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**ANNUAL REPORT FOR 1980 ON
RESEARCH, DEVELOPMENT, AND DEMONSTRATION
OF LEAD-ACID BATTERIES FOR
ELECTRIC VEHICLE PROPULSION
Contract No. 31-109-38-4206**

by

**C&D Batteries Division
of
Eltra Corporation**

**ARGONNE NATIONAL LABORATORY, ARGONNE, ILLINOIS
Operated for the U. S. DEPARTMENT OF ENERGY
under Contract W-31-109-Eng-38**

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Printed in the United States of America
Available from
National Technical Information Service
U. S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

NTIS price codes
Printed copy: A05
Microfiche copy: A01

Distribution Category:
Energy Storage—Electrochemical--
Near-Term Batteries (UC-94ca)

ANL/OEPM-80-10

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Annual Report for 1980 on
RESEARCH, DEVELOPMENT, AND DEMONSTRATION
OF LEAD-ACID BATTERIES FOR
ELECTRIC VEHICLE PROPULSION

Prepared for
The Office for Electrochemical Project Management
Argonne National Laboratory
Under Contract No. 31-109-38-4206

by
Eltra Corporation - C&D Batteries Division
Plymouth Meeting, Pennsylvania

March 1981

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RESEARCH, DEVELOPMENT, AND DEMONSTRATION
OF LEAD-ACID BATTERIES FOR
ELECTRIC VEHICLE PROPULSION

ELTRA CORPORATION

ANNUAL REPORT

FY-1980

CONTRACT NO. 31-109-38-4206

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EXECUTIVE SUMMARY

Considerable progress was made during FY-80 to improve the performance of the initial battery prototypes developed under Eltra's Electric Vehicle Battery Program. Energy densities have been increased from previous average levels of 36 WH/kg to 41 WH/kg; peak power density from 114 W/kg to 128 W/kg; and a previous cycle life of 125 has been surpassed with over 200 cycles attained with cells still on test.

This report presents the progress and status of Eltra's Electric Vehicle Battery Program during FY-80 under five divisional headings: Research on Components and Processes; Development of Cells and Modules for Electric Vehicle Propulsion; Sub-Systems; Pilot Line Production of Electric Vehicle Battery Prototypes; and Program Management.

Considerable attention during the past year was devoted to evaluating the effect of components and processes on cell performance. A factorial experiment initiated early in the program, before establishment of the expanded metal pilot line, was completed. Experimental three cell modules with positive paste densities of 4.39 g/cc gave longer cycle life and also some improvement in specific energy density compared to those with paste densities of 3.97 g/cc. This result has been incorporated in some of our ISOA designs.

Expanded lead-calcium-tin grids with higher density pastes produced thinner more efficient positive electrodes. Higher acid gravity provided higher specific energy density and lower cycle life. Evans "Sub-Micro" and Amerace "Flex-Sil" separators both demonstrated satisfactory resistance to penetration. The Evans material generally gave higher energy densities. Slyver^R glass mat was distinctly superior to random glass mat as a retainer material.

In the area of alloy composition, cast lead antimony grids have given three to five times as many cycles as cast lead-calcium-tin grids. Studies of premature failure during cycle life tests on expanded lead calcium grids were performed. Reaction product impurities have been identified as a contributing factor to early grid corrosion and have been eliminated.

The evaluation of a lead/plastic/non-woven mat composite electrode design as a means of reducing plate weight without diminishing cycle life was initiated. Results obtained on these initial cut-down automotive type plates have encouraged us to continue the evaluation of this electrode concept in full size cells.

The study of innovative grid designs representing a pronounced departure from our present configurations was initiated.

A method was developed to produce isopotential maps showing the difference in potential over the surface of different grid designs.

They are being utilized as a selection guide in establishing more effective grid geometry to attain the advanced performance goals. Expanded lead-calcium-tin grids show a uniform but sharper drop in potential compared to other designs tested.

Improvement in active material utilization and cycle life through the use of tetrabasic lead sulfate pastes and additives was continued. A paste mixture of 70/30 of tetrabasic lead sulfate/leady oxide gave two to three times the cycle life of pastes composed entirely of leady oxide when applied to cast lead-calcium-tin grids. Similar tests with cast lead antimony and expanded lead-calcium-tin grids are in progress. The addition of graphite fibers to the positive paste has increased positive active material utilization as much as 16%.

Development work on full size ISOA and advanced cells and modules has resulted in prototypes for testing in-house and at the NBTL. Three generations of ISOA and three generations of advanced designs have evolved so far with progressive improvements in performance being realized at each step.

The pilot line, for production of ISOA positive and negative plates with expanded metal grids, has been improved with the

replacement of the orifice type pasting machine with a belt type paster and the installation of a center strip guiding system.

A four door converted Dodge Omni electric vehicle was purchased by C&D. It will serve as a test bed for electric vehicle batteries being developed under the ANL program. The test data obtained will supplement in-house testing by providing actual vehicle usage experience. The vehicle will also be used to publicly demonstrate the viability of electric vehicles as an alternative mode of transportation.

1.0 INTRODUCTION

On April 15, 1978, Eltra Corporation signed a contract with ANL for the Research, Development and Demonstration of Lead-Acid Batteries for Electric Vehicle Propulsion. The contract period is for 37 months and is being undertaken by Eltra's Electric Vehicle Group. This involves a combined effort of its Prestolite (automotive) and its C&D (industrial) Battery Divisions.

1.1 Program Goals

ANL's original goals for the ISOA (Improved State of the Art) and the Advanced Lead Acid Batteries are listed in Table 1. Three of the most critical goals are specific energy (energy density), cycle life, and cost.

1.2 Final Cost and Design Study

In the Design and Cost Study (1) under ANL Contract No. 31-109-38-3628, a series of lead-acid cell and battery trade-off studies based on available data were conducted to optimize all cell and battery components and incorporate those projected improvements into an overall battery design suitable for electric vehicle propulsion. Included in these studies were the following components.

1. Electrode Design- this included a study of grid construction and active material composition. The result of this study was a series of active material efficiency and plate energy density curves as a function of plate thickness and grid construction.
2. Separators and Retainers- a review was made of the properties of all candidate separator/retainer systems.
3. Electrolyte- this study defined the minimum volume of electrolyte required as a function of concentration and cell capacity.
4. Cell Packaging- this study defined a light-weight module with through-the-partition intercell connections.

As a result of this effort a battery design was generated which was calculated to meet ISOA goals. One of the unique features of the initial de-

sign is the use of expanded non-antimonial grid metal for both the positive and negative plates. This represented an extension of the continuous fabrication process using expanded metal introduced by Prestolite for the manufacture of their automotive batteries. The details for this design and its potential advantages are presented in Eltra's FY-78 annual report for this contract (2). Since its initiation, technical progress on different aspects of the program have been reported (3-9).

1.3 Work Breakdown Structure

During FY-80 the program's development and production effort was continued under the major tasks shown in Figures 1.3.1 and 1.3.2.

This report presents the progress and status of these tasks under five divisional headings to furnish a clearer perspective of the program's activities to the reader.

TABLE 1
ANL TECHNICAL GOALS

	<u>ISOA</u>	<u>ADVANCED</u>
1. Battery Capacity (kW-hr) *	20-30	30-40
2. Battery Dimension (HxWxL cm)	29.5 x 40.6 x 264	
3. Specific Energy* (W-hr/kg)	40	60
4. Specific Power (W/kg)		
Sustaining	20	30
Peak (15 sec. avg.)	100	150
5. Duty Cycle		
Charge (hr)	4 - 8	4 - 8
Discharge (hr)	2 - 4	2 - 4
6. Cycle Life	800	1000
7. Cost/Energy (\$/kW-hr) **	50	40
8. Energy Efficiency (%)	60	60
9. Typical Installation Voltage	96 - 120V	96 - 120V

* 3 hr rate discharge

** based on 1978 price of lead

FIGURE 1.3.1

WORK BREAKDOWN STRUCTURE

FIGURE 1.3.2

TASK LEVEL

10.0 Battery Fabrication

9.0 Prototype Cell Fabrication & Testing

8.0 Procurement of Cell Battery Components

7.0 Cell & Battery Specifications

6.0 Development

2.0 RESEARCH ON COMPONENTS AND PROCESSES

2.1 Introduction

Considerable effort during the past year was expended on evaluating the effect of components and processes, individually or in combination, on cell performance. The purposes of these studies were to

- . increase energy density
- . extend cycle life
- . technical support to pilot line processing when appropriate

Among the earliest planned investigations was a full factorial study of the influence of paste density, electrolyte gravity, type of glass mat retainer, and type of separator. From this experiment and others which were devoted to specific components, it became evident that two areas, in particular, required further research. These areas related to the grid and to the active material. The aspects that have been examined are as follows:

. Grid:

Alloy composition
Corrosion of Pb/Ca/Sn alloy
Lead/Plastic Composite Electrodes
Isopotential Grid Design Study

. Active Material:

Precursor (tetrabasic lead sulfate
lead oxide)
Curing procedure
Addition of conductive fibers

2.2 Factorial Study

At the outset of this program a series of experiments were planned to evaluate different battery parameters and their effect on performance. The first was a full factorial investigation of the effect on energy density and cycle life of two different paste densities, two different electrolyte gravities, two types of glass mat retainers, and two types of separators. The sixteen different experimental development modules representing combinations of these parameters were assembled in 19-plate cells (9 positives, 10 negatives)

in 3-cell golf-car containers with mud-rests in the bottom. Both positive and negative grids were cast from a 0.07% Ca - 0.7% Sn alloy. A negative expander especially formulated for deep cycle duty was used. The positives were wrapped in the U-fold of a glass mat and inserted into enveloped separators. For each combination, one module was made with individual external terminals for each cell. These modules were used for measured capacity discharges at various amperages. In addition, for each combination two modules were constructed with the three cells connected internally through the cell partition in series. These were used for cycle life determination.

Table 2.2A presents details of the construction of the cells in this factorial study. The electrical testing was completed during fiscal 1980 and is summarized in the same table.

If the values for energy density and cycle life are examined for each one of the parameters alone, the other three being kept the same, one can construct a table (Table 2.2B) which suggests directions worthy of further investigation in attempting to attain certain performance goals. In constructing this table, the greater of the two cycle life values shown in Table 2.2A was used for the purposes of comparison.

TABLE 2.2A
FACTORIAL STUDY

POSITIVE PASTE DENSITY (A)	ACID GRAVITY (B)	SEPARATOR (C)	RETAINER (D)	MODULE NUMBER	ENERGY DENSITY WH/KG (E)	CYCLES TO END OF LIFE (F)	
						REPLICATE NO.	
						1	2
3.97	1.280	SM	G	1	29.5	60	68
			S	2	29.7	61	79
		F	G	3	29.8	44	45
			S	4	30.0	71	73
	1.310	SM	G	5	31.6	48	33
			S	6	32.1	72	(G)
		F	G	7	28.6	29	34
			S	8	30.3	70	56
4.39	1.280	SM	G	9	31.1	48	(H)
			S	10	30.2	65	84
		F	G	11	28.1	34	33
			S	12	31.4	62	89
	1.310	SM	G	13	30.9	61	70
			S	14	32.1	62	62
		F	G	15	29.7	70	63
			S	16	31.1	68	101

(A) G/CC DRY

(B) ± 0.005

(C) SM= EVANS SUB-MICROR

F= AMERACE FLEX-SIL

(D) G= RANDOM FIBER GLASS MAT

S= PARALLEL FIBER GLASS MAT (SLYVER^R)

(E) 3-HOUR RATE, 100% DEPTH OF DISCHARGE

(F) END OF LIFE= WHEN CAPACITY FALLS BELOW
80% OF INITIAL CAPACITY 3 OUT OF 5 CON-
SECUTIVE CYCLES

(G) MODULE USED FOR ANOTHER TEST

(H) MODULE INCORRECTLY ASSEMBLED

TABLE 2.2B

NUMBER OF INSTANCES IN WHICH A PARTICULAR PARAMETER "LEVEL" SHOWED
IMPROVED PERFORMANCE

<u>PARAMETER</u>	<u>"LEVEL"</u>	<u>GREATER ENERGY DENSITY*</u>	<u>LONGER CYCLE LIFE *</u>
PASTE DENSITY	3.97/4.39	2/5 (A)	3/5
ACID GRAVITY	1.280/1.310	3/5	5/3
SEPARATOR	SM/F (B)	5/3	3/4 (A)
RETAINER	G/S (C)	1/7	1/7

(A) NO CHOICE BETWEEN "LEVELS" IN ONE INSTANCE.

(B) SM= SUB-MICRO. F= FLEX-SIL

(C) G= RANDOM GLASS. S= PARALLEL SLYVER

* THIS NOTATION SHOULD BE READ, "OUT OF A TOTAL OF EIGHT PAIRS OF PARAMETER COMBINATIONS WHERE THE ONLY PARAMETER WHICH VARIED WAS PASTE DENSITY, THERE WERE TWO INSTANCES WHERE 3.97g/cc GAVE GREATER ENERGY DENSITY AND 5 INSTANCES WHERE 4.39 g/cc GAVE GREATER ENERGY DENSITY".

In considering the data obtained and the comparisons made, three observations are pertinent. First, the differences in absolute values are not great. This is especially obvious in energy density where all the values lie between 28 and 32 WH/kg and 69% are between 30 and 31 WH/kg. The spread in cycle lives is greater but, as a group, cycle lives were shorter than anticipated and shorter than those obtained with positive grids cast from Pb-Sb alloys to be reported later. Second, the difference in "level" or type of parameter was chosen so that, in any case, a reasonably good battery might be produced. Third, the number of replicates was severely limited. Nevertheless, within these constraints the following comments appear to be warranted:

Paste density. There is some advantage in higher paste density for both greater energy density and longer cycle life. The latter is to be expected, but the former was unexpected since it is a commonly held general principle that greater energy density is achieved with lower paste density. The latter effect was probably due to the fact that plates, regardless of paste density, were pasted with the same weight of paste. Higher paste density therefore gave thinner, more efficient plates.

Acid gravity. Higher gravity provides higher energy density, but lower gravity gives longer cycle life. The weight of evidence from these experiments is not great, but the trends are as would be expected and have been born out by subsequent experiments in advanced modules.

Separator. Evans Sub-Micro gave more numerous instances of higher energy density, while Flex-Sil (Amerace) was present in a longer-cycle life module in only four cases out of seven. More important is the fact that in no case, with either separator, was cell failure due to shorting through the separators or other separator-related factor.

Retainer. Parallel fiber Slyver^R glass mat appeared to be distinctly superior to random fiber glass mat from both energy density and cycle life standpoints. While this is most probably due to better positive active material retention and to better electrolyte mixing during gassing on charge, it is also possible that the slightly thicker and more resilient Slyver may compensate for variations in element pack tightness and thus provide improved overall performance.

Tear-down examinations were performed on all cycled modules at end of life. There was a strong similarity in the appearance of all plates. Negatives were universally in good condition, as were separators and retainers. Failure essentially was due to loosening and washing of active material from the positive plates. Under a gentle stream of water, bands of active material across the top and the bottom of the plate washed out rather easily. These bands ranged from one-half to one inch wide and represented about 20-30% of the plate area. The positive active material in the central portion of the plate remained relatively hard and adherent to the grid. The grid wires were not brittle or reduced in diameter. Gamma radiographs showed grid growth in all instances, especially along the side opposite the lug.

2.3 Grid Studies

Two areas of investigation have been under way since last year. One involved a comparison of the electrical performance of cells made with the 0.07% calcium - 0.7% tin alloy grids with that of cells made with 4.56% antimony alloy grids. In both cases the grids were cast from the same mold.

The second area concerned the cause of extensive grid corrosion encountered in some cells made with expanded metal Pb-Ca-Sn grids.

More recently, another approach relating to grids has been undertaken. This is a study of grid design as it relates to potential distribution. Mapping of isopotential lines across the grid structure reveals the uniformity of such distribution (see Section 2.3.4).

2.3.1 Comparisons of Cast Antimonial Grids and Cast Lead-Calcium-Tin Grids

For comparison of cycle life obtained with modules using lead-calcium-tin grids, several modules were constructed using 80 mil thick cast lead - 4.56% antimony alloy grids. One hundred percent leady oxide paste, hydroset, was used in all cases as were Evans Sub-Micro separators and random fiber glass mat retainers. The construction and performance details are given in Table 2.3.1.

TABLE 2.3.1
100% LEADY OXIDE ON CAST ANTIMONIAL GRIDS

MODULE NUMBER	PASTE DENSITY, G/CC, DRY	ACID GRAVITY, S.G.	ENERGY DENSITY, WH/KG	CYCLES TO END OF LIFE DUPLICATE NO.	
				1	2
SB-1	3.97	1.280	32.7	307	259
SB-2	4.39	1.280	32.3	352	287
SB-3	3.97	1.310	34.2	268	88
SB-4	4.39	1.310	33.6	328	260

The cast Pb-Ca-Sn grid modules to which the above data are most nearly comparable in construction and testing are those described in Section 2.2 on the "Factorial Study". A comparison of these two sets of results shows the antimonial grids to provide four times longer cycle life. (Two cast Pb-Ca-Sn grid modules pasted with a 70/30 mixture of tetrabasic lead sulfate and leady oxide achieved 139 and 185 cycles and an expanded Pb-Ca-Sn grid module pasted with 100% leady oxide reached 150 cycles.) Additional data on cast antimonial grids pasted with 70/30 TTb/LO is reported in Section 2.4.1.

2.3.2 Corrosion of Lead-Calcium-Tin Grids

A number of the early ISOA modules (expanded lead-calcium-tin grids) showed severe grid corrosion at the end of life. Two possible explanations were originally advanced. One possibility was that the cellulosic pasting tissue used in the factory process was hydrolyzed by the electrolyte and oxidized during formation to form organic acids, especially acetic, which are known to be particularly corrosive toward lead. The other possibility was that exposure to elevated temperatures during tunnel drying, curing, or formation caused partial recrystallization of the alloy permitting destructive intergranular corrosion.

2.3.2.1 Influence of Cellulose Pasting Tissue

The Prestolite Laboratories conducted experiments with modules containing expanded Pb-Ca-Sn grids and the 100% rayon pasting tissue originally employed in EV battery pilot line manufacturing, where high rate (18 hour) high temperature ($\sim 95^{\circ}\text{C}$) formation was used. At the end of formation, measurable quantities of acetic acid were found by direct analysis, and the grids were already severely corroded. It was believed that the electrolyte hydrolyzed the cellulose to acetic acid which was oxidized in the vicinity of the positive plate and caused the unusually high degree of corrosion.

The C&D Laboratory sought to determine whether corrosion was equally severe when the customary long term (96 hour), low temperature

(25°C) formation schedule was used. Modules made with cast Pb-Ca-Sn grids, with and without the rayon tissue, and with cast Pb-Sb grids, with and without the rayon tissue were assembled. After formation, the modules were placed on automatic cycle until their capacities fell below 80% of the original capacities. The data are given in Table 2.3.2.1.

TABLE 2.3.2.1

INFLUENCE OF 100% RAYON PASTING TISSUE
CAST GRIDS

<u>MODULE NUMBER</u>	<u>GRID ALLOY</u>	<u>CONTAINS PASTING PAPER A</u>	<u>CYCLES TO END OF LIFE</u>
01	Pb-Ca-Sn	no	144
02	"	yes	107
03	Pb-Sb	no	265
04	"	yes	250

Although cycle life of the modules containing rayon pasting tissue is somewhat lower than those which did not contain tissue, examination at end of life revealed no indication of severe corrosion in any case, nor did failure appear to be related to that cause. In all cases, there appeared to be the same type of washing observed in other plates made with either cast Pb-Ca-Sn grids (Section 2.2) or cast Pb-Sb grids (Section 2.3.1).

In the meantime, Prestolite obtained and tested several other different types of cellulosic pasting tissue. As before, 18-hour 95°C formation was used, and the cells were examined immediately after formation. Pasting paper A produced high levels of acetic acid and disastrous grid corrosion. Pasting paper B gave less acetic acid and some corrosion, but much less than pasting paper A. Pasting paper C produced little acetic acid and almost no corrosion at all.

Pasting paper C was used in some small scale 5-plate cell tests at the C&D Lab with expanded calcium EV plates in comparison with similar plates assembled without any pasting tissue. The 96-hour, 25°C formation was used. After 15 deep cycles no sign of acetic acid was found and both sets of grids showed no severe corrosion. This problem appears to be under control at this time.

2.3.2.2 Influence of Recrystallization of Wrought Lead-Calcium-Tin Alloy

The grids of an ISOA module, which failed after 125 cycles, were found to be extremely brittle and to have corroded through at about the midpoint of most of the wires. Metallographic examination of these grid members revealed them to be highly crystalline, whereas the original expanded grid (like the sheet stock from which it was fabricated) displayed a non-crystalline, wrought structure. The metallurgy Laboratory at C&D has found that the original cold-worked structure undergoes progressive recrystallization as it is subjected to heat treating regimes which may be similar to those encountered in various plate processing stages such as tunnel drying, plate curing, and high temperature formation. These studies are continuing.

The Metallurgy Laboratory also heat treated bare EV grids at 232°C for eight hours, conditions that effected complete recrystallization. These grids, and corresponding non-heat treated specimens, have been undergoing cycling tests for some time and have been sampled periodically. The test is not yet complete, but at present it appears that both wrought and crystalline structures are experiencing rather similar corrosion, both in type and degree of penetration.

2.3.3 Lead/Plastic Composite Electrode (LPCE)

An experimental test cell was assembled with a lead/plastic composite electrode (LPCE) positive plate design and a non-woven mat retention system to evaluate this concept as a means of reducing plate weight without losing cycle life. Initial performance of the positive plates for this cell is compared with the performance of ISOA and Advanced positive plates in Table 2.3.3.

The cell has completed 120 cycles to date at the 3 hour rate and 80% depth of discharge. This test is continuing.

More extensive testing is now underway on a small three-cell module with LPCE positive plates. The initial performance of this module is shown in Table 2.3.3. Cycle life testing of this module is scheduled early in the first quarter of FY-81.

PERFORMANCE COMPARISON - CELLS WITH LEAD/PLASTIC COMPOSITE
ELECTRODES WITH ISOA AND ADVANCED CELLS

Table 2.3.3

	LPCE TEST CELL		LPCE 3 CELL MODULE		ISOA 3 CELL MODULE		ADVANCED 3 CELL MODULE	
	POSITIVE PLATES	FULL CELLS	POSITIVE PLATES	FULL MODULE	POSITIVE PLATES	FULL MODULE	POSITIVE PLATES	FULL MODULE
PASTED PLATE THICKNESS (cm)	.152	-	.152	-	.260	-	.260	-
3 HR. RATE CURRENT DENSITY (mA/cm ²)	13.9	-	13.3	-	10.5	-	12.2	-
CAPACITY DENSITY (AH/KG)	45.1	-	43.5	3.87	53.7	6.23	54.3	6.84
ENERGY DENSITY (WH/KG)	-	-	-	22.6	-	36.0	-	40.0
CALCULATED ENERGY DENSITY WITH ISOA CONSTRUCTION (WH/KG)	-	-	-	29.6	-	36.0	-	41.0
3 HR. RATE CYCLE LIFE @ 80% D.O.D. (CYCLES)	120 CYCLES STILL ON TEST		7 CYCLES STILL ON TEST		150 CYCLES TO DATE		210 CYCLES TO DATE	

2.3.4 Isopotential Grid Design Study

Just as it is necessary to get the highest possible efficiency in the electrochemical use of active materials to achieve high energy density, so it is necessary to get the greatest efficiency of electronic performance from the grid. In the simplest terms this means balancing the amount and uniformity of electronic conductivity against the weight of grid metal.

A direct measure of these grid characteristics is made possible by an isopotential test fixture developed by C&D's General Engineering Battery Testing Lab in 1979. A diagram of this apparatus is shown in Figure 2.3.4.a.

In this test procedure a sheet of lead is placed in the bottom of a tray and covered with a separator. A sample test grid is then placed on the separator and the tray is filled with electrolyte. A power supply is connected to the lead sheet (F) and to the sample test grid (E). The power supply is turned on and the voltage drop from the power exit to points over the sample grid surface is recorded and plotted for evaluation.

ISOPOTENTIAL TEST FIXTURE

A. Tray with electrolyte	E. Power connection
B. Lead sheet	F. Power connection
C. Separator	G. Power supply
D. Test sample	H. Electrolyte

FIGURE 2.3.4.a

Data has been collected and isopotential plots made for evaluation on the four grid designs listed in Table 2.3.4. A comparison of the resulting isopotential maps* of these grids (Figures 1-8) will be analyzed and the most attractive design features will be identified and will be incorporated into a computer program to generate a final design.

ELECTRODE DESIGNS TESTED-ISOPOTENTIAL METHOD

TABLE 2.3.4

GRID DESIGN	FIGURE NUMBER 2.3.4	ELECTRODE DESIGN	POWER EXITS USED
A	b	Long profile positive expanded metal with four power exits	all four
A	c	Long profile positive expanded metal with four power exits	no.1 only
A	d	Long profile positive expanded metal with four power exits	no.2 only
A	e	Long profile positive expanded metal with four power exits	no.3 only
A	f	Long profile positive expanded metal with four power exits	no.4 only
B	g	Prestolite expanded metal positive grid	-
C	h	Prestolite cast positive grid	-
D	i	Cast radial positive grid	-

* All grids have been drawn to the same scale but the isopotential lines do not have the same absolute values.

FIGURE 2.3.4.b Long Profile Expanded Metal With Four Power Exits. All Four Exits Used.

FIGURE 2.3.4.c Long Profile Positive Expanded Metal With Four Exits.
Only Exit No.1 (as shown) Used.

FIGURE 2.3.4.d Long Profile Positive Expanded Metal With Four Power Exits. Only Exit No.2 (as shown) Used.

ISOPOTENTIAL PLOT
DESIGN A

3

FIGURE 2.3.4.e. Long Profile Positive Expanded Metal With Four Power Exits.
Only Exit No.3 (as shown) Used.

ISOPOTENTIAL PLOT
DESIGN A

FIGURE 2.3.4.f Long Profile Positive Expanded Metal With Four Power Exits.
Only Exit No.4 (as shown) Used.

ISOPOTENTIAL PLOT
DESIGN B

FIGURE 2.3.4.g Prestolite Expanded Metal
Positive Grid

ISOPOTENTIAL PLOT
DESIGN C

FIGURE 2.3.4.h Prestolite Cast Positive Grid

ISOPOTENTIAL PLOT
DESIGN D

FIGURE 2.3.4.i Cast Radial Positive Grid

2.4 Active Material Studies

The use of tetrabasic lead sulfate (TTB) in the positive paste has been shown by previous research and development at C&D to produce longer cycle life in deep cycling applications. TTB can be introduced into the positive paste as crystals produced by an independent crystallization process or can be formed by chemical reactions within the pasted plates when they are cured under high temperature/humidity conditions. Both of these methods were evaluated and discussed in the FY-79 Annual Report (8). They were not complete at that time and have progressed considerably farther in Fiscal year 1980.

One investigation centered on the use of a 70/30 blend of tetrabasic lead sulfate with leady oxide as the positive active material precursor applied to cast Pb-Ca-Sn grids. This was completed and the concept extended to pasting 70/30 TTB/LO on cast Pb-Sb grids.

The second study was based upon introducing tetrabasic lead sulfate into the positive paste by in situ high temperature (85°C) and high humidity (100%) conversion of the normal mixture of di- and tri-basic lead sulfate in positive paste. Plates processed in this way were compared with hydroset plates pasted with 100% leady oxide.

During the fiscal year just completed a new line of work involving the admixture of electrically conductive graphite fibers to positive active material has been started.

The purpose of this investigation is to improve positive active material utilization by decreasing the resistance of the active mass.

2.4.1 Tetrabasic Lead Sulfate as Positive Active Material Precursor

Four modules were prepared using a 70/30 blend of tetrabasic lead sulfate (TTB) and leady oxide (LO). The dry paste density was 4.3 g/cc. The grids were 80 mil thick cast Pb-Ca-Sn. The positives were wrapped in random fiber glass mat and enveloped in Evans Sub-Micro separator. Nine positives and ten negatives were used per cell, with 3 cells per module. Conventional formation, conditioning, and cycling procedures were used (8). The results, at two different electrolyte gravities, are shown in Table 2.4.1A.

TABLE 2.4.1.A

MODULES MADE FROM POSITIVES PASTED WITH 70/30 TTB/LO
CAST Pb-Ca-Sn GRIDS

MODULE NUMBER	ACID GRAVITY S.G.	DENSITY Wh/kg	CYCLES TO END OF LIFE
EVM 17-1	1.280	31.9	139
EVM 21-1	1.280	30.7	183
EVM 21-2	1.310	32.3	104
EVM 21-3	1.310	32.1	105

There is a clear advantage in cycle life for these modules over the corresponding 100% leady oxide compositions of the Factorial Study (Table 2.2A), especially in 1.280 electrolyte.

In an attempt to increase cycle life still further, a number of modules have been made in duplicate or triplicate combining TTB, cast Pb-Sb grids, and Slyver glass retainers. (Daramic separator envelopes were used because this material is now being employed at Prestolite.) Only 1.280 S.G. electrolyte has been used in this recent study. Table 2.4.1.B summarizes this test as of the end of September, 1980.

TABLE 2.4.1.BMODULES MADE FROM POSITIVES PASTED WITH 70/30 TTB/LO
CAST Pb-Sb GRIDS

MODULE NUMBER	GRID THICKNESS, MILS	PASTE DENSITY, g/cc DRY	ENERGY DENSITY, Wh/kg	CYCLE LIFE, STATUS 9/30/80
B 3-1	80	4.44	29.2	355, failed
3-2	80	4.44	31.4	389, continuing
B 4-1	80	4.10	32.5	214, failed
4-2	80	4.10	31.3	335, continuing
4-3	80	4.10	30.6	254, failed
B 5-1	60	3.93	31.6	288, continuing
5-2	60	3.93	31.7	340, continuing
5-3	60	3.93	31.2	327, continuing

Although this experiment is not complete, there is a clear superiority in cycle life for 70/30 TTB/LO mixes pasted on Pb-Sb grids compared to similar constructions with Pb-Ca-Sn grids (Table 2.4.1.B vs Table 2.4.1.A). Some indication may also be developing for longer cycle life when 70/30 TTB/LO rather than 100% leady oxide pastes are applied to Pb-Sb grids (Table 2.4.1.B vs Table 2.3.1).

2.4.2 Comparison of Humidity Curing and Hydrosetting of 100% Leady Oxide Pastes

The Annual Report for FY-79 (8) to ANL described the beginning of a comparison of the above curing processes which was expected to demonstrate longer cycle life as a consequence of humidity curing. Three-cell modules (9 positives, 10 negatives per cell) were made with the glass mat retainers and Daramic envelopes on the positives. Cast Pb-Ca-Sn grids were used. Conventional formation, conditioning, and cycling regimes were employed. Variations in processing and total cycle lives are shown in Table 2.4.2.

TABLE 2.4.2

CURING METHODS AND CYCLE LIFE

MODULE NUMBER EVC-	CURING METHOD	PASTE DENSITY, g/cc, dry	ACID GRAVITY S.G.	CYCLES TO END OF LIFE
49	Humidity Curing	3.97	1.280	39
50	" "	3.97	1.310	42
51	" "	4.39	1.280	82
52	" "	4.39	1.310	73
53	Hydroset	3.97	1.280	53
54	"	3.97	1.310	50
55	"	4.39	1.280	70
56	"	4.39	1.310	95

Obviously the data does not support the anticipated advantage for humidity curing. Nevertheless, because of considerable prior experience at C&D and work described by others, a further investigation of humidity curing particularly in conjunction with expanded Pb-Ca-Sn grids is already underway.

2.4.3 Addition of Graphite Fibers

Experimental work on the utility of conductive graphite fibers in positive active material was begun in C&D's Theoretical Research Laboratory as an in-house program early in June, 1979. Possible advantages foreseen for this concept were more complete conversion during formation, higher active material utilization during cycling, and greater high current discharge capability.

Early experiments examined several types of fibers from different manufacturers, different percentages of fiber based on the lead oxide in the paste mix, different thicknesses of grids, and different grid alloys. These experiments focused attention on the following aspects.

- Graphite fibers produced by Great Lakes Carbon Corporation under the tradename Fortafil-3 and Fortafil-5 showed the most promise.
- Concentrations of fiber in the range of 0.5%

produced measurable benefits.

- With thick plates, a notable improvement in rate of conversion to PbO_2 during formation was demonstrated.
- With thin plates (in the proposed EV battery range), an increase in active material utilization was observed.

Further work with graphite fibers relating to the EV battery development program was then transferred directly to that group and is presented in the following account.

At the outset it must be pointed out that the physical property of greatest interest in the Fortafil fibers is their electrical conductivity which is as shown below for the types examined by us.

Electrical Conductivity

Fortafil-3	570 ohm ⁻¹ cm ⁻¹
Fortafil-5	1050 ohm ⁻¹ cm ⁻¹

Cast lead-antimony grids, 70 mils thick, were chosen to make test plates and were pasted with 100% leady oxide pastes containing varying amounts of Fortafil fibers or Dynel fibers, the latter for control purposes. Plates were hydro-set. Five-plate test cells (2 positives, 3 negatives) were assembled, the positives being wrapped in random fiber glass mat and folded in Daramic separators. The cells were packed tightly with polyethylene shims. Ninety-six hour formation was used and cells were put through two conditioning cycles before being put on automatic cycle. During automatic cycling, discharges were run for 2.4 hours to an approximate 80% of calculated capacity and recharged for 9.6 hours. Measured capacities were run periodically to a low voltage cut-off of 1.75 volts, and percent of theoretical positive active material utilization was calculated. Cycling was continued until the test cells fell to 80% of the initial theoretical active material utilization.

The first experiment (Q3) run according to the above plan, compared 0.5% Fortafil-3 (based on leady oxide) with 0.1% Dynel fiber as a control.

The level of Dynel is that generally used in standard automotive batteries. The graphite-containing cells had initial active material utilizations about 9% higher than the controls. This superiority increased to 19% at the sixteenth cycle and fell to 16% at the eighteenth cycle by which time the test cell had only 74% of its initial utilization.

In subsequent tests (Q5 and Q6) 1.0% Fortafil-3 and 0.5% Fortafil-5 were compared, again with 0.1% Dynel. In both cases the graphite-containing cells were higher in active material utilization than Q3 throughout cycling and ran for about 100 cycles before falling below 80% of the initial utilization. However, the controls (0.1% Dynel) were also unaccountably high in the latter tests. The results are summarized in Table 2.4.3.

TABLE 2.4.3

INFLUENCE OF GRAPHITE FIBERS ON ACTIVE MATERIAL UTILIZATION

EXPERIMENT	ADDITIVE	PERCENT THEORETICAL POSITIVE ACTIVE MATERIAL UTILIZATION			
		INITIAL	60	80	100
			CYCLES	CYCLES	CYCLES
Q3	0.5% Fortafil-3(1)	38	31	28	-
	0.1% Dynel (1)	35	26	24	-
Q5	1.0% Fortafil-3(2)	41	40	32	29
	0.1% Dynel (3)	40	39	32	29
Q6	0.5% Fortafil-5(2)	42	39	34	33
	0.1% Dynel (3)	40	38	33	29

- (1) Average of 5 cells
 (2) Average of 3 cells
 (3) Average of 2 cells

It is not surprising that the controls for Q5 and Q6 are nearly identical since they were made from the same batch of paste and cured at the same time under the same conditions. The controls for Q3 were made with the same paste formulations and cured under the same conditions but at a different time. There is no indication, however, of any reason why the Q3 controls should have had lower utilization than the Q5 and Q6 controls.

It is not intended to probe this question further in small, individual test cells. Rather it is proposed to examine the influence of 0.5% Fortafil-3 in full-size 3-cell modules using both cast lead-antimony and expanded lead-calcium grids. The level and type of Fortafil fiber has been selected for reasons of cost; Fortafil-5 is approximately twice as expensive as Fortafil-3.

3.0 DEVELOPMENT OF CELLS AND MODULES FOR ELECTRIC VEHICLE PROPULSION

3.1 ISOA Development

The original ISOA design has been modified in several ways since the first prototype modules were assembled with expanded manually punched and pasted plates. Estimates used in those prototypes for electrolyte volume and positive active material utilization were overly optimistic, and measured amp-hour capacity and weight were less than predicted. Correlations were made to address those problems first, and then other design modifications followed as the EV battery pilot line was installed and adjusted to produce plates using a continuous expanded metal process.

The 1979 Annual Report (8) covers the development phase of the ISOA up to the time when the pilot line was complete but not fully operational. During this period three ISOA modules were submitted to the NBTL, and in-house testing to evaluate the performance of these designs (see Table 3.1A) was not completed.

The performance level established for the ISOA of Fiscal 1979 (8), based upon modules with hand-made plates, is presented in Table 3.1B. Analyses of cells after cycling uncovered an unanticipated and severe positive grid corrosion problem that had a detrimental effect on the cycle life performance (see Section 2.3.2 of this report). The source of this corrosion was suspected to be organic decomposition products of the pasting tissue used to prevent clogging of the pilot line tooling and permit stacking of the freshly pasted plates.

The first set of test modules made with machine pasted plates from the pilot line were 10+/9- configuration with special plate separation to facilitate removal of these decomposition products by dumping the forming acid at the midpoint and end of formation

TABLE 3.1A

ISOA FISCAL 1980

MODULES SUBMITTED TO NBTU

PLATES	1		2	
	POSITIVE	NEGATIVE	POSITIVE	NEGATIVE
Number of plates	10	10	10	9
Height-cm	17.25		17.25	
Width-cm	15.25		15.25	
Grid Construction	Expanded Metal		Expanded Metal	
Grid Thickness-cm	.208	.160	.208	.160
Grid Weight-kg	.53	.46	.53	.46
Plate Thickness-cm	.260	.218	.260	.161
Paste Density-g/cm ³ dry	3.97	4.44	3.97	4.44
Paste Weight/Plate-kg dry	.254	.238	.254	.170
Total Paste Weight/Cell-kg dry	2.54	2.38	2.54	1.53
Total Plate Weight/Cell-kg dry	3.07	2.84	3.07	1.99
Active Material Capacity Density-AH kg	73	78	65	108
Utilization-% of Theoretical	32.6	30.4	28.9	42.0
Separator Type	Daramic		Daramic	
Retainer Type	Glass Mat		Glass Mat	
Separator Thickness-cm	.051		.102	
Retainer Thickness-cm	.102		.051	
Total Separator Weight/Cell-kg	.144		.144	
Total Retainer Weight/Cell-kg	.094		.089	
Grand Total Weight/Cell-kg	.238		.233	
Electrolyte Specific Gravity	1.305		1.280	
Volume/Cell-cm ³	1800		2064	
Weight/Cell-kg	2.349		2.642	
Theoretical Capacity-AH	238.6		262.7	
Final Specific Gravity	1.103		1.124	
Length/Module-cm	26.37		26.37	
Width/Module-cm	18.14		18.14	
Height/Module-cm	27.00		27.00	
Individual Cell Weight-kg	8.50		7.935	
Container and Cover Weight-kg	1.17		1.17	
Connector and Terminal Weight-kg	.766		.766	
Total Module Weight-kg	27.4		25.7	
Energy Density-WH kg	38.7		36.5	
Capacity/Plate-AH	18.6	18.6	16.5	18.3
Total Rated Capacity-AH	186		165	

and replacing with fresh acid each time. Other testing had shown that tissue decomposition took place largely during the formation step of cell processing (see Section 2.3.2.1) and it was hoped that most of the decomposition products could be flushed out of the cells during this period before any significant grid damage had occurred.

TABLE 3.1B

PERFORMANCE LEVEL OF FISCAL 1979 ISOA BATTERIES

Energy Density	36 to 39 WH/kg (3 hr rate)
Power Density	114 W/kg (peak 15 sec)
Cycle Life	125 (80% DOD cycles)

Electrical performance for this group of test modules was less than 32 watt-hours per kilogram. This was partially due to excessive overpasting of the positive plates used and partially due to module construction which resulted in internal shorting. The positive plates used, from an early pasting run, did not meet specifications, and good cells were combined with mechanically defective cells in the same module. Internal examination of these test cells after formation and several conditioning discharges revealed severe positive grid corrosion after relatively few cycles, the usual traces of pasting tissue that had not fully decomposed, and no discernable benefits derived from the special plate separation that was used.

3.1.1 First Generation ISOA Batteries

Two shipments of 5 modules each, required by the ANL contract, were shipped to the NBTL for testing. The first shipment of modules, designated as First Generation ISOA (see Table 3.1C), was taken from the second set of EV modules from the pilot line. Improvements on the line made it possible to produce thinner and lighter negative plates than any used in previous ISOA designs. These were coupled with high density positive plates in an 11+/10- configuration to give reasonable energy density and capacity. With nearly 33% of the module weight proportioned to the positive active material, long cycle life was anticipated.

The premature positive grid corrosion problem was addressed in this group of ISOA modules by

TABLE 3.1C
ISOA FISCAL 1980

MODULES SUBMITTED TO NBT

PLATES	5 FIRST GENERATION		5 SECOND GENERATION	
	POSITIVE	NEGATIVE	POSITIVE	NEGATIVE
Number of plates	11	10	11	11
Height-cm	17.25		17.25	
Width-cm	14.93		14.93	
Grid Construction	Expanded Metal		Expanded Metal	
Grid Thickness-cm	.208	.135	.208	.135
Grid Weight-kg	.59	.46	.67	.51
Plate Thickness-cm	.260	.148	.260	.148
Paste Density-g/cm ³ dry	4.44	4.44	4.08	4.43
Paste Weight/Plate-kg dry	.252	.130	.244	.129
Total Paste Weight/Cell-kg dry	2.77	1.30	2.68	1.42
Total Plate Weight/Cell-kg dry	3.36	1.76	3.35	1.93
Active Material Capacity Density-AH kg	50.9	108	57.2	108
Utilization-% of Theoretical	22.6	42.0	25.4	42.0
Separator Type	Daramic		Daramic	
Retainer Type	Glass Mat		Glass Mat	
Separator Thickness-cm	.102		.102	
Retainer Thickness-cm	.051		.051	
Total Separator Weight/Cell-kg	.159		.159	
Total Retainer Weight/Cell-kg	.047		.047	
Grand Total Weight/Cell-kg	.206		.206	
Electrolyte Specific Gravity	1.280		1.280	
Volume/Cell-cm ³	1950		1950	
Weight/Cell-kg	2.495		2.495	
Theoretical Capacity-AH	256		256	
Final Specific Gravity	1.139		1.127	
Length/Module-cm	26.37		26.37	
Width/Module-cm	18.14		18.14	
Height/Module-cm	27.00		27.00	
Individual Cell Weight-kg	7.82		7.98	
Connector and Terminal Weight-kg	.766		.766	
Container and Cover Weight-kg	1.17		1.17	
Total Module Weight-kg	25.4		25.9	
Energy Density-WH kg	32.0		33.1	
Capacity/Plate-AH	12.8	14.1	13.7	13.7
Total Rated Capacity-AH	141		150	

use of higher specific gravity forming acid. A test group of modules was formed in 1.120 specific gravity acid, and a control group was formed with 1.020 specific gravity acid following the standard procedure. The 1.120 acid was dumped and replaced with fresh acid at the end of formation; the 1.020 acid was dumped and replaced with fresh acid at the midpoint and end of formation. Although a teardown inspection after formation showed no discernable differences, the higher forming gravity was used in the remaining modules.

The performance level established for the First Generation ISOA design is presented in Table 3.1D.

Cycle life results were again adversely affected by cell construction problems which resulted in internal shorting. Cycle testing is being repeated for the First Generation ISOA design in a hand-fabricated module to accurately demonstrate performance. This module has completed 92 cycles to date and is still on test.

3.1.2 Second Generation ISOA Batteries

Three-cell modules of a Second Generation ISOA design were developed, and the representative units were shipped to the NBTL. This design (see Table 3.1C) featured: 1) A stronger positive grid and a more chemically resistant pasting tissue to alleviate the premature corrosion problem, 2) Revised element and module assembly procedures to eliminate the mechanical problems experienced before, and 3) An 11+/11- configuration with lower density positive plates for better capacity and energy density output.

Although the testing on Second Generation ISOA modules is not complete, the results are encouraging and none of the previously mentioned module construction problems have been encountered. The level of performance obtained is shown in Table 3.1D.

TABLE 3.1DPERFORMANCE LEVEL OF FISCAL 1980 ISOA BATTERIES

	<u>1st Generation</u>	<u>2nd Generation</u>
Energy Density, WH/kg (3 hr rate)	34 WH/kg	35 WH/kg
Power Density, W/kg (peak 15 sec)	-	116 W/kg
Cycle Life, 80% DOD cycles	150 cycles	155 cycles still on test

3.1.3 Third Generation ISOA Batteries

A third generation of ISOA modules is in the preliminary testing stage in the time period covered by this report. Initial capacity of 170 amp-hours and energy density of 37 WH/kg at the 3-hour rate and a peak power density of 128 W/kg have been obtained. These tests are continuing.

3.2 Advanced Development

The construction of full scale prototype Advanced cells began during this past year. Two shipments to the NBTL were required (designated First Generation Advanced, 5 cells needed, and Second Generation Advanced, 5 full modules needed). Additional cells and modules were required for in-house testing. These cells and modules were intended to demonstrate, in two stages, the best features of our research and development work toward meeting the ANL advanced goals. However, only advanced concepts with a high probability of success were employed to minimize the risk of possible deleterious side effects.

The advanced cell designs differ from the ISOA in several respects. The major design differences include a cast antimonial positive grid, no pasting tissue, a tight element pack, and totally manual assembly procedures. An elaboration of the First Generation Advanced and Second Generation Advanced design is given in Table 3.2A.

3.2.1 First Generation Advanced Batteries

The First Generation Advanced design was developed by drawing from the ISOA, the Experimental Development Modules (see Section 2.2), and ideas generated by program testing. The result was: 1) A proven long cycle life, cast Pb-Sb grid providing good utilization of positive

TABLE 3.2A

ADVANCED FISCAL 1980

MODULES SUBMITTED TO NBT

PLATES	2 FIRST-GENERATION		5 SECOND GENERATION	
	POSITIVE	NEGATIVE	POSITIVE	NEGATIVE
Number of plates	10	10	11	10
Height-cm	17.15	17.25	17.15	17.25
Width-cm	14.39	15.25	14.39	15.25
Grid Construction	Cast Sb	Expanded	Cast Sb	Expanded
Grid Thickness-cm	.152	.208	.152	.208
Grid Weight-kg	.98	.54	1.08	.53
Plate Thickness-cm	.260	.208	.260	.208
Paste Density-g/cm ³ dry	3.97	4.44	3.97	4.44
Paste Weight/Plate-kg dry	.233	.189	.234	.192
Total Paste Weight/Cell-kg dry	2.33	1.89	2.57	1.92
Total Plate Weight/Cell-kg dry	3.31	2.42	3.65	2.45
Active Material Capacity Density-AH/kg	73.4	90.5	75.9	102
Utilization-% of Theoretical	32.6	35.2	33.7	39.5
Separator Type	Daramic		Daramic	
Retainer Type	Glass Mat		Silver Glass	
Separator Thickness-cm	.127		.102	
Retainer Thickness-cm	.051		.051	
Total Separator Weight/cell-kg	.144		.144	
Total Retainer Weight/cell-kg	.047		.046	
Grand Total Weight/Cell-kg	.191		.190	
Electrolyte Specific Gravity	1.280		1.325	
Volume/Cell-cm ³	1950		1950	
Weight/Cell-kg	2.495		2.584	
Theoretical Capacity-AH	256		297	
Final Specific Gravity	1.109		1.130	
Length/Module-cm	26.37		26.37	
Width/Module-cm	18.14		18.14	
Height/Module-cm	27.00		27.00	
Individual Cell Weight-kg	8.42		8.87	
Container and Cover Weight-kg	1.17		1.17	
Connector and Terminal Weight-kg	.766		.766	
Total Module Weight-kg	27.2		28.5	
Energy Density-AH/kg	35.9		39.4	
Capacity/Plate -AH	17.1	17.1	17.7	19.5
Total Rated Capacity - AH	171		195	

active material; 2) A lightweight, low cost, Pb-Ca-Sn expanded grid negative plate providing good utilization and high energy density; 3) And deep ribbed enveloped separators to provide adequate mixing space to keep stratification of the 1.280 specific gravity acid to a minimum.

3.2.2 Second Generation Advanced Batteries

The Second Generation Advanced design was an extension of the First Generation, combining many of the best components from the Advanced Development Task with the design techniques used successfully in the ISOA Development Task. See Table 3.2A for details.

The electrical performance achieved was 13% better than First Generation. Cycle life performance was discovered to hinge upon forced circulation of electrolyte, however, because a subtle adjustment of the cell packing conditions had altered the mixing patterns within the cell. Prototype pumps were designed and retrofitted to correct this problem. Second Generation Advanced cells are still on test. Performance of the First and Second Generation Advanced designs are given in Table 3.2B.

3.2.3 Third Generation Advanced Batteries

A Third Generation Advanced series is currently under construction. An energy density of 41 WH/kg has been achieved, but better cycle life performance is still required. The mode of capacity degradation is now known for high energy density lead-acid cells, providing a firm basis for further improvement.

TABLE 3.2B

PERFORMANCE LEVEL OF FISCAL 1980 ADVANCED BATTERIES

	<u>1st Generation</u>	<u>2nd Generation</u>
Energy Density	37 WH/kg	41 WH/kg
Power Density	-	-
Cycle Life	210 cycles	165 cycles

3.3 Electric Vehicle Battery Demonstration

A four door converted Dodge Omni electric vehicle was purchased by C&D in the last quarter of FY-80 (Figure 3.3). The vehicle will have three major missions. It will be used in the company's daily operations to perform services within its intended capabilities. It will also serve as a test bed for electric vehicle batteries being developed under ANL's program. The test data obtained will supplement in-house testing by providing actual vehicle usage experience. Finally it will be employed as a public relations medium to publicly demonstrate the viability of electric vehicles as an alternative mode of transportation.

DODGE OMNI ELECTRIC VEHICLE

FIGURE 3.3

4.0 SUBSYSTEMS

During FY-79 considerable progress was made toward designing an explosionproof single point watering device. In designing this subsystem for E.V. applications, questions as to the complexity of the system and the economics of producing the device were foremost considerations. A system that depends on a lot of peripheral equipment and moving parts is most likely subject to high maintenance demands. Eltra's approach was to design a device that would meet the following requirements:

1. Ability of system to maintain the correct electrolyte levels within each cell by methods that require minimum consumer effort.
2. Safe venting of gases generated during normal operation and life.
3. Maintenance free systems- preferably no moving parts to cause premature failure.
4. Economically feasible to manufacture.

In addition, there are considerations for changes in climatic and environmental conditions. At present a prototype system is being evaluated for conformance to these requirements. It contains a central reservoir that feeds the individual cells by a network of connections. Each cell will fill to a predetermined level at which point an equilibrium between cell and fill pressure is established. This stops the filling action, allowing the fill water to continue on to successive cells. After all the cells are filled the excess water continues to flow through to an exit point until the reservoir is completely empty. (The only consumer requirement here is that the reservoir be periodically filled with water.) A prototype model of a single point watering concept has been constructed and the desired requirements have been satisfactorily demonstrated. A patent disclosure covering this invention is being filed. However, a method of incorporating the anti-flame propagation features without adversely affecting the efficient functioning of this device is still under development. The progress of this effort is encouraging and it is anticipated that this feature can be successfully incorporated into the watering device during the coming fiscal year.

5.0 PILOT LINE PRODUCTION OF EV BATTERY PROTOTYPES

The major assignment of Prestolite Batteries, which is Eltra Corporation's automotive division, was to design, install and commission a pilot line capable of producing

commercial quantities of electric vehicle battery modules. The concept envisioned was to translate the automatic manufacturing technique successfully employed by Eltra for the production of automotive batteries to the fabrication of electric vehicle modules. A detailed description of this process is presented in Eltra's FY-79 Annual Report (8). The pilot line's four major continuous operations are: 1) Expanding; 2) Pasting; 3) Drying; and 4) Parting of pasted strip into plates. The remainder of the pilot line, including separator enveloping of plates, stacking, cast on strap element connecting, through the partition resistance welding and final assembly operations are accomplished by manual or semi-automatic laboratory type equipment. Development of equipment to perform these functions automatically will be initiated when the EV design is finalized and when the market for EV batteries exceeds the lines present capabilities and the major capital expenditure required is warranted.

During FY-80 tooling changes and equipment modifications were made in some of these operations in order to overcome problems encountered during the line's start up period or to produce products which met the quality levels prescribed by the design specifications.

5.1 Expanding Line

Expanding is achieved by means of a reciprocating die punch that progressively notches and expands the material as it passes through the die set. The material is further processed by rolling and sizing to the desired dimensions. The process appears to be very straight forward; however, certain subtle conditions exist that determine the outcome of subsequent operations. The expanding line (Figure 5.1) has not undergone any major changes during this past year, although several minor modifications and refinements occurred due to the following experience gained during its initial period of operation.

5.1.1 Material Camber

If a section of strip lead is uncoiled and placed flat down with its edge against a straight line, the maximum distance from the line to the edge of the material determines the amount of camber per unit length of material. Most strip exhibits some camber; however, once a certain level is exceeded, processing is adversely affected. The presence of cambered material may cause problems in pasting and parting operations. The QA inspection of the lead

D.O.E. EXPANDING LINE

FIGURE 5.1

alloy strip obtained from the supplier was closely monitored.

5.1.2 Expanded Strip Sizing

During the sizing of expanded metal, the proper relationship between the expanded areas and the unexpanded center strip must be maintained if flat, uniform material is to be obtained. The ratio of change between these areas during sizing will determine if the finished material is wavy or flat. Excessive camber at this point will make it difficult to control these ratios.

The necessity of having uniform material from the expanding operation is realized at the pasting and parting stations. The physical constraints on the equipment and product alike do not allow for a wide margin of flexibility. Previously these parameters were not well defined; thus, at times it was difficult to ascertain the real problems. Once established, though, the mechanics of correcting for these discrepancies were, for the most part, academic.

5.2 Expanded Strip Pasting and Plate Parting Operations

In contrast to the expanding line, the pasting and plate parting equipment has changed considerably during the past year due to three major problems which were encountered. Two of them have been satisfactorily solved, the third requires some design engineering changes which have not yet been accomplished.

One problem was that the orifice type pasting machine installed in the initial line was found to be inadequate for maintenance of the specified pasting tolerances. It was replaced by a belt type paster.

A second problem was that of providing adequate means of keeping the expanded metal strip centered during the pasting and parting operations. This resulted in incompletely pasted strip and improperly cut plates. A center strip guiding system was incorporated into the pilot line whereby a rectangular guiding slot was punched in the solid center strip of the expanded material. These slots are engaged by guiding lugs which keep the expanded strip in registry during the pasting and parting operations. The guiding system was a major line change and required the addition of a hole punching machine, modifications to the parting machine, respective tooling for each, and the necess-

ary peripheral equipment to complete the line.

The changes in tooling and equipment (Figure 5.2a) to address these two problems resulted in significant improvements in several areas:

- 1) Satisfactory control of strip pasting thickness.
- 2) Reduced pasting machine down time due to mechanical failure by 70%.
- 3) Eliminated incomplete pasting of the expanded strip.
- 4) Provided positive control of pasted strip during the parting operation resulting in consistent plate top frame widths.
- 5) Decreased overall line scrap rate by about 80% (Figure 5.2b).

* MODIFICATIONS TO PILOT LINE
 ** ADDITIONS TO PILOT LINE

ORIGINAL PILOT LINE

REVISED PILOT LINE

FIGURE 5.2a

6.0 PROGRAM MANAGEMENT

6.1 Program Functional Organization

During FY-80 several changes on both the professional and technical level were made in Eltra's EV program personnel. The current organization chart for Eltra's Electric Vehicle Battery Program is shown in Figure 6.1. Pilot line personnel and professional staff members who perform specific technical tasks on a part time basis in support of the program are not included in this chart.

Eltra's Electric Vehicle Battery Program is a joint effort between its Prestolite (automotive) and C&D (Industrial) battery divisions. The Presidents of both these divisions now report to a Battery Group Vice President as the result of an Eltra Organization realignment during FY-80.

ORGANIZATIONAL CHART FOR ELECTRIC VEHICLE BATTERY PROGRAM

10/30/80

FIGURE 6.1

6.2 Future Program Plans

Eltra is approaching the development of a marketable lead-acid battery for electric vehicle propulsion with three general conceptual designs. These are being evaluated against three primary goals; cycle life, energy density, and cost. The overall plan is shown diagrammatically in Figure 6.2. The first alternative is the original single alloy expanded metal design where both the positive and negative electrodes are constructed with wrought Pb/Ca/Sn grids. Prototype modules based on this concept have the advantage of lower cost compared to units produced with cast grids. This lower cost accrues from an automated high rate production process, an environmentally clean production facility, and a reduced production area requirement. The performance advantage inherent in this design is low maintenance exhibiting less water loss, reduced self discharge, and the elimination of stibine or arsine problems potentially present with lead-antimonial alloys. Although good energy densities in the range of 36-41 WH/kg have been demonstrated, adequate cycle life has not been achieved. Many of the premature cycle failures can be attributed to prototype assembly problems understandably associated with a new pilot line/hand assembly operation. However, technical problems do exist and these are being addressed in the development program.

The second design concept being pursued is a dual alloy cast/expanded metal design with the objective of increasing cycle performance while maintaining the energy density level obtained in the original design. Here the positive electrode contains a low antimonial cast grid and the negative an expanded Pb-Ca-Sn grid. The evaluation of several variations of this design concept have been initiated and will be pursued with increased effort during FY-80. The trade-off options presented by this design are between an increase in cost, and a minimal increase in self-discharge and stibine/arsine for satisfactory energy density and adequate cycle life. Initial results with this design have been encouraging with energy densities of 41 WH/kg illustrated and cycle life exceeding that obtained with the original design.

The third design concept is a dual alloy expanded metal approach which incorporates lead antimonial positive grids and lead-calcium-tin negative grids, both fabricated by the expanded metal process. The objective of this design is to regain the processing cost advantages partially traded-off in the second design

ELTRA EV BATTERY DEVELOPMENT PROGRAM

FIGURE 6.2

approach while attaining acceptable battery performance. Prototypes of this design are presently being fabricated.

Results obtained from testing prototypes of cells and modules based on the three concepts will be evaluated to select the most favorable design for near term market entry. A parallel decision will be made on which of the remaining designs will continue to be included in the R&D program irrespective of the particular design selected for market entry.

Eltra's FY-81 battery development program will be focused on battery designs incorporating processing and component improvements generated from four major investigative areas: a) Improved active material utilization, b) Innovative electrode designs/Processing, c) Sub-Systems, d) Grid alloys and grid corrosion.

A series of calculations were made based on the first design and performance of the single alloy/expanded metal system to determine the increase in energy density that would be projected by successive decreases in grid and connector weights. These were compared to similar calculations assuming rather modest increases in active materials utilization. These comparisons clearly indicated that increasing the utilization of active materials presents the most potential for increasing energy density. Major emphasis will be devoted to this area during FY-81.

The development of innovative electrode designs and processing concepts for their commercial manufacture will also constitute an important investigative effort during FY-81. It is apparent from our calculations and experimental results to date that major departures from the initial ISOA design concept will be required to attain the advanced goals especially with respect to cycle life and energy density. Considerable effort will be expended during FY-81 to develop and evaluate innovative battery designs and configurations to realize those goals.

Sub-systems development of an explosion proof watering device will be continued during FY-81 as will development of an on board charger specifically designed for the lead-acid battery selected for commercial EV market introduction.

A major objective of the FY-81 program will be to substantially increase cycle life while retaining as a minimum requirement the energy density level we have

obtained to date. These studies will involve investigation of grid corrosion and the evaluation of different types of alloys.

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