.7	45	36	53	
16			x	36	"	192	5.7	-	-	39	-	-	
17			x	32	"	121	3.5	-	-	44	-	-	

* Special mfg. variable - assemblies placed in -40°F. refrigerator immediately after mfg. and held at that temperature through aging and testing.

Appendix 5

Delayed Services on Low Temperature Flat Cells of HE-266 Construction

FL-5 Size

Item No.	% Water in System	Anode Cur. Dens. 2 Minute Period	LTE No. of Electr.	Age in Mos. at Time of Test	Delayed Service as Indicated in Hours -40°F. Avg.	-40°F. Min.	-40°F. Max.	70°F. Avg.	70°F. Min.	70°F. Max.	
1	36	20.9	7	3	1.3	0.7	1.7	17	13	22	"B1" Section
2	"	"	"	4	0.2	0.0	0.7	-	-	-	
3	"	"	"	5	0.7	0.0	1.3	-	-	-	
4	"	"	"	8	0.7	0.3	1.3	-	-	-	
5	36	"	192	5	1.7	-	-	17	-	-	
6	32	"	158	3	1.0	-	-	22	-	-	
7	"	"	"	5	1.2	-	-	18	-	-	
8	"	"	"	8	1.3	-	-	-	-	-	
9	32	"	121	2	3.0	2.0	4.6	23	22	24	
10	36	31.0	7	3	1.5	0.7	2.0	22	15	28	"B2" Section
11	"	"	"	4	0.6	0.0	2.0	-	-	-	
12	"	"	"	5	0.8	0.0	1.7	-	-	-	
13	"	"	"	8	0.7	-	-	-	-	-	
14	36	"	192	5	2.0	-	-	21	-	-	
15	32	"	158	3	0.7	-	-	27	-	-	
16	"	"	"	5	1.8	-	-	24	-	-	
17	"	"	"	8	0.7	-	-	-	-	-	
18	32	"	121	2	3.5	1.7	5.6	24	23	24	

Appendix 6

Voltage and Amperage Patterns on Low Temperature Flat Cells

FL-5 Size

Item No.	LTE No. of Electr.	No. Cells in Stack	% Water in Mix	No. Tests	14 Days Avg. Volts	14 Days Avg. Amps	3 Mos. Avg. Volts	3 Mos. Avg. Amps	3 Mos. Current Maint. in %
1	7	15	30	24	26.4	0.8	23.7	0.7	88
2	7	15	36	86	26.1	1.7	24.7	1.6	94
3	7	17	36	4	29.9	1.8	27.7	1.7	94
4	158	15	36	13	23.6	1.5	23.6	1.4	93
5	158	17	36	4	26.4	1.6	25.9	1.5	94