292
6-16-84
MS
ANL/OEPM-81-9

ANL/OEPM-81-9

①
I-3799

MASTER

Dr. 622

**ANNUAL REPORT FOR 1981 ON
RESEARCH, DEVELOPMENT, AND DEMONSTRATION
OF LEAD-ACID BATTERIES FOR
ELECTRIC-VEHICLE PROPULSION**

Contract No. 31-109-38-4207

by

Exide Management and Technology Company

ARGONNE NATIONAL LABORATORY, ARGONNE, ILLINOIS

**Operated for the U. S. DEPARTMENT OF ENERGY
under Contract W-31-109-Eng-38**

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

The facilities of Argonne National Laboratory are owned by the United States Government. Under the terms of a contract (W-31-109-Eng-38) among the U. S. Department of Energy, Argonne Universities Association and The University of Chicago, the University employs the staff and operates the Laboratory in accordance with policies and programs formulated, approved and reviewed by the Association.

MEMBERS OF ARGONNE UNIVERSITIES ASSOCIATION

The University of Arizona	The University of Kansas	The Ohio State University
Carnegie-Mellon University	Kansas State University	Ohio University
Case Western Reserve University	Loyola University of Chicago	The Pennsylvania State University
The University of Chicago	Marquette University	Purdue University
University of Cincinnati	The University of Michigan	Saint Louis University
Illinois Institute of Technology	Michigan State University	Southern Illinois University
University of Illinois	University of Minnesota	The University of Texas at Austin
Indiana University	University of Missouri	Washington University
The University of Iowa	Northwestern University	Wayne State University
Iowa State University	University of Notre Dame	The University of Wisconsin-Madison

NOTICE

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

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: A06
Microfiche copy: A01

ANL/OEPM-81-9

ANL/OEPM--81-9

DE82 016225

Annual Report for 1981 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. 31-109-38-4207

by
Exide Management and Technology Company
Yardley, Pennsylvania

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

March 1982

ACKNOWLEDGEMENTS

The annual report was prepared by the ANL-EV Project Team at the Exide Management and Technology Company. Work as performed and reported herein was by:

Mr. H. A. Fuggiti

Mr. D. L. Beals

Mr. C. H. Carr

Mr. C. J. Daly

Mr. R. V. Hight

Ms. D. E. Jefferies

Dr. I. S. Klein

Mr. J. B. Ockerman

Ms. L. M. Reddell

Mr. A. J. Ragolia

Mr. W. N. Sonneborn

In addition, the contributions and efforts of our associates at the various Exide facilities made much of this work possible.

TABLE OF CONTENTS

	<u>PAGE</u>
ACKNOWLEDGEMENTS-----	ii
LIST OF TABLES-----	iv
LIST OF FIGURES-----	v
LIST OF PHOTOGRAPHS-----	vi
1.0 EXECUTIVE SUMMARY-----	1
1.0.1 ISOA Lead Acid Battery Development-----	1
1.0.2 Advanced Lead Acid Battery Development-----	1
1.0.3 Battery Subsystems-----	2
1.1 FP-2 PHASE-----	3
1.2 BATTELLE COLUMBUS SUBCONTRACT 31-109-38-4207-ESB-2-----	7
1.3 TP-1 -----	9
1.3.1 Testing - Characteristics-----	13
1.3.2 Lift Test-----	21
1.3.3 Work Performed Since Last Annual Report-----	27
1.3.4 Postmortem Inspection Results-----	31
1.3.5 TP-1B Phase-----	33
1.4 TP-2 BATTERY DESIGN-----	35
1.5 ADVANCED LEAD ACID BATTERY-----	37
1.5.1 Introduction-----	37
1.5.2 Negative-----	37
1.5.3 Positive-----	67
1.5.4 Electrolyte Circulation-----	74
1.5.5 Conclusions and Accomplishments-----	84
REFERENCES-----	87

LIST OF TABLES

<u>TABLE</u>		<u>PAGE</u>
1-4	TP-1 Positive & Negative Group Wts & Millivolt Drop Test Results-----	16
5-7	TP-1 Characteristics Test Results-----	23
8	Charge Acceptance vs. Temperature & Charge Acceptance vs. Rate of Charge-----	26
9-10	TP-1 Battery Life Cycle Test Status-----	28
11	TP-1 Battery Life Cycle Test Status-----	30
12	TP-1 - Post Life Cycle Inspection Summary-----	32
13	Properties of Grid Materials-----	38
14	Positive Tubular Construction Coupled with Negatives Containing Lightweight Advanced Grids-----	41
15	Construction of Cell TP23 (Type A Negative Grid, EV Size)-----	43
16	The Resistance of Lead Acid Grids-----	49
17	Construction of Cell AEX6 (Type B Negative Grid)-----	52
18	Construction Details for Batteries AEX7A-AEX12A (Type C Negative Grid)-----	62
19	Typical Electrode Voltages vs Cadmium-----	63
20	Construction Details for Battery 1507-11-----	71
21	The Effect of Electrolyte Circulation During Charge on Cell Performance-----	77
22	Decreased Charge Efficiency with Air Bubbling-----	77
23	Construction of Batteries 1507-12, 1507-13-----	79

LIST OF FIGURES

<u>FIGURE NO.</u>		<u>PAGE</u>
1	Advanced Negative Grid, Radial Rib, Type A Construction-----	39
2	Advanced Negative Grid - Lead Lug Insert-----	40
3	Advanced EV Battery - Negative Grid (Unplated) - Type A Construction-----	42
4	Discharge Behavior of TP-23 (Tubular Pos, Electroplated ABS + Lead Lug Insert Neg.)-----	45
5	Discharge Behavior of AEX16 (Tubular Pos., Electroplated ABS + Lead Lug Insert Neg.)-----	47
6	Advanced EV Battery - Negative Grid - Type B Construction-----	50
7	Advanced EV Battery - Negative Grid - Type B Construction-----	51
8	Cured Pasted Plate - Negative Grid - Type B Construction-----	53
9	Formed Pasted Plate - Negative Grid - Type B Construction-----	54
10	Discharge Behavior of AEX-6 (Flat Plate Pos., Electroformed Neg.)-----	57
11	Discharge Behavior of TP-24 (Tubular Pos., Electroformed Neg.)-----	58
12	Type C - Lightweight Negative Grid-----	61
13	Overvoltage of Hydrogen vs. Current-----	64
14	Discharge Behavior of TP35 (Tubular Pos., Unplated Expanded Copper Neg.)-----	66
15	Type D Negative Grid-----	68
16	Discharge Behavior of 1507-11 (Flat Plate Electrodes Stranmat Retainer)-----	73
17	The Effect of Bubbling Air on Cell Performance-----	76
18	Air Bubbling Schematic for Electrolyte Circulation-----	78
19	Discharge Behavior of TP-25 (Tubular Pos., Electroformed Neg.)-----	80

LIST OF FIGURES (Continued)

<u>FIGURE NO.</u>		<u>PAGE</u>
20	Diagram of "Air-Lift" Pump-----	83
21	Discharge Behavior of 1507 - TP-29 (Tubular Positive, Plastic Neg.)-----	85

LIST OF PHOTOGRAPHS

<u>PHOTOGRAPH NO.</u>		<u>PAGE</u>
1	Cladex Tubing -----	10
2	TP-1 Positive Spine, Bottom Bar and Plate -----	11
3	TP-1 Rubber Ribbed Separator-----	12
4	TP-1 Plastic Ribbed Envelope and Ribbed Sheet-----	14
5	TP-1 Containers Standard and Low Sediment Ribs-----	15

1.0 EXECUTIVE SUMMARY

1.0.1 ISOA Lead-Acid Battery Development

The factorial experiment designed to study the interrelationship of 32 component variables based on a tubular positive plate configuration (TP-1) continues on test. Of the 96 modules tested, 19 remain on cycle life testing. Six modules have 420 total cycles, 12 modules are at 400 cycles and one module is at 680 life cycles. For the module designs that have exceeded 600 cycles, energy densities have ranged from 31 to 33 Wh/kg. The best performance module has displayed an energy density of 37.0 Wh/kg and is retaining 76% of its maximum capacity after 420 cycles in ongoing tests.

The redesign of a module with tubular positive plates having improved energy density (TP-2) was completed. All equipment and components are now on hand for assembly of prototype units. It is expected that these units will provide 40 Whr/kg and a cycle life in excess of 800 cycles.

A redesign of the module with flat pasted positive electrodes was completed. Prototype units were built and are under test. These units contain a radial type grid configuration coupled with a more dense positive active material. The best performing module displayed an energy density of 37.8 Wh/kg and is retaining 86% of its maximum capacity after 196 cycles in ongoing tests.

The work done on novel grid designs under a subcontract with Battelle Columbus Laboratories was reported in full in the Exide Annual Report for 1980 on Research, Development and Demonstration of Lead-Acid Batteries for Electric Vehicle Propulsion, Argonne Report ANL/OEPM-80-11, March 1981. Modules are now on test to provide a comparison of the Exide radial and orthogonal grids vs. the grid design developed by Battelle. There is not sufficient data available at this time to draw any conclusions from this test.

1.0.2 Advanced Lead-Acid Battery Development

Advanced cell designs have displayed the following results for various positive electrode constructions:

- a) Tubular - Life in excess of 600 cycles at 80% depth of discharge or greater at the 3-hr rate has been obtained. Positive active material utilization was approximately 33-35% resulting in a battery energy density of 36-38 Whr/kg.
- b) Flat Plate - Life was up to 300 cycles at 80% depth of discharge and at the 3-hr rate. Positive active material utilization was 35-37% resulting in a battery energy density of 38-40 Whr/kg.
- c) Stranmat Retainer - Combining the use of this retainer with flat plate electrodes increased battery life up to 400 cycles or 33% more than with the conventional flat plate construction. However, positive active material utilization was reduced to 35% and the battery energy density to 35 Whr/kg at the three hour rate.

Four unique substrate structures for use in the negative electrode have been developed and tested. Each has contributed to a reduction in the weight of the module and all indications to date show that there is no detrimental effect on capacity and cycle life.

1.0.3 Battery Subsystems

Two methods of mechanical agitation of the electrolyte were tested - air bubbling and an air lift pump.

- a) Air Bubbling - Pumping air through the cell during charge did not significantly increase life. This conclusion applied independent of the positive group construction. During the early stages of cell cycling, air bubbling did permit a reduction in the electrochemical overcharge needed to insure a fully charged condition. However, beyond 150 cycles, normal overcharge was required to maintain cell capacity. It was concluded that the benefits of air bubbling were marginal and the cost involved would not warrant its use in EV applications.
- b) Air Life Pump - It is still premature to reach any definite conclusions regarding the effectiveness of using this device to pump electrolyte during charge. More cycling is needed.

1.1 FP-2 PHASE

Based on an analysis of data and the conclusion of the FP-1 factorial experiment, as reported in the "Exide Annual Report for 1980 on Research, Development and Demonstration of Lead-Acid Batteries for Electric Vehicle Propulsion," Argonne Report ANL/OEPM-80-11, March 1981, the second generation FP-2 battery was designed and fabricated.

- o Standard positive paste - the additive to the positive active material of thin plates improved the initial capacity during characteristics tests but did not retain the active material during life cycles.
- o Microporous polyethylene separators with .25mm glass mat.
- o 1.285 specific gravity electrolyte

It was found in automotive size grids that grids of radial design were more efficient current collectors.

Radial grids are designed at Exide by computer by the convergence method using Kirchoff's Law. Convergence is achieved by iteration and relaxation.

The radial design reduces internal resistance thereby increasing voltage. This is most noticeable at high discharge rates such as during acceleration in an electric vehicle.

The internal resistance of a grid is influenced by the following:

- o Grid thickness
- o The height to width ratio
- o Lug location

Two radial grids were designed. A positive identified as 1 EVR and a negative identified as 2 EVR. Molds to fit our production type casting machines were purchased for both types.

The 1 EVR grids were cast in 6% Sb-Pb alloy and pasted with Exide's high density paste formula. The 2 EVR grids were cast in Ca-Pb alloy and pasted with a negative paste formula containing an organic expander.

Initially three separator systems are being tested in FP-2 batteries. The EBS numbers and their separator systems are listed below:

<u>EBS NO.</u>	<u>SEPARATOR SYSTEM</u>
5924	1.40mm Polyethylene sheet separator and .25mm glass mat.
5925	.94mm Polyethylene sheet separator and .25mm Stranmat.
5926	.94mm Polyethylene envelope on the negative plate and .25mm Stranmat against the positive plate.

Seven batteries were built per EBS 5924, five per EBS 5925 and three per EBS 5926.

All batteries were discharged at 58 amperes.

The best performing battery of EBS 5924 gave 32.29 WH/Kg at cycle 2, 37.79 WH/Kg at 49 cycles and 36.31 WH/Kg at 70 cycles.

The best performing battery of EBS 5925 gave 28.48 WH/Kg at cycle 2, 34.38 WH/Kg at cycle 14 and 34.22 WH/Kg at 70 cycles.

EBS 5926 batteries were the poorest performers. The best cycle life was 129 cycles with energy densities of 28.02 WH/Kg at cycle 2, and 29.29 WH/Kg at 14 cycles.

EBS 5925 batteries did not perform as well as EBS 5924 batteries. The difference between the two being Stranmat retainers. EBS 5926 batteries contained envelopes as well as Stranmat. The Stranmat evidently retards electrolyte circulation and the envelopes compound the problem.

Listed below are the EBS 5924 and 5925 battery serial numbers and their specific energies from the latest available catchout data.

<u>EBS/SER. NO.</u>	<u>Cycle Status</u> <u>7/31/81</u>	<u>Latest Catchout Data</u> <u>Cycle</u>	<u>WH/Kg</u>
5924/001	130	102	31.64
2	130	102	31.73
3	194	166	31.07
4	196	168	32.46
6	196	168	31.57
7	196	168	31.77
5925/001	130	102	31.31
2	130	102	28.79
3	196	168	31.70
4	196	168	31.26
5	196	168	32.44

Additional modules were built with a reduced diameter through-the-partition weld and the internal top lead was milled to reduce the module weight. In place of the previously used 1/2" diameter weld, welds of 3/8" and 7/16" were used.

The weight saving was approximately 0.5 Kg per module, however, the weight of the radial grids was above specification resulting in no weight reduction for the finished modules. These grid molds will require revision should additional modules be built.

There is also a concern that these grids designed using proven techniques of automotive starting batteries may not be optimum for electric vehicle service. In automotive batteries the battery is subjected to a floating type of service rather than the deep discharge cycle characteristic of electric vehicle applications.

The 1 EVR positive radial grid has 30 horizontal members with the seventh, fifteenth and twenty-third member heavier than the other 27. We have seen some evidence that there may be unequal growth of the grid members on either side of the three heavy members with the grid attempting to assume a shape similar to a sine wave.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

1.2 BATTELLE COLUMBUS SUB CONTRACT 31-109-38-4207-ESB-2

A complete report of the work done was reported in the Exide Annual Report for 1980 on Research, Development and Demonstration of Lead-Acid Batteries for Electric Vehicle Propulsion, Argonne Report ANL/OEPM-80-11, March 1981.

The grids produced from the mold designed and fabricated by Battelle were pasted then assembled into 3 cell modules to compare this design with the Exide radial and the older orthogonal design. Included in the experiment was positive active material having tetrabasic lead sulfate as the lead component and two types of organic expanders in the negative mix.

The batteries are presently undergoing characteristics testing and are then scheduled for cycle life testing.

Serial No.	Positives		Negative		
	Grid Type	Oxide	Grid Type	Oxide	Expander
58	Battelle	Tetrabase	2 EVR*	GOX	5212
59	Battelle	Tetrabase	4 GW**	GOX	4640
60	1 EVR*	GOX	2 EVR*	GOX	5212
61	1 EVR*	GOX	4 GW**	GOX	4640
67	Battelle	GOX	Battelle	GOX	5215
68	Battelle	GOX	Battelle	GOX	5215
69	Battelle	GOX	2 EVR*	GOX	5215
70	Battelle	GOX	4 GW**	GOX	5215
71	1 EVR*	GOX	Battelle	GOX	5215
72	2 GW**	GOX	Battelle	GOX	5215

* Exide Radial Design

** Exide Orthogonal

The separator system was Daramic and glass mat in every battery.

By 31 August 1981 the batteries will have approximately 33 life cycles at 58 amperes of discharge.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

1.3 TP-1

Deep cycle service has proven the superiority of tubular positive plates. Exide's standard tubing configurations are 8mm square or round. Power requirements of the ISOA program dictate a rectangular tube shape rather than square or round. Through innovative filling techniques and corrosion resistant alloys for the grid, a positive plate was developed to meet the peak load requirements of this contract, while maintaining the deep cycle capabilities of this design.

Thirty-two battery configurations were designed for the TP-1 factorial experiment. They are:

- o Four positive plates
- o Two separators
- o Two electrolyte specific gravities
- o Two acid volumes above the plates.

Thirty-two Experimental Battery Specifications (EBS 5809- to 5840) were prepared. Copies were included in the Second Annual Report for FY '79 dated September 1979 (Proprietary Version).

Two types of braided glass tubing were manufactured by our supplier. A "standard" braid as is used in industrial battery application and a lighter braid made with fewer strands of glass than the standard in order to improve the diffusion of electrolyte to the active material.

The "standard" tubes were shaped and set with phenolic resin and given two post-shaping applications of phenolic resin. The lighter tubes were only shaped and set with no additional phenolic applications. See Photograph No. 1 "CLADDEX Tubing".

A production injection grid mold was designed and grids were cast in 9 percent SbPb alloy at Exide's Sumter, S.C. factory. See Photograph No. 2 "TP-1 Positive Spine, Bottom Bar and Plate.

Bottom bars were molded in four colors to identify the four types of positive plates. See Photograph No. 2.

The above components and Pb_3O_4 were sent to Exide's facility in Trenton, N.J. Two methods of filling the positive plates with Pb_3O_4 were tried; one was successful. About 1,250 of each of the positive plates were filled. The plate part numbers and their characteristics are shown below:

<u>Plt. No.</u>	<u>Tube</u>	<u>A.M. Fill Wt. Gms.</u>	<u>Bottom Bar Color</u>
85617	Standard	210-220	Black
85195	Light	210-220	Natural (White)
85618	Standard	240-250	Beige
85616	Light	240-250	Red

Two 1.0mm (.040") thick separators were selected; one was ribbed microporous rubber and the other ribbed microporous polyethylene envelopes. See Photograph No. 3 "TP-1 Rubber Ribbed Separator".

4MM X 14MM
LIGHT WEIGHT
CLADEX
TUBING

4MM X 14MM
STANDARD
CLADEX
TUBING

8MM SQUARE
CLADEX
TUBING

PHOTO NO. 1

PHOTO NO. 2

TP-1 POSITIVE SPINE

TP-1 BOTTOM BAR

TP-1 POSITIVE PLATE

TP-1 RUBBER RIBBED SEPARATOR

PHOTO NO. 3

The envelopes were made by thermo-welding a sheet approximately 343mm long by 168mm wide to 171mm by 168mm. See Photograph No. 4 "TP-1 Plastic Ribbed Envelope and Ribbed Sheet".

The two electrolyte gravities were 1.285 and 1.315.

In one half of the modules, the acid volume above the plates is standard. In the other half, acid volume is higher than standard. This was achieved by reducing the height of the sediment ribs in the bottom of the container from about 16mm to 6.3mm. See Photograph No. 5 "TP-1 Containers Standard and Low Sediment Ribs".

The TP-1 battery has 3 cells each of which consists of 21 plates; 10 positives and 11 negatives.

All of the plates that went into the TP-1 batteries were weighed in groups of 10 positives and 11 negatives and the weights recorded.

The plates and separators (or envelopes) were assembled into elements. The positive and negative plates were welded into their respective groups in the cast-on-strap (COS) machine. As the elements were removed from COS machine, they were put into containers and their EBS numbers were stamped on the negative strap. As this was done, the weights of the groups and their assigned EBS and Serial Numbers were recorded. The battery containers were also labeled with the EBS and Serial Numbers.

The elements were then resistance welded through a hole in the intercell partition of the container. In the industry, this is called through-the-partition construction and is abbreviated TTP. After welding, each weld was given a millivolt drop test at 200 amperes to check weld quality. The resistance values averaged less than 2 micro ohms.

The lists of the positive and negative group weights, EBS numbers and Serial Numbers and millivolt drop are shown in Tables 1 through 4.

1.3.1 Testing - Characteristics

The characteristics testing regime is as follows:

<u>Cycle</u>	<u>Discharge Rate</u>		<u>Ambient</u>	<u>Test</u>
	<u>Amps</u>	<u>Hours</u>	<u>Temperature °C</u>	
1	40	5	25	Initial Performance
2	60	3	25	" "
3	75	2	25	" "
4	140	1	25	" "
5	10	20	25	" "
6	240	.5	25	" "
7	40	5	0	Low Temperature Performance
8	60	3	0	" " "
9	75	2	0	" " "
10	140	1	0	" " "

TF-1 PLASTIC RIBBED ENVELOPE

PHOTO NO. 4

TP-1 PLASTIC RIBBED SHEET
BEFORE HEAT SEALING INTO
AN ENVELOPE

PHOTO NO. 5

TABLE 1

TP-1 POSITIVE & NEGATIVE GROUP WTS & MILLIVOLT DROP TEST RESULTS

EBS No.	Ser. No.	Plate Part No.	Pos. Group Weights				Neg. Group Weights				Welds Millivolts Drop Test at 200 A		
			Pos.	Cells Gms	Neg.		Pos.	Cells Gms	Neg.				
5809	097	85617		3586	3580	3572		2632	2675	2669		0.9	0.8
"	098	"		3584	3612	3631		2618	2639	2669		1.0	1.1
"	099	"		3573	3600	3601		2701	2637	2655		1.1	1.4
"	100	"		3606	3565	3587		2652	2659	2670		1.1	1.0
5810	101	"		3669	3613	3554		2585	2576	2551		1.4	1.2
"	102	"		3527	3597	3593		2566	2544	2544		1.4	1.3
"	103	"		3567	3669	3679		2546	2546	2574		1.2	0.9
"	104	"		3621	3692	3607		2567	2594	2570		1.1	0.9
5811	105	"		3614	3545	3603		2593	2549	2591		1.0	1.2
"	106	"		3577	3554	3565		2591	2535	2573		0.9	1.0
"	107	"		3581	3613	3581		2589	2588	2595		0.9	0.7
"	108	"		3574	3641	3704		2591	2539	2605		1.0	1.2
5812	109	"		3585	3548	3598		2540	2576	2582		1.0	1.3
"	110	"		3578	3588	3647		2567	2536	2576		0.9	1.1
"	111	"		3574	3656	3518		2561	2590	2584		0.9	1.1
"	112	"		3558	3562	3553		2553	2590	2586		0.9	1.0
5813	113	85195		3644	3760	3741		2607	2684	2636		2.6	1.1
"	114	"		3701	3695	3737		2646	2664	2647		1.2	1.3
"	115	"		3745	3735	3728		2641	2628	2640		0.8	1.0
"	116	"		3629	3760	3747		2648	2639	2650		1.4	1.0
5814	117	"		3706	3724	3736		2592	2516	2540		0.9	1.1
"	118	"		3779	3771	3703		2539	2510	2526		0.9	1.1
"	119	"		3747	3745	3680		2589	2535	2575		1.0	1.1
"	120	"		3690	3709	3703		2539	2537	2529		1.0	1.1
5815	121	"		3725	3699	3727		2653	2698	2662		0.8	1.1
"	122	"		3721	3699	3726		2649	2656	2650		1.6	1.3
"	123	"		3711	3665	3719		2653	2613	2614			
"	124	"		3737	3669	3733		2616	2632	2636		1.1	0.9
5816	125	"		3600	3793	3659		2579	2532	2529		0.9	1.1
"	126	"		3733	3744	3702		2537	2550	2551		1.6	5.3
"	127	"		3700	3712	3644		2566	2521	2535		1.0	1.3
"	128	"		3717	3724	3702		2537	2542	2538		1.1	0.9
Avg. Wt. of 10 Positive Assemblies (Spines, Tubes & Bott. Bar) =												1,340 gm	
Avg. Wt. of 11 Negative Grids =												792 gm	

TABLE 2

TP-1 POSITIVE & NEGATIVE GROUP WTS & MILLIVOLT DROP TEST RESULTS

EBS No.	Ser. No.	Plate Part No.	Pos. Group Weights			Neg. Group Weights			Welds Drop Test at 200 A	Millivolt
			Pos.	Cells Cen.	Neg.	Pos.	Cells Cen.	Neg.		
5817	129	85618	3840	3821	3830	2663	2654	2653	0.9	1.1
"	130	"	3930	3854	3870	2673	2657	2670	1.1	0.9
"	131	"	3796	3899	3824	2672	2691	2666	1.0	0.9
"	132	"	3845	3913	3877	2643	2678	2628	1.1	0.9
5818	133	"	3833	3891	3828	2540	2554	2538	1.1	1.2
"	134	"	3935	3802	3877	2624	2617	2616	1.3	1.2
"	135	"	3805	3919	3869	2552	2545	2539	1.1	1.2
"	136	"	3939	3782	3821	2523	2520	2589	1.1	1.3
5819	137	"	3836	3817	3796	2639	2660	2629	1.2	1.3
"	138	"	3865	3820	3899	2657	2662	2653	1.6	0.9
"	139	"	3860	3831	3859	2655	2677	2665	1.2	0.9
"	140	"	3790	3842	3811	2665	2668	2634	1.2	1.0
5820	141	"	3902	3780	3792	2593	2612	2594	1.4	0.9
"	142	"	3778	3796	3868	2611	2609	2582	1.3	1.4
"	143	"	3834	3790	3745	2597	2589	2612	1.0	1.3
"	144	"	3853	3841	3784	2602	2619	2613	1.3	1.1
5821	145	85616	3864	3873	3862	2592	2551	2562	0.8	1.1
"	146	"	3892	3913	3858	2534	2546	2533	0.9	1.0
"	147	"	3905	3827	3872	2590	2543	2517	1.1	0.9
"	148	"	3924	3844	3853	2608	2591	2552	1.2	0.9
5822	149	"	3868	3909	3842	2590	2578	2585	1.4	1.2
"	150	"	3899	3941	3875	2590	2580	2605	1.1	1.3
"	151	"	3884	3854	3884	2602	2588	2590	1.7	1.6
"	152	"	3859	3909	3833	2570	2586	2582	1.2	1.1
5823	153	"	3877	3946	3922	2516	2583	2510	1.2	1.1
"	154	"	3870	3855	3860	2553	2583	2575	1.3	0.9
"	155	"	3936	3856	3849	2537	2516	2565	1.0	1.1
"	156	"	3926	3911	3891	2588	2592	2585	1.1	0.9
5824	157	"	3857	3886	3878	2590	2572	2580	1.0	1.9
"	158	"	3885	3888	3838	2608	2578	2566	1.0	2.0
"	159	"	3907	3822	3832	2578	2571	2580	1.2	1.4
"	160	"	3909	3872	3883	2600	2609	2540	1.3	1.4
Avg. Wt. of 10 Positive Assemblies (spines, tubes & bott bars)=			1,340 gm.							
Avg. Wt. of 11 Negative Grids=			792 gm.							

TABLE 3

TP-1 POSITIVE & NEGATIVE GROUP WTS & MILLIVOLT DROP TEST RESULTS

EBS No.	Ser. No.	Plate Part No.		Pos. Group Weights				Neg. Group Weights				Welds Millivolt Drop Test at 200 A	
				Pos.	Gms Cells Cen.	Weights Neg.		Pos.	Gms Cells Cen.	Weights Neg.			
5825	161	85617		3609	3586	3536		2604	2585	2581		1.1	1.3
"	162	"		3660	3520	3550		2600	2603	2668		1.3	1.1
"	163	"		3688	3708	3633		2589	2590	2666		1.3	1.1
"	164	"		3645	3648	3557		2576	2578	2588		1.1	1.4
5826	165	"		3627	3578	3556		2568	2602	2571		1.3	1.1
"	166	"		3641	3607	3650		2602	2601	2608		1.3	1.1
"	167	"		3624	3556	3535		2598	2577	2578		1.3	1.1
"	168	"		3574	3522	3544		2582	2608	2591		1.4	1.2
5827	169	"		3645	3647	3614		2607	2595	2586		1.1	1.6
"	170	"		3553	3584	3616		2565	2605	2571		1.2	1.5
"	171	"		3574	3551	3630		2591	2595	2582		1.3	1.6
"	172	"		3659	3616	3629		2614	2605	2556		1.1	1.4
5828	173	"		3614	3640	3600		2566	2614	2572		1.3	1.2
"	174	"		3636	3557	3636		2587	2583	2601		1.2	1.6
"	175	"		3617	3640	3608		2606	2566	2575		1.1	0.9
"	176	"		3618	3576	3594		2570	2569	2593		0.8	1.1
5829	177	85195		3795	3670	3710		2588	2593	2585		1.4	1.1
"	178	"		3672	3622	3732		2600	2572	2597		1.1	1.4
"	179	"		3717	3730	3720		2554	2591	2510		1.4	1.1
"	180	"		3609	3641	3654		2520	2606	2615		1.2	1.1
5830	181	"		3687	3749	3692		2609	2593	2569		0.8	0.9
"	182	"		3696	3743	3733		2757	2602	2600		1.3	1.2
"	183	"		3730	3675	3649		2539	2600	2615		0.9	1.1
"	184	"		3740	3739	3706		2717	2617	2615		0.9	1.1
5831	185	"		3736	3743	3658		2606	2583	2621		1.1	1.3
"	186	"		3700	3696	3641		2630	2609	2613		1.3	1.2
"	187	"		3669	3658	3772		2611	2591	2611		1.1	1.6
"	188	"		3619	3716	3630		2609	2614	2615		1.3	1.0
"	189	"		3690	3687	3637		2732	2695	2554		1.5	1.2
5832	190	"		3707	3664	3691		2612	2691	2630		1.0	0.9
"	191	"		3730	3701	3741		2598	2667	2604		0.9	1.2
"	192	"		3641	3695	3670		2722	2712	2531		1.3	1.5
Avg. Wt. of 10 Positive Assemblies (spines, tubes & bott. bar)=				1.340 gm.									
Avg. Wt. of 11 Negative Grids=				792 gm.									

TP-1 POSITIVE & NEGATIVE GROUP WTS & MILLIVOLT DROP TEST RESULTS

-19-

<u>Cycle</u>	<u>Discharge Rate</u> <u>Amps</u>	<u>Rate</u> <u>Hours</u>	<u>Ambient</u> <u>Temperature °C</u>	<u>Test</u> <u>Standards</u>
11	240	.5	0	Low Temperature Performance
12	40	5	40	High " "
13	60	3	40	" " "
14	75	2	40	" " "
15	140	1	40	" " "
16	240	.5	40	" " "

Charging for the first 16 cycles was done in two steps - a high-rate mode and a low-rate mode. The high-rate mode is 40 amperes until 90% of the discharge capacity is returned. The low-rate mode is 5 amperes until a total of 115% of the discharged capacity is reached.

The discharge rate for all of the following cycles is 60 amperes (3 hr) at 25°C.

<u>Cycle</u>	<u>Charge Method</u>	<u>Test Standards</u>
17	As in cycles 1-16	Charge Acceptance vs Temperature
18	40A to onset of gassing at 25°C	Charge Acceptance vs Temperature
19	As in cycles 1-16	Charge Acceptance vs Temperature
20	40A to onset of gassing at 0°C	Charge Acceptance vs Temperature
21	As in cycles 1-16	Charge Acceptance vs Temperature
22	140A to onset of gassing at 25°C	Charge Acceptance vs Charge Rate
23	40A to 2.35v/cell maintained for 4 hrs	Special Charging Tests
24	Same as cycle 23	" " "
25	" " " "	" " "
26	" " " "	" " "
27	As in cycles 1-16	" " "
28	" " " "	" " "

<u>Cycle</u>	<u>Charge Method</u>	<u>Test Standards</u>
29	After a 2 week stand on open circuit fully charged	Charge Retention Test
30	As in cycles 1-16	

1.3.2 Life Test

The life test is a 2.4 (80% of 3 hours) hour constant current discharge at the 3 hour rate followed by a two step recharge. The first step is the high rate (40A) until the voltage reads 2.35 volts per cell followed by the low rate (9A) until approximately 120% of the discharge is returned.

The life testing equipment consists of three systems I, II, and III. Each system contains 8 loops. Loops 1 through 7 will accept 8 batteries each while loop 8 will accept 6 batteries.

Lot 6 was given the life cycle testing without experiencing the characteristics testing. A sixteen hour cycle was started per the following parameters:

	<u>Dischg</u>	<u>Stabilization</u>	<u>Hi Chg</u>	<u>Lo Chg</u>	<u>Stabilization</u>
Hours	2.4	1.85	3.9	6.0	1.85
Voltage Limit	1.7		2.35	None	

Lot 6 was put into system III on 8/31/79 on loops 1 through 4. The discharge and charge rates were as follows:

<u>Loop No.</u>	<u>Sp. Gr.</u>	<u>Discharge</u>	<u>Hi Chg</u>	<u>Low Chg</u>	<u>Total Chg</u>	<u>% Overchg</u>
1	1.285	60A (144AH)	29.8A(116AH)	9A(54AH)	170AH	18
2	1.315	58A (139AH)	28.5A(111AH)	8.7(52AH)	163AH	17
3	1.285	59A (142AH)	29.0A(113AH)	8.4A(50AH)	163AH	15
4	1.315	59A (142AH)	29.0A(113AH)	10.0A(60AH)	173AH	22

On 9/4/79 at cycle 6 the testing regime was changed because the batteries were not accepting 80% of the discharged ampere hours before reaching the 2.35 volts per cell limit. The cycle time was extended to 18 hours. The timing and the rate changes are shown below:

	<u>Dischg</u>	<u>Stabilization</u>	<u>Hi Chg</u>	<u>Lo Chg</u>	<u>Stabilization</u>
Hours	2.4	1.85	5.9	6.0	1.85
Voltage Limit	1.7		2.35	None	

<u>Loop No.</u>	<u>Discharge</u>	<u>Hi Chg</u>	<u>Low Chg</u>	<u>Total Chg</u>	<u>% Overchg</u>
1	60A(144AH)	19.7A(116AH)	9A(52AH)	170AH	18
2	58A(139AH)	18.8A(111AH)	8.7A(52AH)	163AH	17
3	59A(142AH)	19.3A(113AH)	8.4A(50AH)	163AH	15
4	59A(142AH)	19.3A(113AH)	10.0A(60AH)	173AH	22

On 9/12/79 at cycle 18 the regime was changed again because the batteries were still not accepting 80% of the discharge amperes before reaching 2.35 volts. The timing and rate changes are shown below:

	<u>Dischg</u>	<u>Stabilization</u>	<u>Hi Chg</u>	<u>Lo Chg</u>	<u>Stabilization</u>
Hours	2.4	1.35	5.9	7.0	1.35
Voltage Limit	1.7		2.35		
<u>Loop No.</u>	<u>Discharge</u>	<u>Hi Chg</u>	<u>Low Chg</u>	<u>Total Chg</u>	<u>% Overchg</u>
1	60A(144AH)	17.1A(101AH)	9.9A(69AH)	170AH	18
2	58A(139AH)	16.5A(97AH)	9.4A(66AH)	163AH	17
3	59A(142AH)	16.8A(99AH)	9.1A(64AH)	163AH	15
4	59A(142AH)	16.8A(99AH)	10.5A(74AH)	173AH	22

On 11/1/79 at cycle 62 the rates were changed due to premature failures; the timing remained the same.

The rate changes are shown below:

<u>Loop No.</u>	<u>Discharge</u>	<u>Hi Chg</u>	<u>Lo Chg</u>	<u>Total Chg</u>	<u>% Overchg</u>
1	50A(120AH)	14.2A(84AH)	8.3A(59AH)	142AH	18
2	50A(120AH)	14.2A(84AH)	8.0A(56AH)	140AH	17
3	50A(120AH)	14.2A(84AH)	7.7A(54AH)	138AH	15
4	50A(120AH)	14.2A(84AH)	8.9A(62AH)	164AH	22

The specific energy values of Lots 4 and 5 during their characteristics testing are shown in Tables 5, 6 and 7.

At characteristic cycle 2 (60A discharge at 25°C) the best specific energy achieved was 37.7 WH/Kg by battery 5811/105. Batteries 5815/121, 5819/137 and 5831/185 gave 37.0 WH/Kg.

The vital statistics of the above batteries are listed.

<u>EBS/SER NO.</u>	<u>TUBES</u>	<u>AM DEN</u>	<u>SEP</u>	<u>SP.GR.</u>	<u>ACID VOLUME ABOVE PLATES</u>
5811/105	Light	210-220g	P-Env	1.315	Low
5815/121	Std	210-220g	P-Env	1.315	Low
5819/137	Light	240-250g	P-Env	1.315	Low
5831/185	Std	210/220g	P-Env	1.315	High

The consistent features of the batteries were polyethylene envelopes and 1.315 specific gravity electrolyte.

Charge acceptance tests followed the initial characteristics tests.

Table 8 lists charge acceptance versus temperature and charge acceptance versus rate of charge.

TABLE 5
TP-1 CHARACTERISTICS TEST RESULTS
SPECIFIC ENERGY WH3/KG

LOT	EBS	SER No.	25°C						0°C					40°C				
			40A	60A	75A	140A	10A	240A	40A	60A	75A	140A	240A	40A	60A	75A	140A	240A
4	5809	097	38.7	34.1	31.2	--	47.0	--	31.6	24.6	20.9	15.3	10.2	39.5	36.0	31.8	28.3	22.8
5	5809	098	39.5	35.0	32.6	28.1	47.8	19.4	26.6	21.0	17.4	11.4	7.2	39.5	33.9	31.9	26.4	21.2
4	5810	101	36.9	33.2	30.6	--	46.3	--	--	25.5	21.8	16.6	11.0	37.2	34.4	30.4	26.7	21.8
5	5810	102	37.0	32.5	30.4	25.6	46.4	17.6	25.4	20.4	17.1	11.5	6.8	36.2	31.8	30.2	25.0	19.6
4	5811	105	42.5	37.7	34.3	--	49.8	--	25.2	17.3	14.2	8.9	5.4	42.1	36.8	30.3	27.7	21.2
5	5811	106	40.6	34.6	31.6	25.6	48.7	14.8	19.3	14.4	11.2	6.7	4.4	38.9	34.2	31.5	24.0	18.2
4	5812	109	40.8	35.9	32.7	--	49.4	--	27.7	19.7	15.2	9.6	5.6	38.9	35.3	30.7	26.9	21.2
5	5812	110	38.8	34.0	31.7	26.6	48.4	17.6	23.3	18.0	14.6	--	5.4	38.5	34.7	32.6	26.4	21.4
4	5813	113	38.7	34.3	31.7	--	47.4	--	32.0	24.9	21.1	15.6	10.2	40.6	36.6	32.6	28.8	23.8
5	5813	114	38.7	34.8	32.4	28.3	46.8	20.2	26.9	21.0	17.7	12.0	8.0	39.9	34.3	32.5	27.1	22.4
4	5814	117	36.2	32.5	30.0	--	45.3	--	32.1	25.7	21.4	16.8	11.4	37.9	34.6	31.0	27.3	22.4
5	5814	118	36.5	32.8	30.9	26.9	45.7	19.0	27.3	21.5	18.2	12.4	8.2	37.4	33.1	31.5	26.7	21.2
4	5815	121	41.5	37.0	34.3	--	49.2	--	28.7	20.4	16.0	10.5	6.4	43.0	38.6	32.7	29.4	23.8
5	5815	122	41.1	35.7	32.7	27.0	49.0	17.2	21.2	16.0	12.6	7.4	5.0	41.6	36.6	33.8	26.1	21.2
4	5816	125	40.4	36.2	33.0	--	50.3	--	27.9	19.5	15.0	9.4	5.6	40.7	37.2	33.9	29.2	23.0
5	5816	126	38.5	34.0	31.6	26.8	48.0	17.6	22.8	17.4	14.6	--	5.6	38.7	35.0	32.8	26.7	21.6
4	5817	129	36.9	32.6	30.1	--	46.2	--	30.5	23.6	19.9	14.8	9.8	38.7	34.9	31.0	27.4	22.4
5	5817	130	37.6	33.4	31.2	26.6	45.8	18.0	24.7	18.6	15.6	10.2	6.8	38.3	32.5	31.0	25.0	20.2
4	5818	134	36.0	32.2	30.4	--	49.4	--	26.0	18.1	19.2	13.6	9.0	36.2	31.9	30.5		22.8
5	5818	136	40.3	36.0	33.0	--	45.2	--	20.1	15.1	17.2	11.8	7.0	39.4	35.8	32.1	28.1	20.6
4	5819	137	42.0	37.0	33.9	--	50.3	--	26.0	18.1	14.0	9.1	5.4	42.1	37.0	30.3	27.7	21.2
5	5819	138	40.6	35.3	32.6	26.6	48.7	16.2	20.1	15.1	12.1	7.2	4.8	40.8	36.0	32.8	25.3	20.0
4	5820	141	39.6	35.3	32.1	--	49.0	--	30.5	22.8	18.4	12.3	7.4	39.8	35.7	31.6	27.7	22.6
5	5820	142	37.2	32.7	30.6	26.0	46.9	16.2	22.8	17.6	14.8	--	5.6	38.2	34.5	32.0	26.1	20.8
4	5821	145	36.8	32.4	30.3	--	45.8	--	30.6	22.8	18.8	13.6	8.6	39.9	36.2	31.9	28.0	23.0
5	5821	146	37.6	32.9	30.3	25.3	45.8	17.8	22.7	17.5	14.8	9.6	6.0	38.7	32.5	31.1	25.1	21.0
4	5822	149	34.8	31.0	28.6	--	44.8	--	30.2	24.2	20.1	15.1	9.8	37.2	33.6	30.0	26.0	21.2

TABLE 6
TP-1 CHARACTERISTICS TEST RESULTS
SPECIFIC ENERGY WHR/KG

LOT	EBS	SER No.	25°C						0°C					40°C				
			40A	60A	75A	140A	10A	240A	40A	60A	75A	140A	240A	40A	60A	75A	140A	240A
4	5822	150	35.7	31.8	29.8	25.8	44.8	18.4	26.0	21.0	16.8	10.7	6.8	36.7	32.1	30.6	25.7	20.6
5	5823	153	39.9	35.5	32.1	--	48.5	--	23.9	15.9	12.5	8.0	5.0	41.0	36.8	32.4	27.5	21.6
4	5823	154	37.6	32.6	30.2	24.9	46.9	16.0	19.5	14.6	12.0	7.2	4.6	39.5	34.9	31.8	24.9	20.2
5	5824	157	39.2	34.6	31.9	--	48.3	--	30.5	22.5	18.0	11.7	7.0	40.0	36.6	32.4	28.3	23.2
4	5824	158	36.4	32.0	29.8	25.1	46.2	18.6	25.5	20.3	16.8	10.6	6.6	37.1	32.4	31.0	25.0	20.8
5	5825	161	29.7	21.6	12.0	--	40.5	--	--	4.0	3.9	2.8	--	--	--	--	--	--
4	5825	162	38.8	34.4	31.5	25.9	49.0	16.6	23.3	18.1	14.6	9.4	5.8	38.2	32.5	30.5	23.9	18.8
5	5826	165	37.2	33.3	30.2	--	47.5	--	33.4	26.2	21.6	16.6	11.0	38.4	35.2	32.0	27.4	22.2
4	5826	166	38.9	34.4	32.3	27.3	49.0	19.0	27.7	22.3	18.7	12.7	8.0	38.6	33.8	32.0	26.8	21.0
5	5827	169	41.9	36.4	32.5	--	48.4	--	23.8	17.1	13.5	8.7	5.2	40.9	33.5	27.8	25.2	18.8
4	5827	170	43.0	36.0	32.3	25.3	50.8	15.2	19.6	14.8	11.6	6.7	4.4	41.1	35.8	31.0	23.2	18.8
5	5828	173	40.3	35.3	31.6	--	49.4	--	29.2	21.5	16.7	11.1	6.4	40.3	35.7	30.7	27.5	21.2
4	5828	174	39.8	33.0	30.2	24.2	48.7	15.0	21.1	16.0	13.0	7.7	4.6	38.1	33.9	30.6	23.6	17.8
5	5829	177	38.1	33.8	31.1	--	47.9	--	30.3	22.6	18.5	12.9	8.4	41.6	37.1	32.2	28.4	22.8
4	5829	178	39.0	34.8	32.4	27.8	48.6	19.4	26.9	21.3	17.6	12.2	8.0	40.3	34.7	32.7	27.3	21.6
5	5830	181	37.0	33.1	30.1	--	47.8	--	33.1	26.1	21.7	17.2	11.4	39.3	35.6	31.6	26.9	21.8
4	5830	182	37.9	34.0	31.7	27.3	48.1	19.0	27.5	21.9	18.7	12.9	8.4	38.1	33.4	31.8	26.7	20.8
5	5831	185	41.7	37.0	33.5	--	49.6	--	24.7	17.6	13.6	9.0	5.4	43.1	37.5	31.0	27.6	20.6
4	5831	186	42.5	36.8	33.9	24.7	51.4	17.2	21.1	16.1	13.0	10.0	5.0	42.1	37.2	33.9	26.3	21.2
5	5832	189	39.8	35.3	32.1	--	50.1	--	31.9	23.9	19.0	13.5	8.0	41.5	37.4	33.3	28.9	20.6
4	5832	190	38.4	33.2	31.0	26.1	48.2	17.6	24.1	18.8	16.0		6.2	38.7	34.4	31.9	25.4	20.6
5	5833	193	40.5	--	33.4	--	49.2	--	31.9	25.0	20.7	15.5	10.4	41.6	37.6	33.0	29.4	23.8
4	5833	194	39.6	34.2	31.8	26.4	48.7	18.4	25.1	19.5	16.3	10.8	7.0	40.2	33.9	31.6	25.9	20.6
5	5834	197	36.5	32.3	29.6	--	47.3	--	32.1	25.5	21.4	16.8	11.2	37.4	34.3	30.4	26.0	20.8
4	5834	198	37.3	33.2	30.8	26.7	47.5	18.4	27.6	22.4	18.8	13.0	8.2	37.7	32.6	31.0	25.8	20.2
5	5835	201	41.4	36.4	33.3	--	49.9	--	25.8	19.0	16.6	12.1	7.2	42.1	36.1	30.8	27.6	21.0
4	5835	202	41.7	34.8	32.1	25.7	50.3	16.2	20.9	15.8	12.9	7.8	5.0	41.4	36.4	32.1	24.1	19.2

TABLE 7
TP-1 CHARACTERISTICS TEST RESULTS
SPECIFIC ENERGY WHR/KG

LOT	EBS	SER No.	25°C						0°C					40°C				
			40A	60A	75A	140A	10A	240A	40A	60A	75A	140A	240A	40A	60A	75A	140A	240A
4	5336	205	40.1	35.8	32.7	--	50.7	--	30.9	23.3	18.4	12.4	7.4	40.5	35.8	31.3	27.5	22.2
5	5836	206	39.0	34.1	31.7	25.7	49.3	18.0	24.7	19.3	15.8	9.7	5.4	39.5	35.8	32.7	26.8	20.8
4	5837	209	38.2	34.0	31.0	--	48.0	--	30.9	23.9	20.5	15.4	10.4	40.6	36.2	32.0	27.8	22.8
5	5837	210-212	33.0	25.7	21.7	--	39.2	--	--	--	--	--	--	--	--	35.3*	30.2*	24.2*
4	5838	213	36.5	32.4	29.7	--	45.2	--	32.8	26.3	22.0	17.4	12.0	37.9	34.0	30.9	25.9	21.0
5	5838	214-216	31.2	26.2	22.8	--	36.9	--	--	--	--	--	--	--	--	33.4 ⁺	28.7 ⁺	22.8 ⁺
4	5839	217	41.1	36.2	33.1	--	49.7	--	28.2	20.7	16.2	11.1	6.8	43.5	38.2	32.1	29.0	22.8
5	5839	218	41.4	35.5	32.4	26.4	50.2	16.6	20.5	15.4	12.4	7.5	4.6	41.3	36.2	32.8	25.2	20.6
4	5840	221	39.8	35.2	32.4	--	49.9	--	32.1	24.4	19.5	13.6	8.2	41.5	37.2	33.0	28.8	23.4
5	5840	222	37.8	33.1	30.8	26.3	48.3	19.0	26.3	21.1	17.8	11.3	7.0	39.4	35.7	32.6	26.9	21.2

* Battery Serial Number 212 Replaced S/N 210 at Cycle No. 14

+ " " " 216 " S/N 214 at Cycle No. 14

TABLE 8

LOT 4				LOT 5			
EBS NO	BATT SER NO	CHARGE ACCEPTANCE VS TEMP AT 25°C %	CHARGE ACCEPTANCE VS CHG RATE AT 140A %	BATT SER. NO	CHARGE ACCEPTANCE VS TEMP AT 25°C %	CHARGE* ACCEPTANCE VS TEMP AT 0°C %	CHARGE ACCEPTANCE VS CHG RATE AT 140A %
5809	097	70.7	13.7	098	66.5	57.0	18.1
5810	101	69.2	15.3	102	67.3	54.0	13.1
5811	105	55.9	8.5	106	59.7	46.4	9.6
5812	109	56.5	8.5	110	61.1	49.3	12.1
5813	113	68.7	14.1	114	68.4	58.6	15.9
5814	117	69.7	14.4	118	66.5	57.5	14.8
5815	121	58.8	9.8	122	60.9	48.6	11.7
5816	125	55.6	9.6	126	60.8	49.2	12.0
5817	129	71.1	14.4	130	66.1	56.2	14.8
5818	136	58.3	11.0	134	67.0	55.8	13.5
5819	137	58.7	8.1	138	59.5	48.4	11.1
5820	141	61.5	10.3	142	64.8	50.0	12.0
5821	145	68.8	13.5	146	64.8	54.2	14.1
5822	149	67.8	14.0	150	67.6	55.3	13.4
5823	153	54.3	9.7	154	61.6	48.4	12.1
5824	157	61.7	11.6	158	67.6	53.2	13.5
5825	-	-	-	162	65.1	52.7	12.6
5826	165	64.8	14.4	166	65.2	56.2	15.1
5827	169	56.3	6.9	170	60.6	45.7	11.9
5828	173	59.1	8.1	174	57.9	55.7	6.4
5829	177	66.4	12.4	178	68.1	60.8	16.2
5830	181	68.3	14.8	182	65.5	58.6	14.1
5831	185	54.1	10.3	186	59.8	48.8	12.2
5832	189	59.8	10.5	190	61.2	49.9	13.0
5833	193	67.4	12.6	194	64.6	56.6	14.0
5834	197	67.9	14.8	198	65.0	56.5	13.8
5835	201	59.2	9.0	202	61.6	49.4	12.6
5836	205	60.0	9.9	206	62.4	49.3	13.0
5837	209	70.8	12.6	212	67.5	62.8	16.1
5838	213	69.7	15.6	216	68.8	63.1	17.2
5839	217	58.7	9.1	218	62.1	46.6	13.2
5840	221	60.6	11.5	222	62.5	50.6	13.1

*This data not available for Lot 4.

1.3.3 Work Performed Since Last Annual Report

As of 8/31/81 the remaining six batteries of Lot 4 have reached 420 life cycles plus an additional 32 characteristics cycles for a total of 452 cycles. See Table 9 for the status of all the batteries in Lot 4.

The design characteristics of the remaining six batteries are shown below:

<u>EBS/SER. NO.</u>	<u>Tubes</u>	<u>AM Den</u>	<u>Sep</u>	<u>Sp. Gr.</u>	<u>Acid Vol Above Plates</u>
5813/113	Std	Light	P-Env	1.285	Low
5814/117	Std	Light	Rubber	1.285	Low
5815/121	Std	Light	P-Env	1.315	Low
5818/136	Light	Heavy	Rubber	1.285	Low
5822/149	Std	Heavy	Rubber	1.285	Low
5825/161	Light	Light	P-Env	1.285	High

As of 8/31/81 the remaining twelve batteries of Lot 5 have reached 400 life cycles plus 32 characteristics cycles for a total of 432 cycles. See Table 10 for the status of all the batteries in Lot 5.

The design characteristics of the remaining 12 batteries are shown below:

<u>EBS/SER. NO.</u>	<u>Tubes</u>	<u>AM Den</u>	<u>Sep</u>	<u>Sp. Gr.</u>	<u>Acid Vol Above Plates</u>
5814/118	Std	Light	Rubber	1.285	Low
5815/122	Std	Light	P-Env	1.315	Low
5816/126	Std	Light	Rubber	1.315	Low
5817/130	Light	Heavy	P-Env	1.285	Low
5818/134	Light	Heavy	Rubber	1.285	Low
5820/142	Light	Heavy	Rubber	1.315	Low
5821/146	Std	Heavy	P-Env	1.285	Low
5822/150	Std	Heavy	Rubber	1.285	Low
5824/158	Std	Heavy	Rubber	1.315	Low
5831/186	Std	Light	P-Env	1.315	High
5837/212	Std	Heavy	P-Env	1.285	High
5839/218	Std	Heavy	P-Env	1.315	High

As of 8/31/81, the remaining battery from Lot 6 reached 680 life cycles as shown in Table 11. The design characteristics of the battery are shown below:

<u>EBS/SER. NO.</u>	<u>Tubes</u>	<u>AM Den</u>	<u>Sep</u>	<u>Sp. Gr.</u>	<u>Acid Vol Above Plates</u>
5822/151	Std	Heavy	Rubber	1.285	Low

TABLE 9

TP-1 BATTERY LIFE CYCLE TEST STATUSLOT 4

24-Hour Regime

<u>EBS/SER.NO.</u>	<u>Date Ended</u>	<u>Last Life Cycle</u>	<u>Life Cycles as of 8/31/81</u>	<u>Remarks</u>	<u>WH/Kg* at Cycle 371</u>
5809/097	10/13/80	186		Test started on 2/7/80	
5810/101	11/17/80	215			
5811/105	7/09/80	112			
5812/109	8/08/80	135			
5813/113			420		28.51
5814/117			420		29.89
5815/121			420		27.99
5816/125			420		23.52
5817/129	7/08/81	386			
5818/136			420		24.12
5819/137	1/16/81	252			
5820/141	12/21/80	229			
5821/145	6/19/81	367			
5822/149			424		25.54
5823/153		319			
5824/157		343			23.66
5825/161				Ended at Char. Cycle 9 12/10/79	
5826/165	9/25/80	152			
5827/169	6/02/80	66			
5828/173	8/08/80	135			
5829/177	3/04/81	296			
5830/181	10/10/80	180			
5831/185	6/02/80	66			
5832/189	9/25/80	167			
5833/193	10/28/80	197			
5834/197	9/25/80	167			
5835/201	4/25/80	46			
5836/205	11/05/80	203			
5837/209	4/25/80	46			
5838/213	9/25/80	167			
5839/217	6/19/81	369			24.10
5840/221	9/25/80	167			

NOTE: Batteries received 32 characteristics cycles prior to start of life test.

*The latest catchout data available from the data bank.

TABLE 10

TP-1 BATTERY LIFE CYCLE TEST STATUSLOT 5

18 Hour Regime

<u>EBS/SER.NO.</u>	<u>Date Ended</u>	<u>Last Life Cycle</u>	<u>Life Cycles as of 8/31/81</u>	<u>Remarks</u>	<u>WH/Kg* at Cycle 371</u>
5809/098	3/04/81	237			
5810/102	10/13/80	86			
5811/106	9/26/80	70			
5812/110	3/30/81	255			
5813/114		318			
5814/118			400		+
5815/122			400		28.71
5816/126			400		26.34
5817/130			400		+
5818/134			400		31.93
5819/138		383			25.58
5820/142			400		25.49
5821/146			400		28.94
5822/150			400		31.98
5823/154	2/09/81	206			
5824/158			400		+
5825/162	9/30/80	74			
5826/166	11/23/80	126			
5827/170	9/26/80	70			
5828/174	9/26/80	70			
5829/178	4/30/81	296			
5830/182	6/24/81	341			
5831/186			400		27.46
5832/190	10/07/80	84			
5833/194	4/19/81	284			
5834/198	12/22/80	152			
5835/202	4/22/81	288			
5836/206	3/30/81	263			
5837/212			400		26.42
5838/216	7/28/81	371			+
5839/218			400		26.61
5840/222	12/28/80	160			

NOTE: Batteries received 32 characteristics cycles prior to start of life test.

* The latest catchout data available from the data bank.

+ Data not available.

TABLE 11

TP-1 BATTERY LIFE CYCLE TEST STATUS

LOT 6

<u>EBS/SER.NO.</u>	<u>Date Ended</u>	<u>Last Life Cycle</u>	<u>Life Cycles as of 8/31/81</u>	<u>Remarks</u>	<u>WH/Kg*</u>	<u>At Cycle</u>
5809/099	8/08/80	337		Test started on 8/31/80		
5810/103	9/30/80	397				
5811/107	12/10/79	98				
5812/111	7/17/81	283				
5813/115	6/10/80	371				
5814/119	9/25/80	667				
5815/123	11/08/79	54				
5816/127	10/30/80	427				
5817/131	10/16/80	413				
5818/135	11/09/80	416				
5819/139	10/16/80	413				
5820/143	9/30/80	397				
5821/147	12/16/80	466				
5822/151			680		26.37	625
5823/156		563				
5824/159		565				
5825/163	6/10/80	283				
5826/167	12/10/79	98				
5827/171	8/31/79	0				
5828/175	12/14/79	103				
5829/179	8/08/80	337				
5830/183	6/10/80	283				
5831/187	9/25/80	390				
5832/191	9/30/80	397				
5833/195	7/09/80	311				
5834/199	7/09/80	311				
5835/203	1/25/80	145				
5836/207	6/10/80	283				
5837/211	9/30/80	397				
5838/215	8/08/80	318				
5839/219	12/13/80	462				
5840/223	9/25/80	390				

NOTE: These batteries were placed on life cycle with no characteristics tests.

*The latest catchout data available from the data bank.

1.3.4 Postmortem Inspection Results

When the batteries failed to reach 80% of the C/3 rate or 2.4 hours, life cycle testing was ended and they were dismantled to determine the cause of the failures.

Of the 77 batteries inspected 35 failed due to missing shorts and 24 due to sulfation of the negative active material.

Some of the batteries that were identified as having failed due to negative sulfation could have succumbed to missing shorts that were dislodged during the dismantling operation.

Missing shorts result from the migration of positive active material to the negative plates where the deposits build up. If enough materials deposits on the negative, a short develops between the positive and negative plates.

In the TP-1 positive plate the migration of positive active material was due to the poor fit of the tubes with both the bell of the positive spine and the plug of the bottom bar resulting in the loss of positive active material.

The sulfation of the negative active material is due to the tight pack of the element which resulted in poor acid circulation or to moss shorts.

Conclusions

Of the 78 recorded post testing battery inspections, 35 were caused by missing shorts and 25 were due to the sulfation of the negative active material. All of the failure modes are shown in Table 12.

Of the 19 batteries remaining on test; 14 have standard Cladex tubes while 5 have the light weave, 12 have 1.285 specific gravity electrolyte while 7 have 1.315 specific gravity electrolyte, 15 have low or standard acid volume above the plates while 4 have high acid volume above the plates. The other design features were of nearly equal distribution. Namely, the active material density; 11 had high density active material and 8 had low, and the separators; 10 had rubber separators and 9 had plastic envelopes.

Therefore, a battery designed for long cycle life should contain the following components:

- o Standard weave Cladex tubes
- o Heavy density (3.6 g/cc) positive active material
- o Plastic separators - better performance during characteristics testing.
- o 1.285 specific gravity electrolyte
- o Low (standard) volume of acid above the plates.

The cause of the migrant positive active material must be overcome.

TABLE 12

TP-1 - POST LIFE CYCLE INSPECTION SUMMARY

EBS NO	FAILURE MODE*					
	LOT 4	LOT 5	LOT 6	LOT 4	LOT 5	LOT 6
5809	253	269	337	3	1	2
10	253	154	376	2	2	10
11	141	152	99	2	2	2
12	167	287	282	2		4
13		318	370			5
14			667			1
15			55			6
16	401		453	1		2
17	438		453	1		2
18			446			1
19	284	415	453	2		1
20	284		453	2		1
21	440		535	1		1
22						
23	384	238	575	2	2	
24	401		575	2		2
25	0	152	282	7	2	2
26	182	210	99	1	1	1
27	144	152	0	2	2	8
28	167	152	104	2	1	9
29	331	350	337	1	1	2
30	253	373	262	1	1	1
31	128		390	2		
32	199	152	453	1	2	1
33	259	350	311		1	2
34	199	228	290	1	1	1
35	75	350	144	4	1	4
36	257	350	282	1	1	1
37	75		453	9		1
38	199	415	318	1	1	2
39	438		499	1		
40	199	228	390	1	1	1

*1 - Moss Shorts

2 - Neg. Sulfation

3 - Broken Strap

4 - Broken Top Bar

5 - Pos. Plates Corroded at Strap

6 - Poor Weld

7 - Formed in Reverse

8 - Torn Envelope

9 - Leaking Electrolyte (Defective

10 - Not Recorded Seal)

1.3.5 TP-1B Phase

To combat the loss of active material from the TP-1 plate, the following alterations were made:

- o The bells of the positive spine were enlarged to better fit the tubing.
- o The bottom of the top bar was widened 0.76mm to provide a cap at the top of the tube.
- o The plug of the bottom bar was enlarged to better fit the tubing.
- o The top of the bottom bar was widened 0.76mm to provide a cap at the bottom of the tube.

The altered plate was identified as type TP-1B.

Two thousand spines were cast at Exide's Sumter, South Carolina factory.

One thousand were trimmed and assembled with tubes.

They were filled with 1173 red lead positive active material, acid dipped and dried at Exide's Pilot Plant in Trenton, New Jersey.

Thirty elements were assembled into 3 cell modules. An element edge binding strip was incorporated into the design to further minimize edge shorting from moss accumulation.

The modules were formed and given an initial discharge. Five were sent to NBTL for testing the week of 24 August 1981.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

1.4 TP-2 BATTERY DESIGN

A new tubular battery intended to overcome the acid circulation problem was designed and named the TP-2. The design features are listed:

- o Positive plate is 168mm wide x 205mm high containing 24 round tubes 6mm in diameter.
- o Negative grid is a radial design 170mm wide x 205mm high x 2.4mm thick.
- o Two separator systems will be tested. One a microporous polyethylene sleeve around the positive plate. The other a microporous polyethylene sheet with the ribs slanted 10° from the vertical.
- o Cell consists of 7 negatives and 6 positives.
- o Overall battery size is 185mm wide x 260mm long x 300mm high.
- o The elements will be cast-on-strap (COS) burned and welded through-the-partition (TTP).
- o A single point watering system is built into the cover.
- o The capacity should be 180AH at the 3-hour rate.
- o The specific energy should be 40WH/Kg.

The following equipment and material has been purchased to produce TP-2 prototype batteries.

- o Positive spine mold
- o Negative grid mold
- o Positive filling fixture
- o Cast-on-strap mold and basket
- o Extrusion die for sleeve separator
- o Grid feeding device for MAC pasting machine
- o Extrusion die for moss protector
- o Fixture to cast bottom bar onto plates
- o Three thousand tubes
- o Six hand fabricated containers and covers

Four thousand five hundred negative grids were cast at Exide's Pilot Plant in Trenton, New Jersey.

The grids were pasted at Exide's Raleigh, North Carolina factory.

Positive spines are being cast at the Pilot Plant in Trenton, New Jersey.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

1.5 ADVANCED LEAD ACID BATTERY

1.5.1 Introduction

During the period 9/80 - 8/81, the primary emphasis in the Advanced Lead Acid EV Battery program has been on the development of a lightweight, conductive, and economical negative grid. Four such grids have been developed and they are in chronological order:

Type A - A plated ABS plastic with lead lug insert. The plating consists of an electroless copper deposit followed by successive deposits of electroplated copper then lead.

Type B - An electroformed copper substrate which is electroplated with lead.

Type C - An expanded copper substrate which is electroplated with lead.

Type D - An expanded copper grid with no subsequent lead plating.

Although all of the above meet the requirements of a lightweight conductive grid, only the last two can be considered economical enough to compete with standard cast or expanded lead grids. Cells and batteries have been fabricated in which these lightweight grids have been coupled with both pasted flat plate tubular positives. In all cases, the tubular electrode contained the TP-1 plate (oval tubes) developed in the ISOA portion of the program. Batteries containing lightweight negative grids and pasted flat plate positives have demonstrated 39-40 Whrs/Kg and 300 cycles when discharged at 80% of the 3-hr rate. With tubular positives, 35-36 Whrs/Kg and 450 life cycles were obtained.

During the past year, methods of improving the life of pasted flat plate positive electrodes were also investigated. Some success was achieved by wrapping a retained called "Stranmat" around the positive plate. With this material, nearly 400 cycles were achieved at 80% of the 3-hr rate but the energy density dropped to 36 Whrs/Kg, 5% lower than obtained with conventional flat plate electrodes.

Two methods of electrolyte circulation during charge were also investigated (1) "airlift" pump (2) simple air bubbling. Mechanical agitation of the electrolyte was used to replace the electrochemical stirring action produced by the gassing normally associated with overcharge of the lead acid battery. By reducing electrochemical overcharge, it was hoped that corrosion and shedding problems at the positive electrode could be reduced. The results indicate that air bubbling during charge provides no benefit. Cells are still on test with the "air lift" pump and it is still premature to reach any conclusions regarding its effectiveness.

1.5.2 Negative

It has been demonstrated that the energy density of the lead-acid battery can be significantly improved by using lightweight, copper containing, negative grids, and that cycle life is not reduced. In a typical EV battery, a cast lead negative grid contributes 9 to 11% of the total battery weight. By substituting lightweight materials such as plastic or copper, a savings of 50-60% in the negative grid weight is achieved. This corresponds

to a 5-6% reduction in the overall battery weight with no loss of performance. In a battery, the negative grid serves a two-fold purpose. (1) It is conductive and carries electrons to and from the active material involved in the electrochemical reaction. (2) It acts as a rigid matrix to hold the active material and to allow handling during pasting and subsequent assembly operations. In 100% lead grids, both functions are served by lead, a material which does not have an exceptionally good conductivity and has a high density. The resulting lead grid, therefore, becomes unnecessarily heavy and the rationale taken in developing a lightweight alternative has been to use plastic or copper as the active material matrix and copper as the electronic conductor. In earlier fabrication methods, a thin coating of lead is finally applied over the copper to make it electrochemically inert, although recent work has shown that this step is really unneeded, and that copper can remain exposed prior to pasting. On a unit volume basis plastic weighs less than one-tenth⁽¹⁾ lead, and copper is nearly thirteen times more conductive⁽²⁾ (cf. Table 13). Therefore, a grid which contains plastic or copper as the active material matrix and incorporates copper as the primary conductor can provide a substantial weight reduction over one which is 100% lead.

Table 13

Properties of Grid Materials^(1,2)

	<u>Density (g/cm³)</u>	<u>Resistivity (microhm cm)</u>
ABS	1.08	∞
Copper	8.92	1.77
Lead	11.34	22

1.5.2.1 Lightweight Negative Grid - Type A

The Type A lightweight negative grid has an ABS substrate molded around a lead lug insert. Figure 1 details the grid configuration while Figure 2 shows the lead lug (Drawings 6024008 and 6024009). In contrast to the standard orthogonal grid geometry, this advanced grid design contains current carrying ribs extending radially from the lug. It contains 18 diagonal members which are used to carry the current and 18 horizontal cross members used as a matrix to support the negative active material. The pastable volume of the grid is the same as a standard GW lead cast orthogonal grid. However, it differs in that the total path length of the current carrying members has been increased by 63% whereas the total length of the horizontal members has been reduced by 22%. The spacing between the horizontal rows is a variable optimized so that the maximum pellet area in any given row equals that of any other row.

To eliminate the problem of the lug and permit the use of conventional burning techniques to assemble the negative plates into a group, the type A grid specification has provided for a lead lug insert around which the plastic matrix is molded. The lug insert weighs about 5 grams and a detailed drawing is presented in Figure 2. Nearly 1500 of these lugs were hand cast from 6B5 antimony - lead alloy for subsequent insertion into the injection molding operation. The base mold for the lead lug insert was made by Lanson Machine Co., Morrisville, Pa., and the plastic grid mold was machined by Scholle Corp., Chicago, IL.

FIGURE 2

A three plate mold system was used to make the plastic matrix with lead lug insert. The polymer extruded was platable ABS (Borg Warner Cycolac APB 3570) and a series of critical operating procedures had to be determined and specified before success was achieved. These involved correct sizing and balancing of the gate and vent systems, and control of the operating temperatures and pressures. A particularly troublesome area was plastic flow around the delicate lower wire section of the insert, where encapsulation of the lead wires occurred. This resulted because a less expensive machining approach was initially used to provide an open frame pocket instead of a closed reinforced pocket which mated with the contour at the bottom of the lead insert. After several trials, several hundred grids were successfully molded to specification. A photograph of the finished insert and the molded grid is shown in Figure 3.

After receiving the plastic grids from Scholle, they were sent to General Super Plating Co., Syracuse, N.Y. The plating operation consisted of three steps:

Electroless Plate Copper - 0.6gm of copper was electroless plated on the ABS plastic bringing the overall grid weight to 13.6 gms.

Electroplate Copper - an additional 8-9 gms of copper was electroplated onto the grid to increase its conductivity to the level obtained with cast lead grids.

Electroplate Lead - an additional 15-18 gms of lead was electroplated over the copper to render it inert, and to reduce hydrogen evolution during charge.

The copper plating increased the grid thickness from 1.47mm to 1.59mm, while the lead resulted in a final grid thickness of 1.77mm. The final grid weight was 40 grams, nearly one-half of the cast lead control. The weight was broken down as follows:

Lead - Lug (5) + Plating (17) = 22 gms.
 Copper - Electroless (0.5) + Electroplate (8.5) = 9 gms.
 ABS Plastic - 8.6 gms.

In order to initially evaluate the performance of these grids, eleven were assembled into a negative group in Cell TP-23. Other work on the project demonstrated that tubular positive plates, TP-1 design, exhibited the longest life of the positive electrode configurations tested, so they were coupled with the Type A negatives. One hundred percent 1173 Red Lead was used as the positive oxide. The tubular plate parameters follow:

TABLE 14

Positive Tubular Construction Coupled with Negatives
Containing Lightweight Advanced Grids

No. of Tubes per Plate:	11
Grid Weight:	lead 122 gms, tubes 16 gms, bottom bar 2 gms, total weight 140 gms
Active Spine Length:	15.3 cm
Volume of Spine (twin):	0.675 cm ³

Table 14 (Continued)

Inside Tubing Dimensions: Avg. Width (cm) - 1.40 cm
 Avg. Thickness (cm) - 0.32 cm
 Cross Section per Tube - 0.45 cm²
 Volume per Tube for Filling
 (15.3)(0.45)-0.675 = 6.21 cm³

Tube Wall: 0.35mm

The filled plate parameters are:

Powder fill per Plate 243 gms
 Fill Density 3.56 g/cc
 Active Material Weight after Dip and
 Dry 245 gms
 Ahrs. per Plate 57.4

Other pertinent details of cell construction can be found in Table 15.

TABLE 15

Construction of Cell TP23
(Type A Negative Grid, EV Size)

A. Negative Electrode

1.	Type of Oxide	GOX
2.	Negative Plate	
a)	Grid Type	Type A - EV Size, Electroplated
Copper and Lead on ABS Plastic
with Lead Lug Insert
b)	Grid Weight (g)	38.4
c)	Paste Density (g/cc)	4.40
d)	Paste/Plate (g)	180
e)	DAM/Plate (g)	167
f)	FAM/Plate (g)	159
g)	Theoretical Ahrs.	41
3.	Negative Group	
a)	Number of Plates	11
b)	Formed Weight (including
strap) g	2342

B. Positive Electrode

1.	Type of Oxide	100% Hammond 1173 R.L.
2.	Positive Plate	Tubular, cf. Table 14
3.	Positive Group	
a)	Number of Plates	10
b)	Formed Weight (including
strap) g	

Table 15 (Continued)

c)	Theoretical Ahrs	574
C.	Electrolyte	
1.	Sp. Gr. Charged (g/cc)	1.300
2.	Volume/Cell (cc)	2000
3.	Weight (g)	2600
4.	Ahr. Theoretical	278
D.	Separators - Ribbed Daramic Envelopes, 0.762mm Rib, 0.254mm Backweb, 4.9 g/seperator	
E.	Cell Weight (calculated - Kg)	9.55

Characterization data obtained for TP23 are shown below.
The initial temperature at discharge was $27 \pm 1^\circ\text{C}$ for all cycles.

Cycle No.	Current (Amps)	Minutes	Avg. Voltage	Ahr. to 1.6 Volts	Whr. to 1.6 Volts	Initial Sp. Gr.	Positive AM Use	Whr/Kg
5	60	182	1.92	182	349	1.300	31.7	36.5
6	75	135	1.90	169	321	1.306	29.4	33.6
7	120	77	1.86	154	386	1.300	26.8	30.0
8	35	346	1.95	202	394	1.310	35.2	41.2
9	25	506	1.96	210	412	1.300	36.4	43.1
11	240(1)	27.5	1.78	110	196	1.310	19.2	20.5
12	500(1)	10.4	1.50	86.7	130	1.300	15.1	13.6

1000 amps(2), full charge, 1.37 volts, 1370 watts, 143 watts/Kg.
1000 amps, 30% discharged, 1.26 volts, 1260 watts, 132 watts/Kg.
1000 amps, 60% discharged, 1.01 volts, 1010 watts, 106 watts/Kg.

Notes:

- (1) The cutoff voltage at 240 amps discharge was 1.5V.
The cutoff voltage at 500 amps discharge was 1.0V.
- (2) The discharge current is maintained for 15 secs, and the average voltage determined.

Following the characterization tests, the cell was placed on extended life cycling where it accumulated 300 deep cycles (100% D.O.D.) before failing. A 32% overcharge was used throughout the test period. Figure 4 illustrates the capacity behavior over the life of the cell. Performance was stable until cycle 275, when rapid failure began to occur. The cell was rated at 170 Ahr, and failure was indicated when capacity dropped below 128 Ahrs (75% of rated value). A postmortem of TP23 revealed little sedimentation or mossing. The negative electrode and the separators appeared in good condition. The positive active material in the tubular pockets was only slightly soft. The primary mode of failure was positive grid corrosion, nearly 60% of the spines in the grid was eroded away severely reducing contact to the positive active material.

FIGURE 4: DISCHARGE BEHAVIOR OF TP-23 (TUBULAR POS., ELECTROPLATED ABS + LEAD LUG INSERT NEG.)

In order to further protect the spine in the tubular positive and to reduce the possibility of corrosion, the fill weight per plate in cell AEX16 was increased to 275 grams. This corresponded to an increase in fill density from 3.56 to 4.02 g/cc. AEX16 was one of six identical cells built to evaluate Type A negatives coupled with "heavy" tubular positives. The other five were shipped to NBTL in 12/80 as part of the requirements of the Advanced Battery phase of the ANL Contract. The cells were identical to TP23 (cf. Tables 14, 15) except for the modifications listed below:

	<u>TP23</u>	<u>AEX16</u>
Positive		
Powder fill per plate (g)	243	275
Fill density (g/cc)	3.56	4.02
Ahrs/plate	57.4	65.0
Electrolyte		
Sp. Gr. Charged (g/cc)	1.300	1.300
Electrolyte/cell (cc)	2000	1900
Weight/cell (g)	2600	2470
Cell Weight (Kg)	9.55	9.75

The added active material weight introduced into the positive plate did not increase the energy output of AEX16. Therefore, corresponding to the 2% increase in cell weight, the energy density of AEX16 was approximately 2% less than TP23 at the various rates tested.

Cell AEX16 was placed on extended life testing, and at present (8/15) has accumulated 310 cycles while normally discharging to 80% depth. On selected cycles, however, a 100% deep discharge was obtained. After an equalizing charge in cycle 305, the cell capacity at 50 amperes to a 1.70V cutoff was 154 Ahrs. This corresponds to 89% of the maximum delivered.

Cycle No.	Current (Amps)	Capacity (Ahrs)	Capacity (Whrs)	Energy Density (Whrs/Kg)
6	55	176	347	35.4
305	50	154	304	31.0

A complete description of the capacity behavior of AEX16 is shown in Figure 5. The spikes indicate 100% discharge. At the present rate of capacity decay, in excess of 500 cycles is expected.

1.5.2.2 Lightweight Negative Grid - Type B

An alternative to the Type A lightweight negative grid already discussed involves the use of electroformed copper. A joint effort between the Exide Management and Technology Company and the Inco Research and Development Center (IRDC) resulted in the design and construction of an EV size grid made as follows: a) a 0.10mm thick substrate of electroformed copper was deposited in an orthogonal grid design b) the copper was plated with 0.05mm thick lead to render it inert and c) 0.10mm thick lead was plated in the lug area to provide strength and rigidity in a region normally subjected to

FIGURE 5: DISCHARGE BEHAVIOR OF AEX16 (TUBULAR POS., ELECTROPLATED ABS + LEAD LUG INSERT NEG.)

considerable forces and moments during pasting, handling, and assembly. A unique and proprietary aspect of the grid design is that the frame and ribs have a concave cross-section. Although the actual grid wall is only 0.20mm, a thickness normally too thin to support a substantial amount of negative active material, the concavity provides an effective thickness of 0.55mm. By promoting a better bond between the paste and the grid, this design permits the overall plate thickness to be as high as 1.8mm.

The Type B grid design was pursued in favor of the Type A approach because:

- (1) The electroless copper deposition process is no longer necessary, and the multi-dip operation associated with it is eliminated.
- (2) Plastic is not required to form an active material support matrix; enough rigidity is provided by the unique concave framework imparted to the grid ribs by the electroforming process. The plastic comprises a significant portion (70 to 110 cc) of the available volume in the cell compartment and eliminating it provides that much more space for electrolyte and active material.
- (3) For a given weight of copper, the electroforming operation results in a grid with a conductivity somewhat higher than electroless deposition followed by electroplating.

The primary disadvantage of the Type B grid is its high cost. IRDC charged \$15,000 to make 500 grids. Now obviously, large scale production could substantially reduce the figure of \$30/grid. Based on its raw material content, the grid costs less than \$0.06 (18 gms copper at \$0.80/lb = \$0.032, 19 gms lead at \$0.44/lb = \$0.018). Nevertheless, electroforming like electroplating is limited by the diffusion rate of ions from a solution to a cathodic collector. This is a relatively slow process and some doubt remains as to whether electroforming of copper could ever be cost competitive with lead casting. It is for this reason that the Type C lightweight negative grid was developed in which electroforming of the copper substrate was replaced by an expanded metal process.

A considerable amount of time and effort was spent on testing the Type B grid in various types of cells and batteries. Although we knew the grid to be uneconomical, the technical information obtained regarding the behavior of a lead plated electroformed copper substrate is relevant to predicting the performance of negative grids which are structurally similar but fabricated by a different process (e.g. expanded metal).

A total of 550 electroformed grids were made by IRDC to test in advanced lead acid batteries. The first fifty were slightly thinner and contained less copper than the rest. Significant grid parameters are:

	<u>Grid Numbers</u>	
	<u>1-50</u>	<u>51-551</u>
Copper		
Wt (g)	9	18
Thickness(mm)	0.05	0.10
Lead		
Wt (g)	19	19
Thickness(mm)	0.05	0.05
Total Grid Wt. (g)	28	37
Total Grid Thickness(mm)	0.15	0.20

Note: The lug in all grids contained 0.10mm lead plate.

Although the thinner electroformed grids had more than adequate conductivity, we decided to specify the heavier grid because of its greater rigidity and ease of handling. Figure 6 shows a photo-reduction of the blueprint for the Type B lightweight electroformed negative grid, and Figure 7 is a photograph of a plated sample. The grid geometry is orthogonal. The inherent conductivity of copper and the amount present (18g) resulted in a grid which was significantly more conductive than the cast lead controls so that there was no need to employ a radial rib design to accommodate high rate discharges.

A study was made to evaluate and compare the relative conductivities of various advanced grids containing plastic and/or copper and those made from cast lead. A milliohmmeter was used to measure resistance; one set of probes was plated on the grid lug and the other set on the bottom of the grid frame diagonally opposite the lug (the voltage monitoring probes were placed inside of the current carrying probes). The results are presented in Table 16.

TABLE 16

The Resistance of Lead Acid Grids

<u>Grid Designation</u>	<u>Thickness (mm)</u>	<u>Lead Weight(g)</u>	<u>Grid Composition</u>	<u>Lug Position</u>	<u>Resistance (mΩ)</u>
GW(orthogonal)	1.47	80	6% Sb-Pb	Offset	3.77
GW(orthogonal)	1.47	76	0.1% Ca-Pb	Offset	3.61
GW(orthogonal)	1.47	73	0.1% Ca-Pb	In-line	3.58
2 EVR(radial)	1.47	84	6% Sb-Pb	In-line	3.23
2 EVR(radial)	1.47	76	0.1% Ca-Pb	In-line	3.00
2GW(orthogonal)	1.83	90	6% Sb-Pb	Offset	3.75
2GW(orthogonal)	1.83	90	6% Sb-Pb	In-line	3.50
1EVR(radial)	1.83	92	6% Sb-Pb	Offset	3.07
1EVR(radial)	1.83	91	6% Sb-Pb	In-line	3.18

ADVANCED EV BATTERY - NEGATIVE GRID -
TYPE B CONSTRUCTION

FIGURE 7

Table 16 (Continued)

<u>Grid Designation</u>	<u>Thickness (mm)</u>	<u>Lead Weight(g)</u>	<u>Grid Composition</u>	<u>Lug Position</u>	<u>Resistance (mΩ)</u>
1GW(orthogonal)	2.08	105	6% Sb-Pb	Offset	3.07
Type A(radial)	1.77	40	Cu+Pb+ABS	In-line	2.05
Type B(orthogonal)	0.15	28	.05mm Cu+.05mm Pb	Offset	2.00
Type B(orthogonal)	0.20	37	.10mm Cu+.05mm Pb	Offset	1.05
Type C(diamond)	0.267	32	.127mm Cu+.07mm Pb	Offset	1.40
Type D(diamond)	0.254	29	100% Cu	Offset	1.30

As indicated in the above table, the finalized Type B design resulted in a grid which was three times as conductive as cast lead but weighed 55% less.

Highlighting the work done with Type B grids has been the design, fabrication and testing of the following:

Cell AEX6: 29 plate element outside positives, negative grid contains 0.10mm Cu, flat plate positives.

Cell TP24: 21 plate element, outside negatives, negative grid contains 0.10mm Cu, tubular positives.

Batteries AEX1A - AEX6A: three cell modules, scaled up versions of cell AEX6. Cell AEX6 is a duplicate of the five cells shipped to NBTL in 4/80. It contained 14 lightweight electroformed grids each weighing 37 grams and pasted with 125 grams of negative active material. A typical cured pasted plate is shown in Figure 8, and formed plate in Figure 9. Complete details of cell construction are listed in Table 17.

TABLE 17Construction of Cell AEX6 (Type B Negative Grid)

A. Negative Electrode

1. Type of Oxide - 100% GOX
2. Negative Plate

- a) Grid Type - Electroformed copper substrate 0.10mm thick, 0.05mm lead plating
- b) Grid Wt (g) - 37
- c) Paste Density (g/cc) - 4.40
- d) Paste/Plate (g) - 125
- e) DAM/Plate (g) - 117
- f) FAM/Plate (g) - 110
- g) Theoretical Ahrs - 28.5

3. Negative Group

- a) Number of Plates - 14
- b) Formed Weight (including strap) g - 2234
- c) Theoretical Ahrs - 28.5

CURED PASTED PLATE - NEGATIVE GRID
TYPE B CONSTRUCTION

FIGURE 8

FORMED PASTED PLATE - NEGATIVE
GRID TYPE B CONSTRUCTION

FIGURE 9

Table 17 (Continued)

B. Positive Electrode

1. Type of Oxide - 90% GOX, 10% 1173 Red Lead
2. Positive Plate
 - a) Lead grid type - 2GW, 1.83mm thick, 6% Sb-Pb
 - b) Grid Weight (g) - 93
 - c) Paste Density (g/cc) - 4.27
 - d) Paste/Plate (g) - 172
 - e) DAM/Plate (g) - 159
 - f) FAM/Plate (g) - 161
 - g) Theoretical Ahrs - 36.1
 - h) Cured Thickness (mm) - 2.16
3. Positive Group
 - a) Number of Plates - 15
 - b) Formed Weight (including strap) - 3900
 - c) Theoretical Ahrs - 544

C. Electrolyte

1. Sp. Gr. Charged (g/cc) - 1.285
2. Volume/Cell (cc) - 2160
3. Weight (g) - 2776
4. Ahr Theoretical - 284

D. Separators - Ribbed Daramic Envelopes, 0.762mm Rib, 0.254mm Backweb,
4.9 g/separator

E. Cell Weight (Kg - 9.40

Cell performance was characterized at selected discharge rates and the results follow. The initial discharge temperature was $27 \pm 1^\circ\text{C}$, and the specific gravity was $1.290 \pm .005$.

Current (Amps)	Minutes	Avg. Voltage	Ahr. to 1.6V	Whr. to 1.6V	Positive AM Use	Whr Kg
22.5	1350	1.97	225	443	41.4	47.1
36.0	360	1.97	215	423	39.5	45.0
62	180	1.95	186	363	34.2	38.6
140	60	1.88	140	264	25.7	28.1
240 (1)	30	1.82	120	218	22.1	23.2
500 (1)	10.7	1.61	90	143	16.5	15.2

1000 amps(2) full charge, 1.55 volts, 1550 watts, 165 watts/Kg.

Notes:

- (1) The cutoff voltage at 240 amps discharge was 1.5V.
" " " " 500 amps " " 1.0V.
- (2) The discharge current at 1000 amps is maintained for 15 seconds, and the average voltage determined.

Following the characterization tests, the cell was placed on extended life cycling where it was repetitively discharged to 1.70V (100%). Overcharge ranged from 25 to 33% during this test. Failure occurred after 290 cycles when the cell capacity failed to reach 75% of the 180 Ahr rated value. A postmortem revealed significant sedimentation; active material accumulated to the top of the sediment ribs and the electrolyte turned dark brown at the top of charge. Virtually no grid remained in the positive plate which literally crumbled when handled. Figure 10 illustrates the capacity behavior of AEX6 over the life of this test.

Cell TP24 is a duplicate of the five cells shipped to NBTL in 6/80. It contained 11 lightweight electroformed grids each weighing 37 grams and pasted with 180 grams of negative active material. The 0.20mm thick electroformed grid was rigid enough to handle this relatively large amount of paste without any problem. Pasting, handling, and burning were accomplished with no grid member or lug distortion. Except for the negative grid, TP24 was built identically to TP23 (cf. Table 14 to obtain details of the tubular positive grid, and Table 15 to obtain negative and positive electrode parameters). TP24 contained 2090 cc of acid and weighed 9.65 Kg, the ratio of positive to negative formed active material was 1.46.

Characterization testing of TP24 has been completed and the results are shown below.

Cycle No.	Current (Amps)	Minutes	Avg Voltage	Ahr to 1.6V	Whr to 1.6V	Initial Sp.Gr.	Positive AM Use	Whr/Kg
3	60	182	1.94	182	353	1.300	31.7	36.6
10	75	133	1.91	166	318	1.290	28.9	33.0
9	120	72	1.88	144	271	1.290	25.1	28.1
12	35	348	1.96	203	398	1.300	35.4	41.2
13	25	504	1.97	210	414	1.300	36.4	42.9
8	240	28.3	1.79	113	203	1.290	19.7	21.0
5	500	10.4	1.56	86.7	135	1.300	15.1	14.0

1000 amps, full charge, 1.39 volts, 1390 watts, 144 watts/Kg.

1000 amps, 30% discharged, 1.29 volts, 1290 watts, 134 watts/Kg.

1000 amps, 60% discharged, 1.09 volts, 1090 watts, 112 watts/Kg.

A comparison of this data with that of TP23 discussed earlier indicated very little difference in the performance characteristics of the two cells. Only at high current drains does the cell containing the lightweight electroformed grids (Type B construction) show a significant improvement over the cell with the plated plastic negatives (Type A construction). The increased energy output is due primarily to a higher average cell voltage generated by the more conductive electroformed copper grids.

Following characterization, the cell was placed on extended life testing where it is still discharging after 480 cycles. The cell is discharged to 1.70V and overcharge has ranged from 25 to 33%. At this point in the test, capacity has dropped near the failure point - 132 Ahrs. - which corresponds to 75% of the rated capacity (175 Ahrs). The rate of decay is, however, very slow as indicated in Figure 11 which illustrates the performance behavior of TP24 during life cycling.

FIGURE 10: DISCHARGE BEHAVIOR OF AEX-6 (FLAT PLATE POS., ELECTROFORMED NEG.)

FIGURE 11: DISCHARGE BEHAVIOR OF TP-24 (TUBULAR POS., ELECTROFORMED NEG.)

Batteries AEX1A - AEX6A represent six three cell modules that are sealed up versions of cell AEX6 discussed earlier. Of these batteries, five were shipped to NBTL in 7/81 and one is being tested at Exide. It is still too early in the test program to predict cycle life performance, but significant variation from that obtained with AEX6 (~ 300 cycles) is not anticipated. Initial characterization work showed that the maximum 3-hr rate energy density was 38.1 Whr/Kg (27°C initial discharge temperature, 5.1V cutoff).

Battery	Cycle No.	Current (Amps)	Time (Mins)	Capacity (Ahrs)	Avg Volts	Capacity (Whrs)	Battery Wt (Kg)	Energy Density(Whr/Kg)
AEX6A	7	57	192	182	5.91	1075	28.2	38.1

The energy density was 2 Whr/Kg less than expected. Part of the reason was that the weight of the 2GW positive grid was 14 grams more than specified (102 grams instead of 88 grams). This increased the total battery weight by 630 grams or 2.2%. Also, because of its greater reliability, over the partition rather than through the partition intercell construction was used and this increased the battery weight by another 1%. We also determined the 1000 ampere power rating for these batteries at the top of charge. An average value of 4500 watts, 159 watts/Kg, was obtained for a 15 second long, 1000 ampere pulse.

The primary cell design parameters for AEX1A - AEX6A are:
a) Positive - 15 plates, each pasted with 172 grams of oxide (90% GOX, 10% 1173 Red Lead) b) Negative - 14 plates, grid consists of electroformed copper (17 grams) electroplated with lead (18 grams), pasted with 125 grams of 100% GOX
c) Separators - ribbed Daramic enveloping the negative, 0.762mm rib, 0.254mm backweb d) Acid - 1.300 specific gravity at the top of charge. These are some minor modifications in the construction parameters for AEX6 and for the batteries AEX1A - AEX6A. These are listed below.

	Cell AEX6	Batteries AEX1A - AEX6A
Negative Grid (grams)	35	37
Positive Grid (grams)	93	102
Acid Specific Gravity	1.285	1.300
Acid Volume per Cell (cc)	2160	2030
Acid Weight per Cell (g)	2775	2639
Ahrs Theoretical per Cell	284	282

Otherwise, the information in Table 17 detailing AEX6 can be directly applied to these batteries.

1.5.2.3 Lightweight Negative Grid - Type C

The processing cost of electroforming the copper substrate makes it uneconomical relative to casting standard lead grids. The speed at which a grid can be electroformed is limited by the diffusion rate of ions from a solution to a cathodic collector. Therefore we decided to examine the feasibility from both a processing and cost perspective of making expanded copper grid substrates from rolled sheet stock. A quote from Die Mesh Corp., Pelham, N.Y. indicated that 0.127mm thick copper, 15.5 cm wide could be expanded into a diamond matrix for less than \$0.16/foot (equivalent to 2 grids) in quantities

of 1000 linear feet. For 1,000,000 linear feet this drops to \$0.10/foot.

Die Mesh Corp. supplied an initial order to 1000 feet of expanded copper processed according to specification. A roll of 0.127mm (5 mil) copper sheet was expanded into a diamond geometry in which the diamond had equal sides approximately 5mm long. The resulting mesh was 16 cm wide and its effective thickness for pasting was 2.4mm (95 mils). 100 EV size grids were cut from the expanded copper rolls. A lead lug was spot-welded on to each of the shaped grids to facilitate assembly into a negative group using conventional burning techniques. The weight of copper per grid was 12 grams and the lug weighed another 3 grams. The grids were then shipped to General Super Plating Co., Syracuse, N.Y. for subsequent lead plating. A 0.05 to 0.076mm (2-3 mils) thickness of lead was applied bringing the overall average grid weight to 32 grams.

This lead plated, expanded copper, lightweight negative grid was termed Type C, and a photograph of it is shown in Figure 12. Its conductivity as indicated in Table 16 is comparable to the Type B grid as is its weight. It should be noted that the Type C grid cannot be used to make 29 plate elements with flat pasted plate positives (e.g. cell AEX6, Batteries AEX1A - AEX6A). The negative grid thickness for this type of element has to be less than 1.52mm (60 mils). Attempts to press the mesh down to this thickness resulted in severe distortion of the grid pattern and generally unacceptable grids.

The Type C grid must be used in a negative electrode which is coupled with a tubular positive, therefore, cell TP36 was built to evaluate its performance. Except for the differences listed below, TP35 was identical to TP24 described earlier (cf. Tables 14 and 15).

Cell	Negative Grid Type	Neg. Grid Wt(g)	Neg Paste Wt(g)
TP24	Lead plated electroformed Cu	37	180
TP36	Lead plated expanded Cu	32	170

Preliminary cycling indicated no significant difference in the performance of the two cells.

Cell	Cycle	Current (Amps)	Minutes	Avg Voltage	Ahr to 1.6V	Whr to 1.6V	Cell Wt Kg	Energy Density Whr/Kg
TP24	4	60	182	1.94	182	353	9.65	36.6
TP36	4	60	177	1.96	177	347	9.48	36.6

This data confirmed that substituting lead plated expanded copper grids for lead plated electroformed grids resulted in no loss in battery energy density. When the decision was made to send to NBTL five 3-cell modules to represent scaled up versions of cells containing tubular positives and lead plated copper negatives, we felt confident in scaling up TP36 which contained expanded copper rather than TP24 with electroformed copper. This decision was made even though five cells, duplicates of TP24, had been shipped to NBTL in 6/80 and had performed well.

**EXPANDED COPPER
LEAD PLATED**

TYPE C - LIGHTWEIGHT
NEGATIVE GRID

FIGURE 12

Complete details of construction for these modules, AEX7A - AEX12A can be found in Table 18.

TABLE 18

Construction Details for Batteries AEX7A-AEX12A
(Type C Negative Grid)

A. Negative Electrode

1. Type of Oxide - 100% GOX
2. Negative Plate
 - a) Grid Type - Type C, lead (17 grams) plated on an expanded copper substrate (15 grams)
 - b) Grid Weight (g) - 32
 - c) Paste Density (g/cc) - 4.4
 - d) Paste/Plate (g) - 170
 - e) DAM/Plate (g) - 158
 - f) FAM/Plate - 150
 - g) Theoretical Ahrs - 38.9
 - h) Cured Thickness (mm) - 2.00
3. Negative Group
 - a) Number of Plates - 11
 - b) Theoretical Ahrs - 389
 - c) Formed Weight (including strap) - 2275

B. Positive Electrode

1. Type of Oxide - 90% GOX, 10% 1173 Red Lead
2. Positive Plate
 - a) Grid Type - Tubular, TP-1, cf. Table 14 for additional details
 - b) Fill Weight (g) - 256
 - c) Cured Weight (g) - 271
 - d) Average Fill Density (g/cc) - 3.71
 - e) Theoretical Ahrs - 58.5
3. Positive Group
 - a) Number of Plates - 10
 - b) Formed Weight (including strap) g - 4198
 - c) Theoretical Ahrs - 585

C. Electrolyte

1. Sp. Gr. Charged (g/cc) - 1.300
2. Volume/Cell (cc) - 1980
3. Weight (g) - 2574
4. Ahr Theoretical - 275

Table 18 (Continued)

D. Separators - Ribbed Daramic Envelopes, 0.762mm Rib, 0.254mm Backweb, 4.9g/Separator

E. Module Weight Total (Kg) - 29.0

1.5.2.4 Lightweight Negative Grid - Type D

The Type D lightweight negative grid differs from the others developed in this program because lead is not used as a final coating on the grid surface. Instead, the grid consists of 100% copper and the lead oxide active material is pasted directly on the copper substrate.

It should be emphasized that with the current designs proposed for advanced EV batteries in all cases the cells are positive limiting. Therefore, under normal cycling conditions (i.e. no cell reversal), corrosion or dissolution of the copper cannot happen. Table 19 lists the maximum voltage of the negative electrode which occurs at the end of discharge as 0.2V vs. Cadmium. This is nearly 0.5V less than the point where copper begins to dissolve.

TABLE 19

Typical Electrode Voltages vs Cadmium

Positive Electrode, cell fully charged	2.5V
Positive Electrode, cell fully discharged, cell negative limiting	2.1V
Positive Electrode, cell fully discharged, cell positive limiting	1.9V
Copper dissolution at negative	0.7V
Negative Electrode, cell fully discharged, cell negative limiting	0.4V
Negative Electrode, cell fully discharged, cell positive limiting	0.2V
Negative Electrode, cell fully charged	-0.2V

However, the major reason for plating lead over copper on the negative is to increase the hydrogen overvoltage and to reduce the grids gassing characteristics. The use of unplated copper significantly increases the evolution of hydrogen at the negative electrode above that obtained on a pure lead grid. However, we do not anticipate using pure lead, i.e. non-antimony, alloy in both the positive and negative grids in advanced EV batteries. In the proposed design with tubular plates, the positive grid contains 9% antimony. Therefore, even if a pure lead or lead-calcium (0.1% Ca) grid is used in the negative electrode, in time, enough of the antimony will migrate to the negative and significantly reduce its hydrogen overvoltage. Therefore, it serves no purpose to coat a copper substrate with pure lead in order to render it inert if antimony contamination eventually takes place and becomes the overriding factor affecting hydrogen evolution.

The overvoltage of hydrogen on 4 different unpasted negative grids was carefully determined versus a cadmium reference electrode in 1.285 specific gravity electrolyte. The counter electrode was a standard EV size flat pasted plate positive. Before recording the data, hydrogen was allowed to bubble for at least one hour to insure that no oxygen contaminated the negative. The results are shown in Figure 13, and they indicate that the

FIGURE 13: OVERVOLTAGE OF HYDROGEN vs CURRENT

hydrogen overvoltage on a copper grid is only slightly less than on a lead grid containing 6% antimony. We can therefore predict that while unplated copper negatives will initially (1) increase the amount of hydrogen evolved per charge (2) increase the watering needs of the battery and (3) reduce the energy efficiency, with prolonged cycling, the migration of antimony to the negative electrode will cause one containing cast lead grids to gas at the same rate as one with copper.

To evaluate the performance of copper negatives, cell TP35 was built. Except for the negative grid, TP35 was identical in all respects to TP36 discussed earlier. The negative grid consisted of the Type C configuration but without the lead plating, and it weighed approximately 15 grams. After 85 cycles, the cell has exhibited no drop in capacity.

Cycle No.	Current (Amps)	Time (Mins)	Capacity (Ahrs)	Capacity (Whrs)	Energy Density (Whrs/Kg)
4	60	171	171	332	35.9
81	55	187	172	332	35.9

The life test behavior of TP35 is shown in Figure 14. The constant discharge performance is remarkable. Normally cells with lead negatives show an initial drop in capacity before performance levels out. Based on this data, it is now evident that unplated expanded copper grids can be placed in the negative electrode without loss of performance or cycleability. We recently became even more convinced regarding the technical feasibility of using unplated copper because we observed that after 10 or 20 cycles a mossy lead deposit began to plate over any exposed copper in the cell. This created a self-healing mechanism for low overvoltage on bare copper. There is apparently sufficient solubility of $PbSO_4$ in the electrolyte so that lead ions plate in situ (in the battery) on the copper. Stand loss tests for cell TP35 indicated a 0.5% loss in capacity per day so that self discharge at the negative was not excessive. We do, however, plan to do more elaborate gassing tests to determine the relative hydrogen evolution on pure lead, pure copper, and on lead antimony grids.

The expanded copper grids cycling in TP35 were made from 0.127mm thick copper sheet (cf. Type C grid specifications). Some handling problems in element assembly were encountered due to the flimsy nature of this grid, particularly in the lug area. Therefore, we ordered and received new expanded copper material from Die Mesh Inc. which had the following features:

- (1) The material was expanded from 0.254mm (10 mils) thick copper sheet.
- (2) The diamond geometry used earlier was maintained. The diamond was equilateral, 5mm on a side. The angle, however, was slightly altered.
- (3) The effective thickness for pasting of the expanded roll was 1.52mm (60 mils).
- (4) The roll width was 15.5 ± 0.3 cm (6.1 ± 0.1 inches).
- (5) The roll was fabricated so that a 3.17 cm (1.25 inch) solid border was alternated between regions of expansion which are 15.9 ± 0.6 cm (6.25 ± 0.2 inch) long; an integral lug can then be cut from this solid border in

FIGURE 14: DISCHARGE BEHAVIOR OF TP35 (TUBULAR POS., UNPLATED EXPANDED COPPER NEG.)

a subsequent operation. Furthermore, a frame now exists at both the top and bottom of the grid to provide added rigidity and conductivity. Over 1000 EV size lightweight negative grids have been cut from this expanded mesh. A photograph of a typical grid is shown in Figure 15. This expanded copper grid with an integral lug has been termed Type D, and it weighs approximately 29 grams. Within the next couple of months, we plan to build, test, and evaluate both cells and batteries containing these grids.

The use of Type D copper grid in the negative instead of a conventional cast GW grid results in a grid which is 3-4 times more conductive and weighs 65% less. Furthermore, as indicated below, the copper grid is 35% cheaper. Cost figures are based on \$0.46 lead and \$0.82 copper (8/10/81).

<u>Raw Material</u>	Expanded or Cast Lead	Expanded Copper
Lead (80 gms)	\$0.081	-
Copper (28 gms)	-	\$0.051
<u>Process</u>		
Expanding	\$0.005	\$0.005
Total	\$0.086	\$0.056

Therefore, the use of copper would represent a technological breakthrough in the performance of lead acid batteries, it is an economic breakthrough as well.

1.5.3 Positive

The positive electrode is a critical component affecting the energy density of the lead-acid battery. Typically, it comprises 40% of the total battery weight (the positive grid 15% and the positive active material 25%). In the past year, our work has involved three types of positive electrodes a) tubular b) pasted flat plate and c) pasted flat plate with "Stranmat" retainer. Unfortunately, our work has shown that no one electrode design is optimum in all respects, i.e. gives maximum energy and longest life at the lowest cost.

The tubular electrode gives the longest life. Some batteries built for the ANL program have exceeded 600 cycles at the 3-hr rate, 80% discharge. Positive active material utilization is approximately 33-35% resulting in a battery energy density of 36-38 Whr/Kg. The cost of the tubular electrode is greater than the other two under consideration.

The pasted flat plate electrode gives the highest energy density. Active material utilization is approximately 35-37% resulting in a battery energy density of 38-40 Whr/Kg. Our longest life batteries with flat plate positives have reached 300 cycles at the 3-hr rate, 80% discharge. The flat plate electrode is the least costly to build.

**EXPANDED COPPER
WITH INTEGRAL LUG**

TYPE D NEGATIVE GRID

FIGURE 15

The pasted flat plate electrode with "Stranmat" retainer is an attempt to combine the best features of both the tubular and flat plate electrodes. The "Stranmat" is however, rather bulky and reduces the space available for active material. Positive active material utilization is approximately 35% and the battery energy density is 35 Whr/Kg at the 3-hr rate. Four-hundred cycles have been obtained, 33% higher than for conventional pasted flat plate positives. The cost of this electrode lies somewhere between the other two.

1.5.3.1 Tubular Electrode

In a tubular electrode, the positive active material is encapsulated in a phenolic impregnated woven glass fiber tube, and shedding is thereby restrained. Preferred oxides for filling the tubes are 2 to 4 microns in diameter, and consist of either GOX (nominally 70% PbO and 30% finely divided lead) or Red Lead (nominally 73% Pb₃O₄ and 27% PbO). A slight difference in maximum cell capacity and active material utilization was noted when using 100% GOX rather than 100% Red Lead. GOX is less expensive than Red Lead and is more desirable from a cost point of view. However, positives containing 100% Red Lead reach full capacity within 1 to 3 cycles whereas those with 100% GOX take 10 to 20 cycles - which is unacceptable for most users.

In contrast to flat plates which are pasted with a mixture of oxide, sulfuric acid, and water, tubular positive plates are filled with dry oxide powder only. The powder is introduced in the space between the tube wall and the centrally located lead spine. The process is considerably aided by vibration or shaking which is absolutely needed to achieve the required fill density. An optimum fill density exists above which utilization of the active material is poor, yielding a low energy density, and below which washout occurs and plate life is short. The optimum density should ideally result in a tubular electrode which combines long life and good utilization. Our work has indicated that oxide fill densities ranging between 3.6 - 4.0 g/cc with 2-4 micron diameter powder maximizes cycle life while still maintaining utilization of the positive active material above 33% at the three-hour discharge rate.

The tubular grid used was the same as the one designed for the ISOA-TP1 battery. Typical grid dimensions are presented in Table 14. After the tubes were filled with oxide, they were "soaked" in sulfuric acid. This step sulfates the active material and binds it together transforming it from a loose packed powder into a rigid matrix. Alternatively, the plates could have been "dipped" in sulfuric. The "soak" step consists of: (1) immersing the plates for 24 hours in acid (1.3 l/lb of active material) (2) surface washing in water, and (3) drying. The "dip" step consists of: (1) dipping the plates for 15 minutes in acid (0.4 l/lb of active material) (2) surface washing in water (3) curing for 48 hours and (4) drying.

A possible solution towards improving the active material utilization is to maximize the surface area of the tubular positive group. This reduces the rate of electrochemical reaction per unit surface area (the current density) without altering the diffusion rate of the electrolyte, and in effect enhances accessibility of the positive active material to sulfate ions needed for discharge. With the plate thickness of the tubular ISOA grid held as a constraint, maximizing the surface area of the positive group meant

squeezing as many plates as possible into the EV cell compartment while still remaining positive limiting. Even so, the utilization of the active material in the tubular electrode was nearly 10% less than obtained with a pasted flat plate construction. Part of the problem may be that tubular plates are nearly twice as thick as flat plates. The positive active material is not nearly as accessible to the electrolyte even though low fill densities are specified. This is particularly true at high discharge rates. It may be necessary to make the tubular electrodes thinner thereby increasing the surface area of the group. Manufacturing them, however becomes quite difficult and tube dimensions are very difficult to hold. Also, the tube wall becomes a substantial portion of the total electrode thickness and the room remaining for the positive active material is substantially reduced.

1.5.3.2 Flat Plate Electrode

The flat pasted plate electrode is the simplest and lowest cost plate to build and exhibits the best energy density of all those tested. It is made by pasting a grid with a mixture of fine oxides, water and sulfuric acid. The paste composition is adjusted to a selected density and viscosity. The pasted plate is then hydro-set and dried. It is stored until the positive group is ready to be assembled. As indicated earlier, this type of electrode can be made thin to enhance acid penetration into the positive active material, and it contains no inert material such as plastic or glass which tend to increase the current density at the electrode surface. These factors make for good utilization of the active material. The only disadvantage of the flat pasted plate construction is that it is not conducive to long life.

No significant work was done in the past year to further optimize the paste density, plate thickness, grid configuration, or group size for pasted flat plate electrodes. Nor were paste additives investigated. These studies were completed at the end of 1980 and the results are summarized in the Exide Annual Report for 1980 on Research, Development and Demonstration of Lead-Acid Batteries for Electric Vehicle Propulsion, Argonne Report ANL/OEPM-80-11, March 1981. (3)

1.5.3.3 Flat Plate Electrode with "Stranmat" Retainer

Battery 1507-11 was designed and constructed in order to evaluate the use of "Stranmat" retainer as a means to increase the life and retard shedding of pasted positive plates. The 0.75mm thick "Stranmat" from Hydramatic Co. was u-folded around the positive plates. The battery contained conventional orthogonal lead grids in both the positive and negative electrodes. Experience with industrial lead-acid batteries which normally operate at lower discharge rates has shown that this material which consists of uni-directional glass fibers bonded to a Vitrex backing helps retain the positive active material, and still allows good acid transfer from top to bottom of the cell container. Inclusion of the "Stranmat" increased the weight of the 3-cell battery by 0.45 Kg, and reduced the electrolyte volume per cell by 130cc. Complete details of battery construction can be found in Table 20. Battery 1507-11 was placed on automatic life cycling to test the effects of "Stranmat" on long term battery behavior. It was discharged at 55 amperes for 2.4 hours or to 5.1 volts - whichever came first. Charging was in two steps: high rate

charge - 18 amperes for 5.9 hours, low rate charge - 10 amperes for 7 hours. The overcharge was 33%. At selected cycles, the battery was given an equalization charge and discharged at 60 amperes to 5.1 volts. As indicated below, the use of "Stranmat" decreased the capacity of a 25 plate element battery by 7.5%.

Battery	Cycle No.	Current (Amps)	Time (Mins)	Initial Temp(°C)	Initial Sp.Gr.	Positive Material Use (%)	Active Use (%)	Capacity (Whr/Kg)
1507-11	15	60	165	29	1.290	35.0		34.8
Control	15	60	176	29	1.290	37.3		37.0

TABLE 20

Construction Details for Battery 1507-11

A. Negative Electrode

1. Type of Oxide 100% GOX
2. Negative Plate
 - a) Grid Type GW, 1.47mm thick
0.1% Calcium Alloy
with Lead
 - b) Grid Weight (g) 74
 - c) Paste Density (g/cc) 4.40
 - d) Paste/Plate (g) 130
 - e) DAM/Plate (g) 123
 - f) FAM/Plate (g) 117
 - g) Theoretical Ahrs. 30.26
3. Negative Group
 - a) Number of Plates 12
 - b) Formed Weight (including strap) 2442
 - c) Theoretical Ahrs. 363

B. Positive Electrode

1. Type of Oxide 90% GOX, 10% 1173 R.L.
2. Positive Plate
 - a) Lead Grid Type 2 GW, 1.83mm Thick
6% Antimony Alloy
 - b) Grid Weight (g) 90
 - c) Paste Density (g/cc) 4.27
 - d) Paste/Plate (g) 172
 - e) DAM/Plate 160
 - f) FAM/Plate 162
 - g) Theoretical Ahrs. 36.3
3. Positive Group
 - a) Number of Plates 13

Table 20 (Continued)

b)	Formed Weight (including strap)	3426
c)	Theoretical Ahrs.	472
C.	Electrolyte	
1.	Sp. Gr. Charged (g/cc)	1285
2.	Volume/Cell (cc)	2050
3.	Weight (g)	2634
4.	Ahr. Theoretical	269
D.	Separators - Ribbed Daramic Envelopes, 0.762mm Rib, 0.254mm Backweb, 4.9 g/seperator	
E.	Retainer	1.00mm Thick Stranmat 12.5 g/u-folded retainer
F.	Cell Weight (calculated-Kg)	9.26
G.	Battery Weight (actual-Kg)	27.8

However, by cycle 85, the performance of the "Stranmat" containing cell exceeded that of the control. This demonstrated that the drop in capacity as a function of cycle number was much less with "Stranmat," and that this retainer increased the life of pasted flat plate positives and under EV bench type charge and discharge cycling.

Figure 16 illustrates the cycle life behavior of 1507-11. It should be pointed out that the overcharge was increased to 36% from 33% in cycle 240. This was probably necessary because of the progressive migration of antimony to the surface of the negative plate. The increased antimony buildup reduced the hydrogen overvoltage and hence more gas was evolved and the conversion of lead sulfate to lead became less efficient. Battery 1507-11 failed after completing 382 cycles at 80% depth of discharge or greater. Failure was indicated when capacity dropped below 75% of the rated value (165 Ahr). The life of this battery was more than twice as long as that of a control without "Stranmat" but otherwise built and cycled identically. A postmortem revealed little sedimentation or mossing. Any loss of positive active material was trapped in the mat, and that which remained on the electrode was still fairly hard. The negatives and separators appeared in good condition. Primary mode of failure was near total disintegration of the positive grid.

The major disadvantage of using "Stranmat" as presented in the design of Battery 1507-11 is that it occupies considerable volume and reduces the space available in the cell compartment for the reactants (electrolyte, positive, and negative active material) and grids. Therefore, the size of the flat plate element must shrink from 29 to 25 plates, and the electrolyte volume drops by 5%. Because of these factors, the maximum battery capacity decreased from 40 Whr/Kg down to 35 Whr/Kg.

FIGURE 16: DISCHARGE BEHAVIOR OF 1507-11 (FLAT PLATE ELECTRODES, STRANNAT RETAINER)

"Stranmat" is a rather expensive retainer, and we investigated ways to reduce its cost. One method, which involved the design of a new and unique separator-retainer construction was incorporated in 1507-14. This construction was the result of a joint effort with Hydramatic Co. and proved to be just as effective, yet cheaper, than the one used in 1507-11. In 1507-11, we used Daramic envelopes as the separator and the Stranmat, consisting of unidirectional glass fibers bonded to a Vitrex backing, was U-folded around the positive plate. In 1507-14, the Vitrex was eliminated and unidirectional glass fibers were directly bonded to a roll of Daramic as a backing. This made the separator and retainer an integrated component of the battery rather than two discrete items, and resulted in a net cost savings.

Battery 1507-14 was placed on automatic life cycle as follows:

Discharge - 55 amperes for 2.4 hours (80% of the 3-hr rate), or to a 5.1 V cutoff whichever comes first.

Charge (High Rate) - 16 amperes for 5.9 hours, or to 7.05 V whichever comes first.

Charge (Low Rate) - 10 amperes for 7.0 hours.

Total Overcharge - 25%

On selected cycles, the battery was discharged 100% to a 5.1 V cutoff. After 170 cycles, battery capacity now stands at 87% of maximum.

Cycle No.	Current (Amps)	Capacity (Mins)	Capacity (Ahrs)	Capacity (Whrs)	Energy Density (Whrs/Kg)
13	55	185	170	991	33.5
34	55	178	163	950	32.0
70	55	169	155	900	30.4
125	55	168	156	894	30.2
150	55	165	152	886	30.0
165	55	162	149	865	29.3

Over the last hundred cycles, less than a 3% loss in capacity has been noted, and the battery will be tested until 128 Ahrs are recorded at the end of discharge.

1.5.4 Electrolyte Circulation

1.5.4.1 Air Bubbling

In order to avoid or minimize the shedding and corrosion problems normally associated with the positive plate, a study was initiated to investigate the effect of mechanically agitating the electrolyte during charge. Mechanical agitation of the electrolyte is used to replace the electrochemical stirring action produced by the gassing normally associated with overcharge of the lead acid battery. Therefore, overcharge of the battery can be significantly reduced. Overcharge is quite detrimental to life. It increases corrosion of the positive grid, and it promotes shedding of the active material

by generating gas bubbles within the internal structure of the positive plate. It is normally needed, however, to completely charge the positive and negative plates since it promotes acid transfer to the active material and helps water diffuse from the positive. The lower the paste density, the more pronounced the effect of shedding produced by the electrochemical effects of overcharge. A further advantage of mechanical agitation is that the ampere-hour and watt-hour efficiencies of the battery are improved, and this would more than offset the energy consumed by the outside source used to stir the electrolyte. The need for watering is also reduced.

Two important questions regarding electrolyte circulation during charge were resolved during the course of this study:

- (1) Does mechanical agitation significantly reduce shedding below that normally seen with overcharge.
- (2) Can mechanical agitation be used to satisfactorily charge a battery with little or no overcharge needed.

In the initial phase of this study, we investigated the use of simple air bubbling through the electrolyte during charge. A manifolded exit pipe was placed at the bottom of the cell container through the sediment ribs to insure good air distribution throughout the electrolyte. The cell under test (TP25) was identical to TP24 (cf. Table 13 for tubular positive electrode design) except that it contained a 19 plate element rather than a 21. Cell TP25 contained 10 lightweight electroformed grids each weighing 37 grams and pasted with 180 grams of negative active material. It contained 2150cc of acid and weighed 9.15 Kg. The theoretical Ahrs of positive active material were 513. The bubbling rate of air through the electrolyte was approximately 100 cc/min. Over a 13.5 hr. period of charge, 81,000cc of gas passed through the cell. With a normal 25% overcharge, nearly 18,800cc of H_2 and 9400cc of O_2 are evolved for a 180 Ahr rated cell. Therefore, approximately three times as much gas passed through with mechanical bubbling - more than adequate stirring was achieved. A schematic illustrating the piping and control of the bubbling apparatus is shown in Figure 17. The control box shown was built in house and did the following: (1) it monitored the cell, and when its voltage dropped below 1.7V, the cell was automatically placed on charge, the solenoid opened the air valve, and a timer was activated (2) when the timer completed its cycle, the cell was placed on discharge, the solenoid relay was deactivated, and the air supply was shut off. The air flow rate was controlled with no significant fluctuation at 100cc/min.

Although TP25 was usually cycled with air bubbling through during charge, on selected cycles the gas was turned off and the electrochemical overcharge increased from 3 to 4% up to 25%. Table 21 below summarizes the data obtained on selected cycles early in the test program.

Figure 17: The Effect of Bubbling Air on Cell Performance

TABLE 21

The Effect of Electrolyte Circulation
During Charge on Cell Performance

Cycle No.	Discharge Current (Amps)	Time (Mins)	Ahrs	Charge Current (Amps)	Time (Mins)	Ahrs	% Over-Charge	PAM Use(%)	Whr Kg
23	50	204	170	13	810	176	3.2	33.1	36.4
24	50	203	169	13	810	176	4.1	32.9	36.2
25	50	203	169	13	810	176	4.1	32.9	36.2
27	50	212	177	13	1086	235	32.9	34.5	37.9
28	50	209	174.5	13	1050	227.5	30.4	34.0	37.2
29	50	209	174	13	1008	218.4	25.5	34.0	37.2

Figure 18 illustrates the voltage-time behavior of TP-25 with and without bubbling during charge (note: at no time is air bubbled during discharge). It is apparent from this data that during early cell cycling, air bubbling permitted a reduction in overcharge from 25% down to 4% and yet the discharge capacity dropped by less than 3%. The ampere-hr. and watt-hour efficiencies exhibited a tremendous improvement.

	Avg Charge Voltage	Avg Dischg Voltage	Ahr Dischg	Ahr Charge	Ahr Effic.	Whr Effic.
Bubbling	2.20	1.95	170	176	96.6	85.6
No Bubbling	2.29	1.96	175	218	80.3	68.7

As we began long term life cycling of TP25, it became evident, however, that even with air bubbling, the cell capacity could not be maintained with only a 4% overcharge. After 40 cycles, the charging efficiency with air bubbling began to decrease, and it became necessary to increase the electrochemical overcharge in order to maintain performance. This behavior is evidenced by the data in Table 22.

TABLE 22

Decreased Charge Efficiency with Air Bubbling

Cycle No.	Discharge Current(Amps)	Time (Mins)	Capacity (Ahrs)	Charge Current(Amps)	Time (Mins)	Ahrs Charge	Percent Overcharge
23	50	204	170	13	810	176	3.5
25	50	203	169	13	810	176	4.2
42	50	198	165	13	810	176	6.7
68	50	195	162	13	810	176	8.7
82	50	188	157	13	810	176	12.1
96	50	190	158	13	810	176	11.4
110	50	188	157	13	810	176	12.1
118	50	185	154	13	810	176	14.3

Figure 18: AIR BUBBLING SCHEMATIC FOR ELECTROLYTE CIRCULATION

Long term cycling of TP25 to 100% depth of discharge resulted in failure after 375 cycles. Figure 19 illustrates the capacity behavior over the life of the cell. Performance was stable until cycle 200, when gradual failure began to occur. The cell was rated at 170 Ahr, and the test was terminated when capacity dropped below 128 Ahr (75% of rated value). The data obtained for this cell strongly suggest that air bubbling during charge does not produce a large increase in the life of tubular electrodes. At most, a 10-20% improvement occurs. A postmortem revealed that the primary mode of failure was shedding of the positive active material. The positive grid spines showed little corrosion or pitting and remained in generally good condition. The results indicated that while air bubbling coupled with a lower degree of overcharge did reduce corrosion of the positive grid, it still could not significantly retard shedding and improve battery life.

In order to further assess the efficiency of air bubbling during charge, the bubbling apparatus was scaled up to accommodate a 3-cell module. Two identical 3-cell modules were built containing flat pasted plate positive electrodes. One module was used as the control and the second had air bubbling through it during charge (100 cc/min). Details of construction for the two modules, 1507-12 and 1507-13, can be found in Table 23.

TABLE 23

Construction of Batteries 1507-12, 1507-13

A. Negative Electrode

1. Negative Plate

- a) Lead Grid Type - 2 GW, 2.0mm thick, 6% Sb alloy
- b) Grid Weight (g) - 100
- c) Paste Density (g/2 in³) - 147
- d) Paste/Plate (g) - 188
- e) DAM/Plate (g) - 165
- f) FAM/Plate (g) - 153
- g) Theoretical Ahrs - 39.7
- h) Cured Thickness (mm) - 2.36

2. Negative Group

- a) Number of Plates - 11
- b) Theoretical Ahrs - 437

B. Positive Electrode

1. Positive Plate

- a) Lead Grid Type - 1GW, 2.1mm thick, 6% Sb alloy
- b) Grid Weight (g) - 105
- c) Paste Density (g/2 in³) - 146
- d) Paste/Plate (g) - 204
- e) DAM/Plate (g) - 191
- f) FAM/Plate (g) - 191
- g) Theoretical Ahrs - 42.8
- h) Cured Thickness (mm) - 2.40

FIGURE 19: DISCHARGE BEHAVIOR OF TP-25 (TUBULAR POS., ELECTROFORMED NEG.)
CELL ADAPTED FOR AIR BUBBLING DURING CHARGE

Table 23 (Continued)

C. Electrolyte

1. Specific Gravity Charged - 1.285
2. Volume/Cell (cc) - 1800
3. Theoretical Ahrs/Cell - 232

D. Separators - 1.15mm ribbed microporous rubber

E. Total Battery Wt. (Kg) - 30.9 Kg

Battery 1507-12 (the control battery) and 1507-13 (the test battery) were placed on automated equipment and were life cycled as follows:

Battery No.	Dischg Rate (Amps)	Time (hrs)	Dischg Cap. (Ahrr)	High Rate Chg (Amps)	Time (hrs)	High RateChg (Ahrr)	LoRate Charge (Amps)	Time (hrs)	LoRate Charge (Ahrr)
1507-12	55	2.4 ⁽¹⁾	132	16	5.9	94.4	10	7	70
1507-13	55	2.4 ⁽¹⁾	132	16	5.9	94.4	6.5	7	45.5

(1) 2.4 hours nominally represents 80% discharge; the batteries were cycled for 2.4 hours or to a 5.1 volt cutoff - whichever came first.

Battery 1507-12 was, therefore, subjected to a 24% overcharge with no air bubbling through the electrolyte while 1507-13 was subjected to only 6% overcharge with air bubbling. On selected cycles, an equalization charge was applied and the batteries were discharged 100%. The data showed that by cycle 100, the application of a 6% overcharge to the battery through which air was bubbled failed to maintain capacity at 132 Ahr, while the control still had an end of discharge voltage of 5.50V after 132 Ahr were withdrawn. The capacity of 1507-13 dropped to 124 Ahrr before equilibrating so that a 12-14% overcharge was needed to maintain battery performance even though air bubbling was used. The decrease in charging efficiency with increased cycle life confirmed earlier data obtained for TP25. Subsequent to cycle 100, 1507-13 was cycled with a 12% overcharge and air bubbling while 1507-12 (control) continued to cycle at a 24% overcharge with no air bubbling.

Both batteries were cycled 166 times and both exhibited failure at this point in the test. The data below summarize the batteries' capacity after equalization.

Initial Performance - Cycle 23

Battery No.	Current (Amps)	Time (Mins)	Capacity (Ahrr)
1507-12 (Control)	55	181	166
1507-13	55	173	159

Performance - Cycle 162

Battery No.	Current (Amps)	Time (Mins)	Capacity (Ahrs)
1507-12	55	132	121
1507-13	55	131	120

Battery 1507-12 exhibited a 27% drop in capacity while the test battery, 1507-13, showed a 25% drop. We, therefore, conclude that air bubbling during charge through batteries with flat plate electrodes does not prolong cycle life. Apparently the major mode of failure - shedding of the positive active material - is not significantly altered by using this charging technique.

1.5.4.2 "Air-Lift" Pump Circulation

In order to test the effectiveness of using an "air-lift" pump to circulate electrolyte during charge, we built Cell TP29. This cell contained a positive group constructed with 10 tubular plates, and a negative group incorporating 11 electroplated lightweight plastic grids. The cell was identical in construction to AEX16 discussed earlier (also refer to Tables 14 and 15 for more details). The use of an "air-lift" pump differs from air bubbling in that (1) the electrolyte is more effectively transported as the more dense regions present near the bottom of the cell are forced up and over the top of the plates and (2) the air bubbles are kept away from the active material since their only path to the top is through an enclosed tube. A schematic diagram of an "air-lift" is shown in Figure 20. This type of pump is extremely simple; it consists of a small diameter tube positioned inside one with a larger diameter. Air is introduced into the top of the small bore tube, and as it escapes into the large diameter tube it pushes liquid in front of it. In a typical cell, the top of the tubing is approximately the same height as the bottom of the container - fill hole and the electrolyte being pumped is directed up and over the plates. As the liquid is displaced from the outer tube, it is replaced by more entering through the tube bottom. The rate of pumping is controlled by the gas pressure set at the inlet of the inner tube.

Cell TP29 was discharged 100% at the 3-hr rate. Initially, a 6% overcharge was applied coupled with a pumping rate of 150 cc/min of electrolyte. However, as cycling continued it became necessary to increase the electrochemical overcharge in order to maintain cell capacity. This type of behavior also was observed with air bubbling during charge (cf. Cell TP25, Battery 1507-13). It has, therefore, become apparent that the improvement in charging efficiency resulting from mechanical agitation of the electrolyte decreases with cycling.

Cycle No.	Discharge Current(Amps)	Time (Mins)	Capacity (Ahrs)	Charge Current(Amps)	Time (Mins)	Ahrs Charge	Percent Overcharge
23	45	239	179	14.5	13.1	190	6.2
40	50	198	165	14.5	12.9	187	13.3
60	50	198	165	14.5	12.9	187	13.3
72	50	200	169	14.5	12.9	187	10.7
114	55	174	160	14.5	12.9	187	16.9
155	55	173	158	14.5	12.8	186	17.8

FIGURE 20: DIAGRAM OF "AIR-LIFT" PUMP

Long term cycling of TP29 has resulted in more than 320 cycles. At this point, the cell delivers 84% of maximum capacity and is generally cycling well. Figure 21 illustrates the capacity behavior over the life of the cell. Cell TP29 is still on test and as yet we cannot draw any definite conclusions regarding the effectiveness of using an air-lift pump to increase battery life. For comparison, a cell of identical construction but without electrolyte agitation (Cell AEX16, see page 46) delivers 89% of the maximum capacity after 305 cycles.

1.5.5 Conclusions and Accomplishments

1. Negative Grid

a) A low cost, highly conductive, lightweight negative grid has been developed. The grid, fabricated by expanding 0.254mm copper sheet is 3-4 times as conductive, weighs 65% less, and is 35% cheaper than a conventional cast lead grid. The use of an all copper negative grid increases the energy density of an EV battery by 6-8% with no decrease in cycleability.

b) Overvoltage studies have shown that the amount of hydrogen evolved on negatives with copper grids is not significantly greater than on lead-antimony grids.

c) As long as cell reversal did not occur, all types of negative grids developed in the course of this program behaved well during extensive life cycling - up to 500 cycles to date.

d) The use of plastics as a matrix to support the active material on a lightweight grid is technically feasible, however, an all copper or lead plated copper grid would be preferred. From the standpoint of economics the electroless plating of copper onto the plastics grid followed by the electroplating of copper then lead onto the grid results in an expensive process when compared to the electroplating of lead onto a copper substrate.

e) The use of electroforming to fabricate a copper substrate is more costly than expansion of rolled copper sheet which also permits good control of the finished product.

f) Most of the excellent results we have obtained with copper grids involved those with an electroformed substrate. Although we know the grid to be uneconomical, the technical information obtained is relevant to predicting the performance of negative grids which are structurally similar but fabricated by a different process (e.g. expanded metal).

2. Positive Electrode

a) Tubular - Life in excess of 600 cycles at 80% depth of discharge or greater at the 3-hr rate has been obtained. Positive active material utilization was approximately 33-35% resulting in a battery energy density of 36-38 Whr/Kg.

b) Flat Plate - Life was up to 300 cycles at 80% depth of discharge and at the 3-hr rate. Positive active material utilization was 35-37% resulting in a battery energy density of 38-40 Whr/Kg.

FIGURE 21: DISCHARGE BEHAVIOR OF 1507 - TP-29 (TUBULAR POSITIVE, PLASTIC NEG.)

c) Stranmat Retainer - Combining the use of this retainer with flat plate electrodes increased battery life up to 400 cycles or 33% more than with the conventional flat plate construction. However, positive active material use was reduced to 35% and the battery energy density to 35 Whr/Kg at the 3-hr rate. Since the "Stranmat" is rather bulky, the compartment space normally available for active material was somewhat reduced.

3. Electrolyte Circulation

a) Air Bubbling - Pumping air through the cell during charge did not significantly increase life. This conclusion applied independent of the positive group construction. During the early stages of cell cycling, air bubbling did permit a reduction in the electrochemical overcharge needed to insure a fully charged condition. However, beyond 150 cycles, normal overcharge was required to maintain cell capacity.

b) Air Lift Pump - It is still premature to reach any definite conclusions regarding the effectiveness of using this device to pump electrolyte during charge. More cycling is needed.

REFERENCES

- (1) CRC Handbook of Chemistry and Physics, Robert C. Weast, Editor, CRC Press, Cleveland, Ohio, 1977 page B-122, C-800.
- (2) Ibid., pages (B-109, E-84).
- (3) Exide Annual Report for 1980 on Research, Development and Demonstration of Lead-Acid Batteries for Electric Vehicle Propulsion, Argonne Report ANL/OEPM-80-11, March 1981.

DO NOT
MICROFILM

Distribution for ANL/OEPM-81-9

Internal:

D. Barney
M. H. Bhattacharyya
E. S. Beckjord
M. Bernard
R. Biwer
R. Breyne
L. Burris
A. A. Chilenskas
C. C. Christianson
G. Cook
D. Corp
E. Creamer

W. DeLuca
F. Foster
D. Fredrickson
B. R. T. Frost
E. C. Gay
J. Geller
E. Hayes
F. Hornstra
S. J. LaBelle
T. S. Lee
J. Marr
J. Miller

P. A. Nelson
D. Poa
J. Rajan
J. J. Roberts
R. K. Steunenbergh
C. Swoboda
A. Tummlillo
R. Varma
D. S. Webster
N. P. Yao (50)
ANL Contract File
ANL Libraries (2)
TIS Files (6)

External:

DOE-TIC, for distribution per UC-94ca (292)

Manager, Chicago Operations Office, DOE

Chief, Office of Patent Counsel, DOE-CH

R. Gariboldi, DOE-CH

Argonne Universities Association:

President

C. B. Alcock, U. of Toronto

T. Cole, JPL

W. L. Worrell, U. of Pennsylvania

W. Ahmad, KW Battery, Skokie, IL

R. Alkire, University of Illinois, Urbana

H. C. Allen, Union Electric Co., St. Louis, MO

M. Allen, Mechanical Technology Inc., Latham, NY

E. T. Ames, TRW Systems, Redondo Beach, CA

L. Andrews, Electric Vehicle Council, Washington, DC

S. J. Angelovich, Mallory Battery Co., Tarrytown, NY

D. H. Antonsen, International Nickel Co., New York City, NY

G. M. Arcand, Idaho State University, Pocatello

R. Aronson, Electric Transportation Management, Inc., Fort Lauderdale, FL

G. N. Ault, NASA Lewis Research Center

R. H. Auris, Philadelphia Electric Co., Philadelphia, PA

J. D. Baker, Stewart Warner Corp., Chicago

W. Bales, Jet Industries, Inc., Austin

H. Balzan, Chattanooga, TN

K. F. Barber, DOE, Office of Vehicle and Engine Research and Development,
Washington

T. M. Barlow, Lawrence Livermore National Laboratory

D. L. Barnes, Arizona Public Service Company, Phoenix, AZ

J. H. Hampton Barnett, Tennessee Valley Authority, Chattanooga

R. Barnstead, Aerospace Corporation, Washington DC

D. Barron, Delco-Remy Div., GMC, Anderson, IN

R. Bassett, Sandia National Laboratory, Albuquerque

W. Bauer, Hittman Associates Inc., Columbia, MD
 W. Bauer, KW Battery, Skokie, IL
 E. Baumann, LILCO, Mineola, NY
 W. C. Beasley, Union Carbide Corporation, New York, NY
 H. Bell, Arizona Public Service Co., Phoenix
 J. Bellack, Cleveland Electric Illuminating Co., Cleveland
 W. R. Benn, Great Lakes Carbon Corporation, New York
 D. Bennion, Brigham Young University, Provo, UT
 D. Bergmann, GM Transportation Systems Center, Warren, MI
 L. Berkowitz, Esso Research Co., Linden, NJ
 C. Berlsterling, C. Franklin Research Institute, Philadelphia
 J. Birk, Electric Power Research Institute, Palo Alto
 W. S. Bishop, Air Force Aero Propulsion Lab, Wright-Patterson AFB
 D. P. Boden, C&D Batteries, Plymouth Meeting, PA
 B. Borisoff, Borisoff Engineering, Van Nuys, CA
 D. Borrello, Die Mesh Corporation, Pelham, NY
 A. Borucka, Borucka Research Co., Livingston, NJ
 P. Bowen, C&D Batteries, Plymouth Meeting, PA
 D. Bowman, Globe Battery Division, Milwaukee, WI
 D. Bowman, United States Postal Service, Washington
 J. C. Boylan, Electric Dynamics Corp., Plainwell, MI
 B. J. Bragg, Bell Laboratories, Murray Hill, NJ
 J. Brennand, General Research Corp., Santa Barbara
 A. F. Brewer, Malibu, CA
 D. C. Briggs, Philco-Ford Corp., Palo Alto
 P. Bro, P. R. Mallory & Co., Inc., Burlington, MA
 J. Broadhead, Bell Laboratories, Murray Hill, NJ
 E. P. Broglio, Eagle-Picher Industries, Joplin, MO
 A. D. Brown, EVE Electric Motor Car, Inc., East Lansing, MI
 P. J. Brown, DOE, Office of Vehicle and Engine Research and Development,
 Washington
 R. A. Brown, Eagle-Picher Industries, Joplin, MO
 B. S. Brummer, EIC Corporation, Newton, MA
 R. Buchholz, Honeywell Corp., Minneapolis
 A. J. Burgess, Lucas Industries, Inc., Troy, MI
 H. Burghart, Cleveland State University, Cleveland
 D. Burns, Onan Corporation, Minneapolis
 R. Burns, Marathon Battery Corp., Waco, TX
 B. W. Burrows, Gould Inc., Rolling Meadows, IL
 M. Burtgon, Delco-Remy Div. of GMC, Anderson, IN
 J. D. Busi, USA Foreign Science & Tech. Center, Charlottesville, VA
 E. Buzzelli, Westinghouse Electric Corp., Pittsburgh
 W. P. Cadogan, Emhart Corp., Hartford, CT
 E. Cairns, Lawrence Berkeley National Lab.
 E. Campbell, Electric Vehicle Consultants, Inc., New York, NY
 P. Campbell, University of Southern California, Los Angeles
 J. Campbell, DOT/UMTA, Washington, DC
 R. T. Carpenter, Kimberly Clark Corp., Neenah, WI
 A. Charkey, Energy Research Corp., Danbury, CT
 L. D. Christian, General Electric, Gainesville
 R. C. Chudacek, McGraw Edison Co., Bloomfield, NH
 R. Clark, Sandia National Lab., Albuquerque
 J. E. Clifford, Battelle Memorial Institute, Columbus
 J. A. Consiglio, Solva-Tek Associates, Topsfield, MA

K. E. Cooper, Trojan Battery Co., Santa Fe Springs, CA
 G. Coraor, E. I. DuPont de Nemours & Co., Inc., Wilmington, DE
 R. E. Corbett, Lockheed Missiles & Space Co., Sunnyvale
 D. Crane, United States Postal Service, Washington
 R. A. Crawford, PPG Industries, Barberton, OH
 C. Dacres, White Oak, Silver Spring, MD
 R. H. Dare, Batronic Truck Corp., Boyertown, PA
 D. Davis, Lawrence Livermore National Laboratory
 R. J. Dawson, Exide Management and Technology Co., Madison, WI
 G. A. DeBari, INCO, Sterling Forest, Suffern, NY
 R. DePaul, MPD Technology Corp., Wyckoff, NJ
 A. N. Dey, P. R. Mallory & Co. Inc., Burlington, MA
 W. J. Dippold, DOE, Office of Vehicle and Engine Research and Development, Washington
 T. P. Dirske, Calvin College, Grand Rapids, MI
 D. DiVirgilio, Lockheed Missiles and Space Co. Inc., Sunnyvale
 D. Douglas, Electric Power Research Institute, Palo Alto
 J. Doe, International Lead Zinc Research Organization, Inc., New York, NY
 D. Dow, Detroit, MI
 D. Dunoye, Reston, VA
 T. Dwyer, Corning Glass Works, Corning, NY
 E. F. Echolds, AiResearch Manufacturing Co., Torrance, CA
 M. Eisenberg, Electrochimica Corp., Mountain View, CA
 D. B. Eisenhaure, Charles Stark Draper Lab., Inc., Cambridge, MA
 T. Eissenberg, Oak Ridge National Lab.
 D. Elson, Black and Decker Inc., Towson, MD
 C. English, University of New Mexico, Albuquerque
 R. English, General Battery Co., Reading, PA
 R. Enters, McGraw Edison Co., Bloomfield, NJ
 E. C. Essig, Long Island Lighting Co., Mineola, NY
 G. Farbman, Westinghouse Electric Corp., Pittsburgh
 W. Feduska, Westinghouse Electric Corp., Pittsburgh
 W. H. Fengler, Meteor Research Limited, Roseville, MI
 F. Feres, KW Battery Co., Skokie, IL
 R. Ferraro, Electric Power Research Institute
 D. T. Ferrell, Exide Management and Technology Co., Yardley, PA
 E. Fiss, Duke Power Co., Charlotte, NC
 A. Fleischer, Orange, NJ
 C. W. Fleischmann, C&D Batteries, Plymouth Meeting, PA
 R. F. Fogle, North American Rockwell, Anaheim
 R. T. Foley, American University, Washington, DC
 F. Fontana, Consolidated Edison Co., Astoria, NY
 L. R. Foote, Vehicle Systems Department, Ford Motor Co., Dearborn, MI
 J. S. Fordyce, NASA Lewis Research Center
 H. A. Fuggiti, Exide Management and Technology Co., Yardley, PA
 T. Fujita, Pasadena, CA
 B. Ganji, KW Battery Co., Skokie, IL
 G. Gelb, Advanced Ground Systems, Long Beach, CA
 M. Genge, IIT Research Institute, Chicago, IL
 J. H. B. George, George Consulting International Inc., Concord, MA
 S. Geppert, Eaton Corporation, Southfield, MI
 L. J. Gerlach, United States Postal Service, Rockville, MD
 T. Gerstenberger, Northrop, Hawthorne, CA
 J. A. Gilchrist, Chloride America, Tampa

W. Gillespie, Structural Plastics Inc., Tulsa
 J. R. Gilmore, Ford Motor Co., Dearborn, MI
 C. Glassman, Transportation Research Center, East Liberty, OH
 H. Glixon, Chevy Chase, MD
 M. Globerman, General Services Administration, Washington
 W. Goldman, Electric Vehicle Engineering, Lexington, MA
 G. Goodman, Globe Battery Division, Milwaukee
 J. Gould, Unique Mobility Inc., Englewood, CO
 L. B. Gratt, IWG Corp., San Diego
 V. Green, U.S. Naval Weapons Center, China Lake, CA
 G. Greenberg, Electric Vehicle Battery Technology, Stamford, CT
 D. Griter, Solar Centra, Mechanicsburg, OH
 E. E. Grough, Lucas Industries Inc., Troy, MI
 R. Guess, General Electric Research Lab., Schenectady
 R. G. Gunther, General Motors Research Labs., Warren, MI
 M. Hadden, Billing Energy Corp., Provo, UT
 G. Hagey, DOE, Division of Technology Overview, Washington
 H. Hamilton, University of Pittsburgh
 W. Hamilton, General Research Corp., Santa Barbara
 B. Hamlen, Exxon Enterprises Inc., Florham Park, NJ
 D. Hanify, Fiat, Chicago
 K. L. Hanson, General Electric Co., Philadelphia
 W. Harhay, Electric Vehicle Associates, Cleveland
 G. Hartman, Exide Management and Technology Co., Yardley, PA
 J. Hartman, General Motors Research Labs., Warren, MI
 W. Harvey, Arlington, MA
 C. Hayden, General Telephone and Electronics, Stamford, CT
 E. A. Heintz, Airso Speer Carbon Graphite, Niagara Falls, NY
 E. V. Hellman, EDA, Madison Heights, MI
 R. Heppenstall, Penn Jersey Suburu Inc., Pennsauken, NJ
 A. Himy, Naval Sea Systems Command, Washington
 V. Hlavin, NASA Lewis Research Center
 M. Hodgman, General Electric, Gainesville
 R. Hoenburg, Mechanical Technology Inc., Latham, NY
 J. Hooker, Electric Motor Cars, Dallas, TX
 R. Hudson, Eagle-Picher Industries, Joplin, MO
 J. R. Huff, US Army Mobility Equipment R&D Command, Fort Belvoir, VA
 H. L. Hughes, Oklahoma State University, Stillwater
 W. Hull, USPS Research and Development Laboratory, Rockville, MD
 H. Hwang, University of Hawaii at Manoa, Honolulu, Hawaii
 B. Iseard, Freeport, Bahamas
 H. R. Ivey, Wood-Ivey Systems Corp., Winter Park, FL
 J. Jacus, Moore Haven, FL
 M. A. Jansen, Allegheny Power Service Corporation, Greensburg, PA
 G. H. Jantz, Rensselaer Polytechnic Institute
 A. W. Johnson, General Electric Co., Philadelphia
 L. Jokl, MERADCOM, Fort Belvoir, VA
 K. R. Jones, Thiensville, WI
 W. J. Jones, Westinghouse Electric Corp., Pittsburgh
 E. Kanter, Gulton Battery Corp., Metuchen, NJ
 N. Kaplan, Harry Diamond Laboratories, Washington
 V. Kapur, Arco Solar Inc., Chatsworth, CA
 R. Kaylor, Kaylor Energy Products, Menlo Park
 J. Keith, Kaman Sciences, Colorado Springs, CO

J. G. Kennard, NASA Lewis Research Center
 R. L. Kerr, Aero Propulsion Lab., Wright Patterson AFB
 J. A. Kerrella, Delco-Remy Division/GMC, Anderson, IN
 R. A. Keyes, Robert A. Keyes Associates, Martinsville, IN
 R. S. Kirk, DOE, Office of Vehicle and Engine Research and Development, Washington
 M. Klein, Energy Research Corporation, Danbury, CT
 G. B. Kliman, General Electric Co., Schenectady
 G. B. Klinean, General Electric Co., Schenectady
 R. C. Knechtli, Malibu, CA
 R. A. Knight, AMF Inc., Stamford, CT
 O. R. Kozak, American Battery Corp., Long Beach, NY
 J. G. Krisilas, Aerospace Corporation, El Segundo, CA
 P. E. Krouse, Exide Management & Technology Co., Yardley, PA
 R. R. Kubalek, St. Joe Lead Co., Clayton, MD
 L. Kulin, Whirlpool Corp. Benton Harbor, MI
 C. M. Langkau, Union Carbide Co., Cleveland
 H. Lauve, Electric Transportation Management, Inc., Fort Lauderdale, FL
 E. Lawlor, Membrana Incorporated, Chicago, IL
 J. Lee, RAI Research Corp., Hauppauge, NY
 I. J. Levine, Consolidated Edison, New York
 H. Lim, Hughes Research Lab., Malibu, CA
 D. Linden, Little Silver, NJ
 E. Ling, Revere Research, Inc., Edison, NJ
 E. L. Littauer, Lockheed Palo Alto Research Laboratory
 J. Long, Jet Propulsion Laboratory, Pasadena, CA
 P. Lu, Westinghouse Electric Corporation, Pittsburgh, PA
 J. T. Lundquist, W. R. Grace & Co., Columbia, MD
 T. Lynch, Fiber Materials, Inc., Biddeford, ME
 D. E. Mains, Naval Weapons Support Center, Crane, IN
 J. Mader, Electric Power Research Institute, Palo Alto, CA
 J. Maisel, Cleveland State University, Cleveland
 J. S. Makulowich, Electric Vehicle Council, Washington
 V. Manson, National Aeronautics and Space Adm., Washington
 L. Mapa, KW Battery, Skokie, IL
 L. S. Marcoux, Hughes Aircraft Company, Los Angeles
 T. W. Martin, United States Postal Service, San Bruno, CA
 J. Masson, Martin Marietta Corp., Denver, CO
 V. Matricardi, Aerospace Corp., Washington, DC
 C. E. May, NASA Lewis Research Center
 E. Meeks, Derl Manufacturing Co., Compton, CA
 L. Mercatanti, Advanced Vehicle Technology Inc., Princeton, NJ
 P. Mighdoll, Booz-Allen & Hamilton, Cleveland
 R. P. Mikkelsen, General Dynamics, San Diego
 D. G. Miley, U.S. Naval Ammunition Depot, Crane, IN
 H. Miller, Department of Transportation, Cambridge, MA
 D. K. Miner, Copper Development Associates, Birmingham, MD
 R. Miner, DOE, Office of Vehicle and Engine Research and Development, Washington
 L. G. Morin, Tarrytown, NY
 F. Morse, Silver Spring, MD
 A. Moss, Leesona Moos Laboratories, Warwick, RI
 R. Mueller, University of California, Berkeley
 J. H. Muir, Dimension V Inc., Indialantic, FL

J. P. Mullin, National Aeronautics & Space Administration, Washington
 G. Murphy, Northwestern University
 N. T. Musial, Nasa Lewis Research Center
 B. McCormick, Los Alamos Scientific Lab.
 L. R. McCoy, Energy Systems Group, Canoga Park
 A. H. McCutcheon, Texas State University, Waco, TX
 R. McKee, McKee Engineering, Palatine, IL
 F. McLarnon, Lawrence Berkeley National Lab.
 J. N. McNamara, Northrop Corporation, Hawthorne, CA
 P. McRay, ILC Technology, Sunnyvale
 W. J. Nagle, NASA Lewis Research Center
 J. Newman, Univ. of California, Berkeley
 J. S. Newton, Newton Engineering Co., Glen Ellyn, IL
 A. O. Nilsson, NIFE Incorporated, Lincoln, RI
 A. C. Occhipinti, Kenner, LA
 L. G. O'Connell, Lawrence Livermore Lab.
 G. Odom, Georgia Power Company, Atlanta, GA
 R. Oglesby, GM Transportation Systems Ctr., Warren, MI
 J. M. Olsen, Detroit Edison, Detroit, MI
 L. Omohundro, Kingery Research & Development, Wake Forest, NC
 E. I. Onstott, Los Alamos Scientific Lab
 R. Osteryoung, State University of New York at Buffalo
 B. N. Otzinger, North American Aviation, Downey, CA
 J. P. Overman, Hammond Lead Products Inc., Hammond, IN
 J. E. Oxley, Olin Corp. New Haven, CT
 E. Papandreas, REI, Lake Worth, FL
 J. S. Parkinson, Johns-Manville R&D Center, Manville, NJ
 J. M. Parry, Arthur D. Little Inc., Cambridge, MA
 E. Patagalia, General Services Administration, Washington
 S. Pauling, Naperville, IL
 J. E. Pavolsky, NASA/Lyndon B. Johnson Space Ctr., Houston
 J. P. Pemsler, Castle Technology Corp., Woburn, MA
 G. F. Pezdirtz, DOE, Office of Advanced Conservation Technology, Washington
 A. Pivec, Public Service Electric and Gas, Newark, NJ
 A. G. Plunkett, General Electric R&D Center, Schenectady
 R. A. Powers, Union Carbide Corp., Cleveland
 V. J. Puglisi, Yardney Electric Corp., Pawcatuck, CT
 A. D. Raynard, AiResearch Manufacturing Co., Torrance, CA
 E. C. Read, Exxon Enterprises, Linden, NJ
 H. L. Recht, Atomics International Division, Canoga Park
 C. Ridgway, Walt Disney World Co., Lake Buena Vista, FL
 W. Rippel, Jet Propulsion Laboratory, Pasadena
 E. Rizkalla, DOE, Office of Controller, Washington
 R. A. Rizzo, Globe Battery Division, Milwaukee
 R. Robert, The MITRE Corporation, McLean, VA
 F. T. Rooney, Bureau of Automotive Maintenance, Norfolk, VA
 L. Rosenblum, NASA Lewis Research Center
 N. Rosenberg, Department of Transportation, Cambridge, MA
 R. Rosey, Westinghouse, Pittsburgh
 J. Rossmon, Cornell University
 C. V. Rowan, Philadelphia Electric Co., Philadelphia, PA
 G. Rowland, General Electric, Schenectady
 H. E. Ruskie, Naval Intelligence Support Center, Washington
 A. J. Salkind, Rutgers Medical School, Piscataway, NJ

R. T. Schneider, RTS Laboratories, Gainesville, FL
 L. W. Schopen, NASA Lewis Research Center
 H. J. Schwartz, NASA Lewis Research Center
 W. R. Scott, TRW Systems Inc., Redondo Beach
 H. Seiger, Harvey Seiger Associates, Waterford, CT
 J. Seliber, Fluid Drive Engineering Co., Wilmette, IL
 E. Seo, Gates Energy Products, Denver, CO
 L. Shahnasarian, Elcar Corp., Elkhart, IN
 R. C. Shair, CENTEC Corporation, Fort Lauderdale
 H. Shalit, ARCO Chemical Corp., Glendolden, PA
 D. W. Sheibley, NASA Lewis Research Center
 G. L. Silverman, Ford Motor Co., Dearborn, MI
 G. A. Smith, Englehard Industries, Iselin, NJ
 V. Smith, Delco-Remy Div. GMC, Anderson, IN
 J. Smits, Nevada Operations Office, Las Vegas
 I. J. Soloman, IIT Research Institute, Chicago
 W. C. Spindler, Electric Power Research Institute, Palo Alto
 J. S. Stanley, U.S. Army Foreign Sci. & Tech. Center, Charlottesville, VA
 E. J. Steeve, Commonwealth Edison Co., Chicago
 I. Stein, Jet Propulsion Laboratory, Pasadena
 T. A. Stoneham, Marathon Battery Company, Waco, TX
 R. Strauss, Communications Satellite Corp., Clarksburg, MD
 W. E. Strawbridge, Caterpillar Tractor Co., Peoria, IL
 R. L. Strombotne, DOE, Department of Transportation, Washington, DC
 S. Sudar, Rockwell International, Canoga Park
 F. Swoboda, GMC Truck and Coach, Pontiac, MI
 P. C. Symons, Birmingham, MI
 F. Tepper, Catalyst Research Corp., Baltimore
 R. Thacker, General Motors Research Labs, Warren, MI
 G. Thiess, Electric Motor Cars, Dallas, TX
 C. E. Thomas, Chrysler Corporation, New Orleans, LA
 F. Thomas, Grumman Aerospace Corp., Bethpage, NY
 M. Thorpe, Towson, MD
 G. M. Thur, DOE, Office of Vehicle and Engine Research and Development, Washington
 W. H. Tiedemann, Globe Battery Division, Milwaukee
 C. W. Tobias, University of California, Berkeley
 A. Topouzian, Ford Motor Co., Dearborn, MI
 W. Toth, Society of Automotive Engineers, Inc., Warrendale, PA
 H. Toulmin, Bloomfield, MI
 I. Trachtenberg, Texas Instruments, Dallas
 J. C. Trocciola, United Technologies Corp., South Windsor, CT
 G. W. Tuffnell, The International Nickel Co., Troy, MI
 D. Turford, Western Mining Corp., Pittsburgh
 G. H. Turney, Western Research Industries, Las Vegas, NV
 E. A. Ulrich, Creative Automotive Research, Whittier, CA
 R. L. Ulrich, General Services Administration, Washington
 T. Ulrich, McGraw-Edison Co., Bloomfield, NJ
 G. Underhill, A. D. Little, Cambridge, MA
 H. B. Urbach, Naval Ship R&D Center, Annapolis, MD
 H. Vaidyanathan, Energy Research Corp., Danbury, CT
 C. J. Venuto, C&D Batteries, Plymouth Meeting, PA
 S. W. Vreeland, General Dynamics, Convair Division, San Diego
 A. Waddell, EBCO Battery Co., Columbus, GA

G. Walker, DOE, Office of Vehicle and Engine Research and Development, Washington
 R. Walker, University of Florida, Gainesville
 C. H. Waterman, C. H. Waterman Industries, Althol, MA
 G. Way, Troy, MI
 R. D. Wehrle, Sandia National Labs, Albuquerque, NM
 S. A. Weiner, Ford Motor Co., Detroit, MI
 C. Weinlein, Globe Battery Division, Milwaukee
 M. Weinreb, Con Edison, New York
 E. Y. Weissman, GASF Wyandotte Corp., Wyandotte, MI
 H. B. West, McGraw-Edison Company, Bloomfield, NJ
 J. H. Whitmore, Binghamton, NY
 J. Wiegmann, Booz-Allen & Hamilton, Bethesda, MD
 M. E. Wilke, Burgess Battery Company, Freeport, IL
 R. Wilks, Lavelle Aircraft Co., Newton, PA
 C. F. Williams, Teledyne Isotopes, Timonium, MD
 H. R. Williams, Detroit Edison Co., Detroit
 J. M. Williams, E. I. duPont de Nemours & Co., Wilmington, DE
 E. Willhnganz, C&D Batteries, Plymouth Meeting, PA
 N. L. Willmann, Delco Remy Div. of GMC, Anderson, IN
 J. F. Wing, Booz-Allen & Hamilton Inc., Bethesda, MD
 R. Wood, Electric Transportation Systems, Denver, CO
 G. A. Wooldrige, Boeing Aerospace Co., Seattle
 V. Wouk, Petro-Electric Motor Ltd., New York
 W. Wylam, Delco-Remy, Anderson, IN
 R. A. Wynveen, Life Systems Inc., Cleveland
 L. Yanni, Booz-Allen and Hamilton, Bethesda, MD
 H. Yoder, Battronic Truck Corp., Boyertown, PA
 M. Yontar, Jersey City, NJ
 R. Zalosh, Factory Mutual Research, Norwood, MA
 J. E. Zanks, NASA Langley Research Center, Hampton, VA
 D. Ziemer, GMC Truck and Coach, Pontiac, MI
 M. Zlotnick, DOE, Div. of Conservation Research and Technology, Washington

Do not
micronize