

## APPENDIX A

### TYPICAL PERFORMANCE CHARACTERISTICS OF LEAD-ACID BATTERIES AND CELLS

Representative data is summarized in the following appendices giving discharge and cycle life characteristics of cells and modules of the four major lead-acid battery types: pure lead flat plate, lead-calcium flat plate, lead-antimony flat plate and tubular positive lead-antimony.

Data is given for these parameters:

- Discharge voltage vs. depth of discharge
- Energy output and energy density per unit weight and volume at 25<sup>0</sup>C with estimates for 0<sup>0</sup>C and -18<sup>0</sup>C.
- Wet life and estimated cycle life Vs depth of discharge on cycling regimes.

This data is calculated from manufacturer's specification sheets, observed in laboratory tests on small samples of cells, or estimated from the performance of similar cells tested under the same conditions.

## APPENDIX A-I

### PURE LEAD CHARGE RETAINING BATTERIES (I 10-600 Ah)

- Figure A-1-1 Discharge Voltage Vs Percent Time to End Voltage, 11 to 500 Hour Discharge Rate, 110, 220, and 600 Ah Cells, 1.300 Specific Gravity, 25<sup>0</sup>C.
- Figure A-1-2 Energy Density per Unit Weight, Charge Retaining 110, 220 and 600 Ah Cells Vs Discharge Rate, 10-500 h, 25<sup>0</sup>C.
- Figure A-1-3 Energy Density per Unit Volume, Charge Retaining 110, 220 and 600 Ah Cells Vs Discharge Rate, 10-500 h, 25<sup>0</sup>C.
- Table A-1-1 Discharge Energy Output Vs Discharge Rate, 600 Ah Low Rate Charge Retaining Cell, 25<sup>0</sup>C.

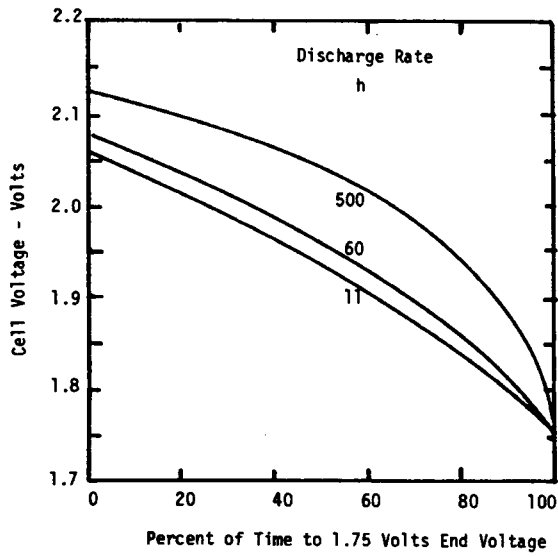


Figure A-1-1 Discharge Voltage vs. Discharge Rate, 11-500 Hours, Low Rate 110, 220 and 600 Ah Charge Retaining Pure Lead Cells, 1.300 Specific Gravity, 25°C.

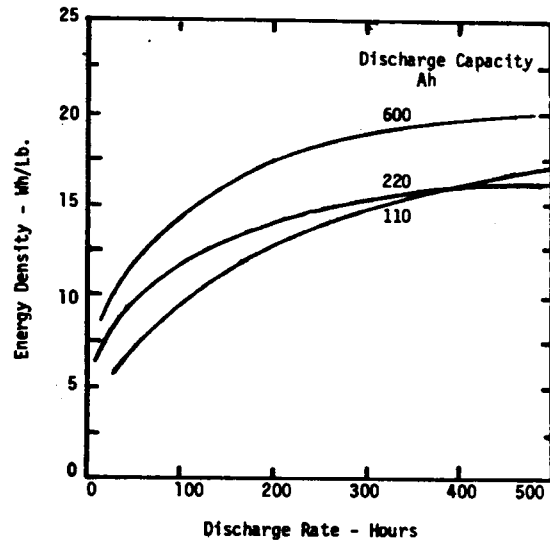


Figure A-1-2 Energy Density per Unit Weight vs Discharge Rate, 11-500 Hours, Low Rate Charge Retaining Pure Lead Cells, 110-600 Ah, 1.300 Specific Gravity, 25°C.

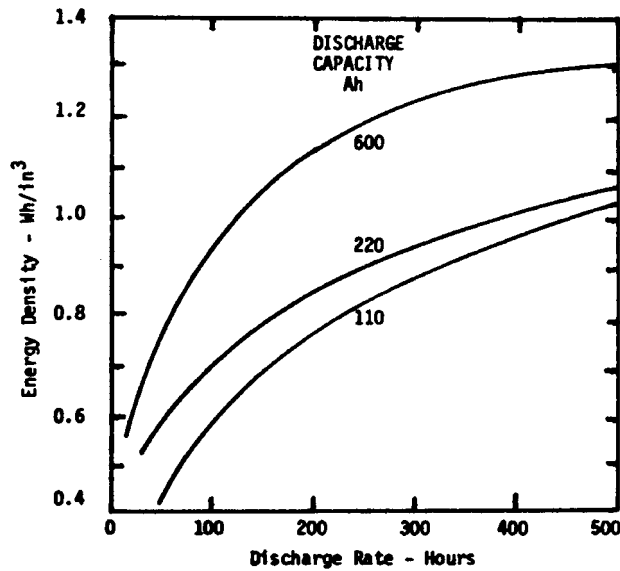


Figure A-1-3 Energy Density per Unit Volume vs Discharge Rate, 11 to 500 Hour Rate, Low Rate Charge Retaining Pure Lead Cells, 110-600 Ah, 1.300 Specific Gravity, 25°C.

TABLE A-1-1

Discharge Energy Output vs. Discharge Rate  
600 Ah Low Rate Charge Retaining Cell, 25<sup>0</sup>C

Discharge Time	Capacity Current	Energy to 1.8 V	Energy Density to 1.8 V Output		
			Wh	Wh/lb.	Wh/in <sup>3</sup>
h	A	Ah			
600	1.0	600	1210	21	1.38
160	3.0	480	960	17	1.09
80	5.0	400	780	13	.88
50	7.0	350	680	12	.77
30	10.0	300	580	10	.66

Cell Dimensions, inches:

H	14.0
L	7.6
W	8.3
Volume:	880 in <sup>3</sup>
Cell Weight:	58 lbs.

Note: Charged and maintained in accord with manufacturer's operating instructions.

## APPENDIX A-2

### LEAD-CALCIUM PASTED FLAT PLATE CELLS (50-200 Ah)

- Table A-2-1      Energy Output, Energy Density at 25, 0 and -18<sup>0</sup>C of 50, 100 and 200 Ah Cells at the 1, 3, 8 and 500 Hour Discharge Rate.
- Figure A-2-1      Cell Voltage vs. Percent Time to Final Voltage of 50-200 Ah Cells at 25<sup>0</sup>C, 1.215 Specific Gravity Sulfuric Acid.
- Figure A-2-2      Energy Density per Unit Weight vs. Discharge Rate (Hours) at 25<sup>0</sup>C, 50-200 Ah Cells, 1.215 Specific Gravity Acid.
- Figure A-2-3      Energy Density per Unit Volume vs. Discharge Rate (Hours) at 25<sup>0</sup>C, 50-200 Ah Cells, 1.215 Specific Gravity Acid.

TABLE A-2-1

Energy Density vs. Discharge Rate and Operating Temperature  
Lead-Calcium Flat Plate Cells

50-200 Ah

Discharge Rate	Cell Capacity (Nominal)	Energy Output to 1.75 V/c 25 <sup>0</sup> C	Energy Density at Operating Temperature, <sup>0</sup> C					
			Wh/lb.			Wh/in <sup>3</sup>		
h	Ah	Wh	25	0	-18	25	0	-18
500	50	371	11.2	8.4	4.5	.44	.33	.18
	100	784	11.5	8.7	4.6	.93	.70	.37
	200	1568	12.9	9.5	4.6	1.07	.80	.43
8	50	185	5.7	4.3	2.3	.22	.17	.09
	100	564	8.3	6.2	3.3	.57	.43	.23
	200	1128	9.3	7.0	3.7	.77	.58	.31
3	50	144	4.4	3.3	1.8	.17	.13	.01
	100	431	6.3	4.8	2.5	.51	.38	.21
	200	860	7.1	5.3	2.9	.58	.44	.23
1	50	99	3.0	2.3	1.2	.12	.09	.05
	100	301	4.4	3.3	1.8	.35	.27	.14
	200	603	4.9	3.7	2.0	.41	.31	.17

Notes: (1)

Cell Size	Module Weight	Module Volume	Module Type
Ah	lb.	in <sup>3</sup>	
50	33	844	2 cells in series
100	68	844	3 cells in series
200	122	1471	3 cells in series

(2) Charged and maintained in accord with manufacturer's operating instructions.

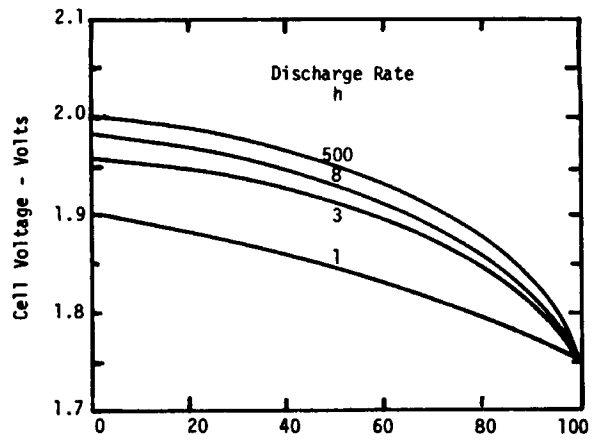


Figure A-2-1 Cell Voltage vs Percent Time to 1.75 Volts End Voltage, Lead-Calcium Cells, 1.215 Specific Gravity, 25°C.

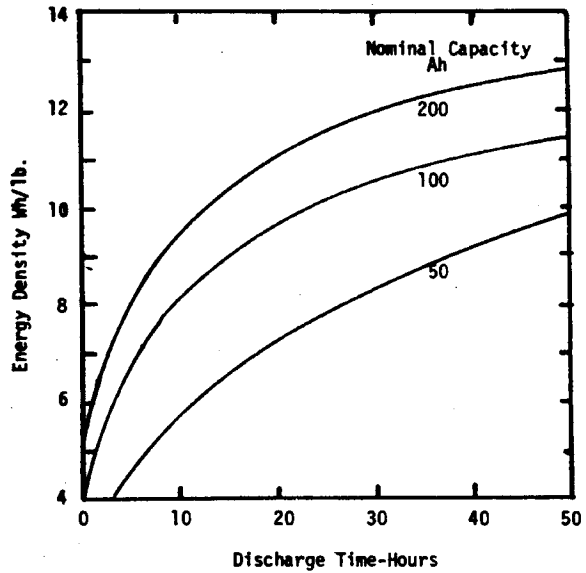


Figure A-2-2 Energy Density per Unit Weight vs Discharge Rate, 50-200 Ah Lead-Calcium Cells, 1.215 Specific Gravity, 25°C.

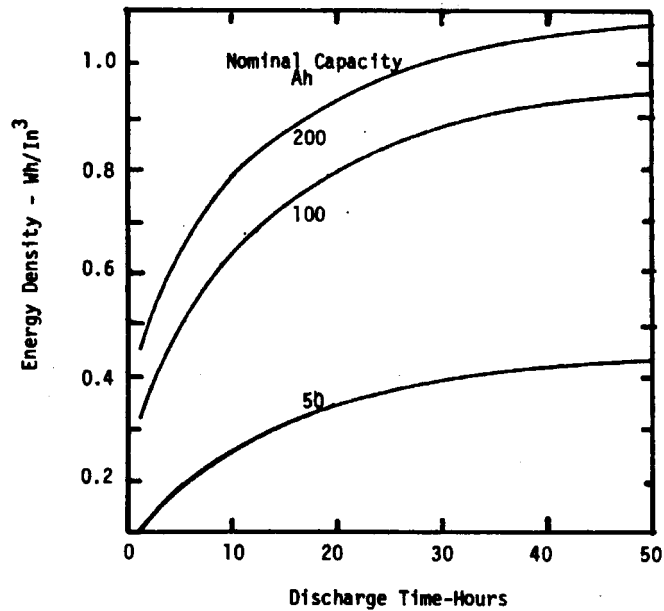


Figure A-2-3 Energy Density per Unit Volume vs Discharge Rate, 50-200 Ah Lead-Calcium Cells, 1.215 Specific Gravity, 25°C.

## APPENDIX A-3

### LEAD-CALCIUM PASTED FLAT PLATE CELLS (1850-3700 Ah)

- Table A-3-1 Energy Output <sup>A-2-</sup> Energy Density vs. Discharge Rate, 1, 3, 8 and 500 Hours at -18, 0 and 25<sup>0</sup>C.
- Figure A-3-1 Discharge Cell Voltage vs. Percent of Time to 1.75 Volts End Voltage, 1, 3, 8 and 500 Hour Discharge Rate, 25<sup>0</sup>C.
- Figure A-3-2 Energy Density per Unit Weight vs. Discharge Rate, 1-500 Hours, 25<sup>0</sup>C.
- Figure A-3-3 Energy Density per Unit Volume vs. Discharge Rate, 1-500 Hours, 25<sup>0</sup>C.



TABLE A-3-1

Energy Density vs. Discharge Rate and Operating Temperature  
Lead-Calcium Flat Plate Cells  
(1020-3700 Ah)

Discharge Rate h	Cell Capacity (Rated 8-h) Ah (8-h)	Energy Output to 1.75 V/c 25 <sup>0</sup> C Wh (25 <sup>0</sup> C)	Energy Density at Operating Temperature, <sup>0</sup> C						
			Wh/Lb.		Wh/in <sup>3</sup>				
			25	0	-18	25	0	-18	25
500	1020	5472	13.6	10.2	5.4	1.11	.83	.45	
	1850	5350	14.0	10.5	5.6	1.08	.81	.43	
	2530	7086	13.6	10.2	5.4	1.07	.81	.43	
	3150	8345	13.9	10.4	5.5	1.26	.95	.50	
	3700	9300	13.4	10.1	5.4	1.41	1.05	.56	
8	1020	3667	9.1			.75			
	1850	3490	9.2			.71			
	2530	4780	9.2			.72			
	3150	5900	9.9			.90			
	3700	6990	10.1			1.06			
3	1020	2680	6.7	5.0	2.7	.54	.41	.31	
	1850	2460	6.4	4.8	2.6	.50	.37	.19	
	2530	3515	6.8	5.1	2.7	.53	.40	.21	
	3150	4340	7.3	5.4	2.9	.66	.49	.26	
	3700	5190	7.6	5.6	3.0	.78	.59	.32	
1	1020	1567	2.0	1.5	.8	.16	.12	.05	
	1850	1385	3.6	2.7	1.5	.28	.21	.11	
	2530	2080	4.0	3.0	1.6	.32	.24	.13	
	3150	2625	4.3	3.3	1.8	.41	.30	.16	
	3700	3113	4.5	3.4	1.8	.47	.35	.19	

Notes: (1) Cell Size	Weight Volume			Battery Type
	Ah	lb.	in <sup>3</sup>	
	1020	402	4943	2 cells in one jar
	1850	382	4943	single cell
	2530	520	6621	single cell
	3150	601	6621	single cell
	3700	693	6621	single cell

(2) Charged and maintained in accord with manufacturer's operating instructions.

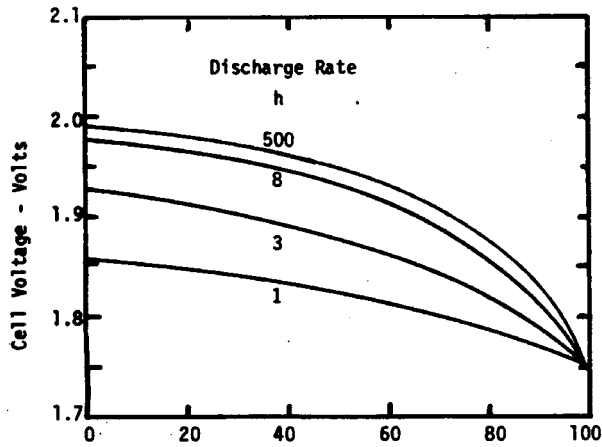


Figure A-3-1 Discharge Cell Voltage vs Percent Time to 1.75V, 1850-3700 Ah Lead-Calcium Cells, 1.215 Specific Gravity, 25°C.

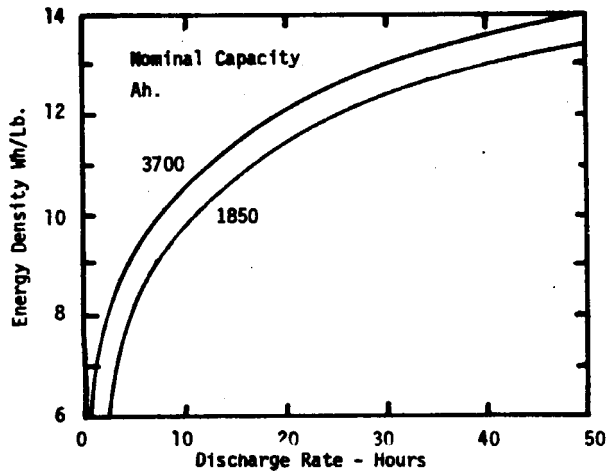


Figure A-3-2 Energy Density per Unit Weight, 1850-3700 Ah Lead-Calcium Cells, 1.215 Specific Gravity, 25°C.

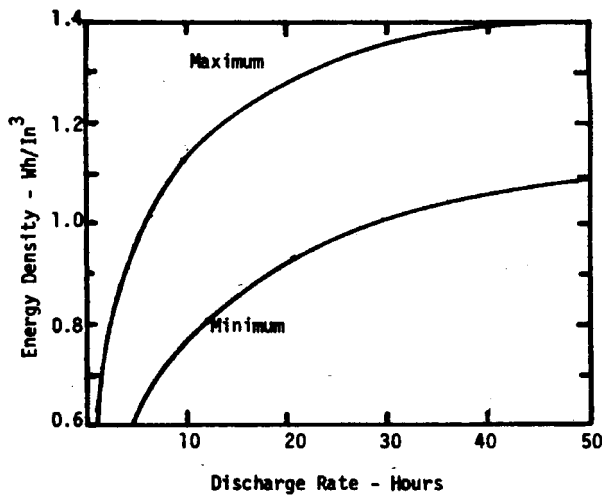


Figure A-3-3 Energy Density per Unit Volume vs. Discharge Rate, 1850-3700 Ah Lead-Calcium Cells, 1.215 Specific Gravity, 25°C.

## APPENDIX A-4

### LEAD-ANTIMONY PASTED FLAT PLATE CELLS (50-200 Ah)

- Table A-4-1 Energy Output and Energy Density per Unit Weight and Volume at -18, 0 and 25<sup>0</sup>C vs. Discharge Rate 1, 8 and 500 Hours to 1.75 Volts per Cell, 50-200 Ah Cells.
- Figure A-4-1 Discharge Voltage vs. Percent Time to End Voltage of 1.75 Volts at 1, 8 and 500 Hour Rate, 25<sup>0</sup>C.
- Figure A-4-2 Energy Density per Unit Weight vs. Discharge Rate, Hours, 25<sup>0</sup>C.
- Figure A-4-3 Energy Density per Unit Volume vs. Discharge Rate, Hours, 25<sup>0</sup>C.
- Figure A-4-4 Wet Life and Cycle Life vs. % Depth of Discharge, 25<sup>0</sup>C.

**TABLE A-4-1**

**Energy Density vs. Discharge Rate and Operating Temperature  
Lead-Antimony Flat Plate Cells  
(50-200 Ah)**

Discharge Rate	Cell Capacity (Nominal)	Energy Output to 1.75 V	Energy Density at Operating Temperature °C					
			Wh/lb.			Wh/in <sup>3</sup>		
h	Ah	Wh (25°C)	25	0	-18	25	0	-18
500	50	249	6.6	5.0	2.6	.29	.22	.11
	100	788	11.6	8.7	4.6	.93	.07	.04
	200	1576	13.0	9.8	5.2	1.10	.83	.44
8	50	191	5.0	3.8	2.0	.23	.17	.09
	100	573	8.4	6.3	3.4	.68	.51	.27
	200	1146	9.5	7.1	3.8	.78	.59	.30
1	50	96	2.5	1.9	1.0	.11	.08	.04
	100	282	4.1	3.1	1.6	.33	.25	.13
	200	574	4.7	3.5	1.9	.39	.29	.16

Cell Notes: (1)

Capacity Ah	Weight LB	Volume in <sup>3</sup>	Module Type
50	38	844	2 Cells in Series
100	68	844	3 Cells in Series
200	121	1471	3 Cells in Series

(2) Charged and maintained in accord with manufacturer's operating instructions.

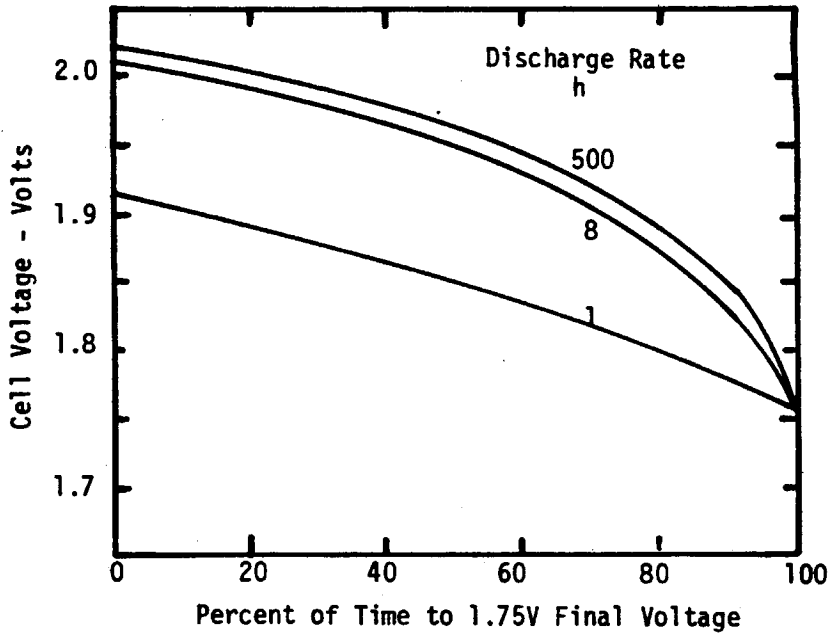


Figure A-4-1 Discharge Voltage vs Percent Time to 1.75V, 50-200 Ah Lead-Antimony Pasted Flat Plate Cells, 1.215 Specific Gravity, 25°C.

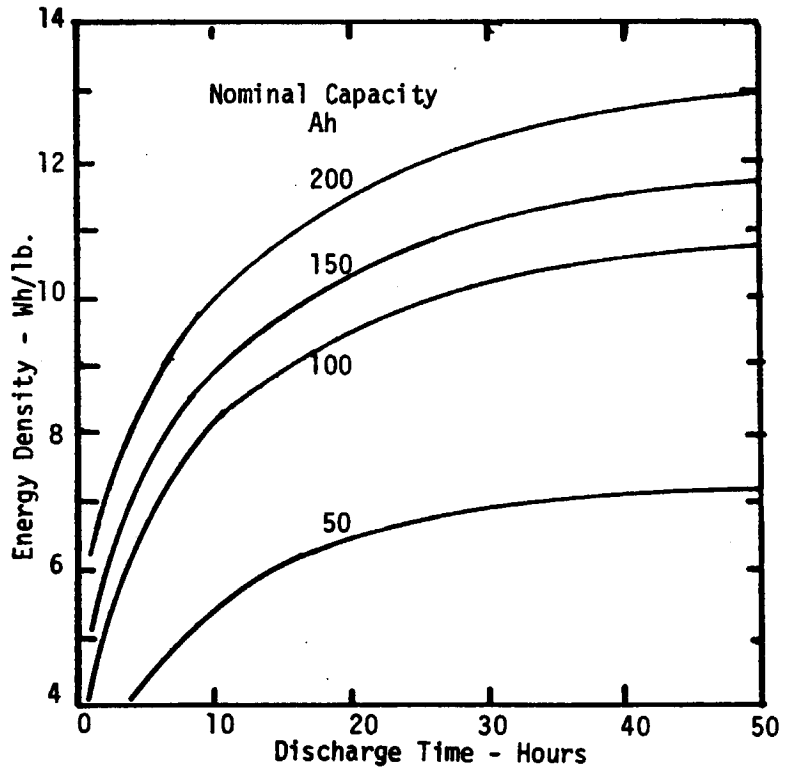


Figure A-4-2 Energy Density per Unit Weight vs Discharge Rate, 1-50 Hours, 50-200 Ah Flat Plate Lead-Antimony Cells, 1.215 Specific Gravity, 25°C.

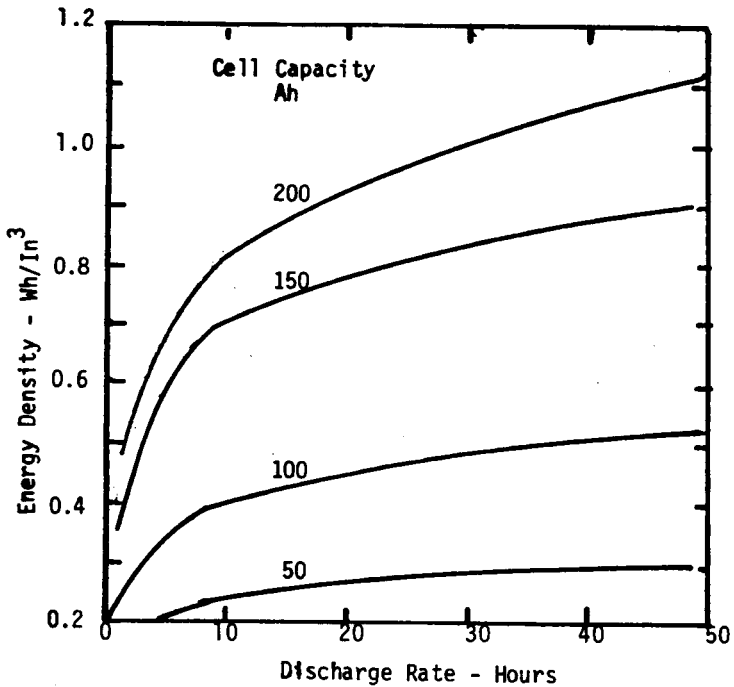


Figure A-4-3 Energy Density per Unit Volume vs Discharge Rate, 1-50 Hours, 50-200 Ah Flat Plate Lead-Antimony Cells, 1.215 Specific Gravity, 25°C.

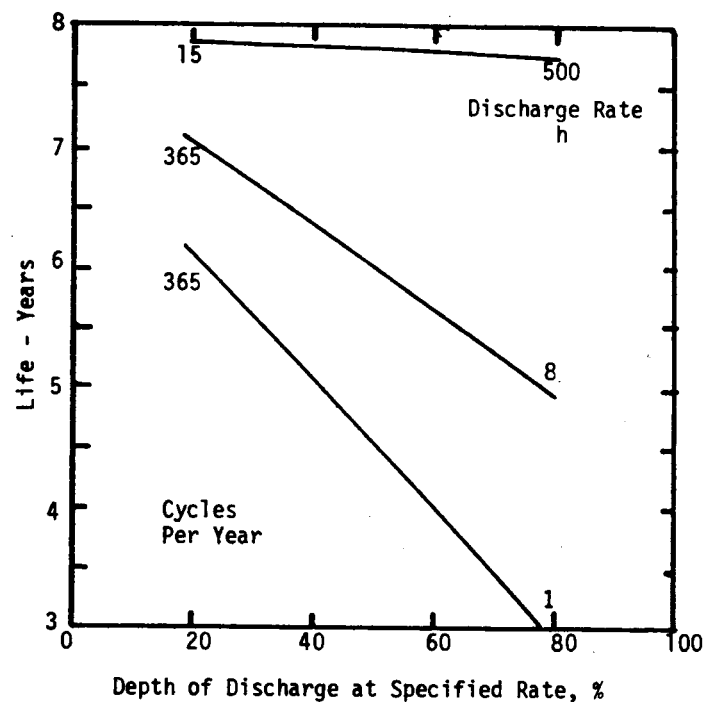


Figure A-4-4 Wet Cycle Life vs. Depth of Discharge, 50-200 Ah Flat Plate Lead-Antimony Cells, 1.215 Specific Gravity, 25°C.

## APPENDIX A-5

### LEAD-ANTIMONY PASTED FLAT PLATE CELLS

(100-900 Ah)

A-4-

- Table A-5-1 Discharge Voltage vs. Discharge Rate and Depth of Discharge, Motive Power Cells, 25<sup>0</sup>C.
- Table A-5-2 Energy Output, Energy Density vs. Discharge Rate 3, 8 and 72-Hours, Motive Power Cells, 25<sup>0</sup>C.
- Table A-5-3 Wet Life and Cycle Life vs. Depth of Discharge, Motive Power Cells, 25<sup>0</sup>C.
- Table A-5-4 Discharge Capacity, Energy Output, and Energy Density, 25<sup>0</sup>C, 6 Volt Electric Vehicle Type Batteries

TABLE A-5-1

Discharge Voltage vs. Discharge Rate and Depth of Discharge  
 Pasted Flat Plate Lead Antimony Industrial Truck Cells

(150-1200 Ah)

Discharge Depth %	Cell Voltage - Volts		
	72-h Rate	8-h Rate	3-h Rate
0	2.10	2.03	1.99
20	2.05	2.00	1.95
40	2.02	1.97	1.92
60	1.98	1.94	1.88
80	1.92	1.88	1.82
100	1.75	1.75	1.75



TABLE A-5-2

Energy Output, Energy Density vs. Discharge Rate 3, 8 and 72-Hours,  
25<sup>0</sup>C, Pasted Flat Plate Motive Power Cells

Discharge Rate	Capacity to 1.70 VPC	Energy Output to 1.70 VPC	Energy Density	
			Unit Weight	Unit Volume
h	Ah	Wh	Wh/lb.	Wh/in <sup>3</sup>
72	327	650	14.1	1.77
	655	1295	16.0	1.94
	980	1940	16.4	1.98
	1310	2595	16.9	2.02
8	240	465	10.1	1.26
	480	930	11.5	1.39
	720	1400	11.9	1.43
	960	1860	12.1	1.45
3	195	365	7.9	.99
	390	735	9.1	1.10
	585	1100	9.3	1.12
	780	1465	9.5	1.14
Nominal 6-Hour Rated Capacity	Cell Weight	Cell Volume		
Ah	lbs.	in <sup>3</sup>		
225	46	368		
450	81	669		
675	118	980		
900	154	1284		

Includes cell share of steel battery tray.

Note: Charged and maintained in accord with manufacturer's operating instructions.

TABLE A-5-3

Wet Life and Cycle Life vs. Depth of Discharge, 25<sup>0</sup>C  
 Pasted Flat Plate Motive Power Cells

Depth of Discharge % 6-Hour Rated Capacity	Cycle Life 2 Cycles per Day (Estimated)	Wet Life (Estimated) Years	Accumulative Output X Rated Capacity C Ah
10	6000	8.5	600 C
30	4400	6.	1320 C
50	3250	4.5	1625 C
80	2000	3.	1600 C

Note: Charged and maintained in accord with manufacturer's operating instructions.

TABLE A-5-4

Discharge Capacity, Energy Output and Energy Density

6V Electric Vehicle Batteries, 25<sup>0</sup>C

Lead-Antimony, Pasted Flat Plate Cells

Nominal Capacity 3-Hour Rate Ah	Discharge Rate h	Discharge Capacity to 1.70VPC Ah	Energy Output to 1.70VPC kWh	Energy Density	
				Per Unit Weight Wh/lb.	Per Unit Volume Wh/in <sup>3</sup>
110	72	180	1.09	18.2	1.56
	24	165	0.99	16.5	1.41
	12	150	0.89	14.9	1.27
	6	135	0.79	13.2	1.13
	3	110	0.64	10.7	0.91
133	72	200	1.22	18.7	1.74
	24	185	1.10	16.9	1.57
	12	170	1.01	15.5	1.44
	6	155	0.91	14.0	1.30
	3	133	0.77	11.8	1.10

Notes: (1) Dimensions, volume, wet weight

Nominal Capacity Ah.	Volume in <sup>3</sup>	Weight, Wet lb.
110	700	59.8
133	700	65.2

(2) Cycle life: about 500 cycles at 80% depth in 500 days wet life in ambient conditions.

## APPENDIX A-6

### LEAD-ANTIMONY TUBULAR POSITIVE CELLS AND BATTERIES (220-1820 Ah)

#### A-5-

- Figure A-6-1 Discharge Voltage vs. Percent Time to End Voltage of 1.75 Volts per Cell at 25<sup>0</sup>C at 1, 8 and 500 Hour Discharge Rate.
- Figure A-6-2 Wet Cycle Life vs. Percent Depth of Discharge, 220-400 Ah Tubular Positive Cells, 1.28 Specific Gravity, 25<sup>0</sup>C.
- Table A-6-1 Energy Output 6-Hour Rate, Energy Density vs. Operating Temperature, -18, 0 and 25<sup>0</sup>C for 12 V Motorized Hand Truck Batteries.
- Table A-6-2 Energy Output, Average Voltage, Energy Density vs. Discharge Rate, 1, 8, 100 and 500 Hours 25<sup>0</sup>C General Purpose Tubular Positive Cells, 760-1820 Ah.
- Table A-6-3 Energy Output, Energy Density vs. Discharge Rate 6, 12 and 72-Hours, 25<sup>0</sup>C Tubular Positive Motive Power Cells, 510-1200 Ah.
- Table A-6-4 Wet Life and Cycle Life vs. Depth of Discharge, Tubular Positive Industrial Truck Cells, 25<sup>0</sup>C.

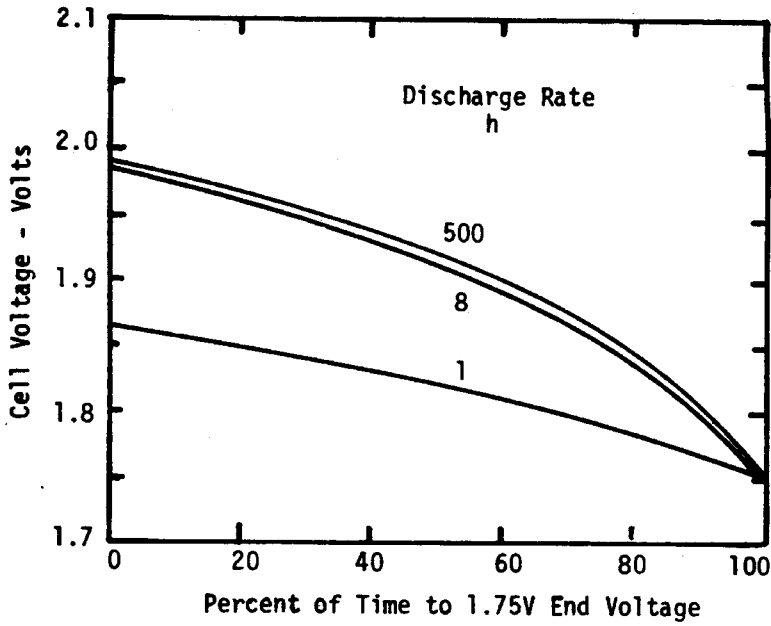


Figure A-6-1 Cell Discharge Voltage vs Percent Time to 1.75V End Voltage, 220-400 Ah Tubular Positive Lead-Antimony Cells, 1.280 Specific Gravity, 25°C.

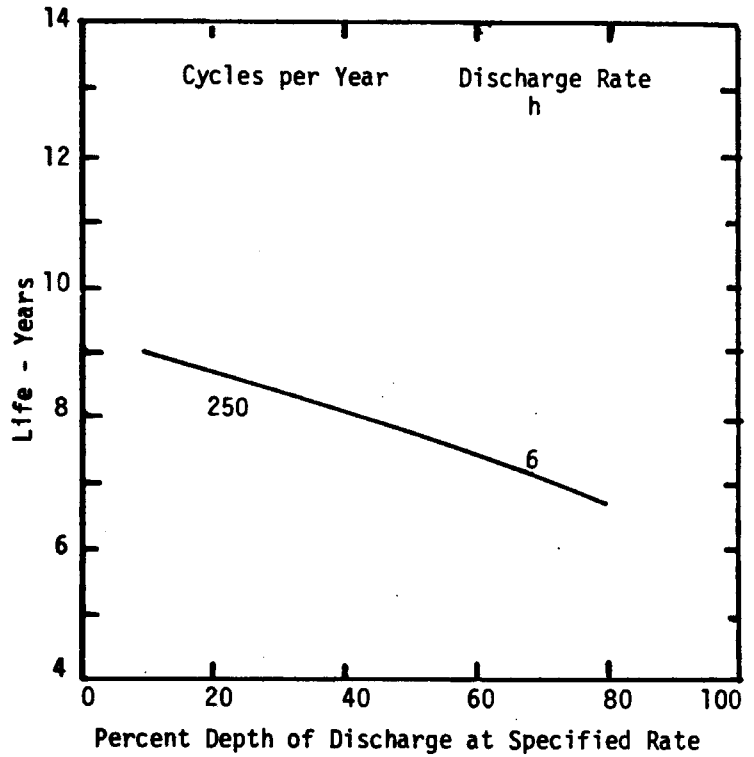


Figure A-6-2 Wet Cycle Life vs Percent Depth of Discharge, 220-400 Ah Tubular Positive Cells, 1.28 Specific Gravity, 25°C.

TABLE A-6-1

Energy Output 6-Hour Rate, Energy Density vs. Operating  
Temperature, -18, 0 and 25°C  
12 V Motorized Hand Truck Batteries

Cell Capacity (Nominal) 6-Hour Rate Ah	Energy Output to 1.75 VPC (1) Wh	12 V Battery (2)			Energy Density at Operating Temperature °C				
		Weight Volume		Per Unit Weight	Per Unit Volume		Per Unit Volume		
		lb.	in <sup>3</sup>		Wh/lb.	Wh/in <sup>3</sup>	-18	0	25
					<u>0</u>	<u>25</u>	<u>-18</u>	<u>0</u>	<u>25</u>
220	2600	236	3060	4.4	8.3	11.0	.34	.64	.85
300	3500	304	4066	4.6	8.6	11.5	.34	.64	.86
340	4000	330	4066	4.5	9.1	12.1	.39	.74	.98
400	4600	347	4547	5.3	9.4	13.3	.41	.76	1.01

Notes: (1) Batteries discharged at 6-h rate to 10.5 V at 25°C.

(2) Nine plate cells assembled as 12 V battery in a steel tray.

(3) Reference: Exide Lead Acid Batteries for Industrial Trucks, Section 20.02, page 1.

(4) Charged and maintained in accord with manufacturer's operating instructions.

TABLE A-6-2

Energy Output, Average Voltage, Energy Density vs. Discharge Rate, 25<sup>0</sup>C  
 General Purpose Tubular Positive  
 Lead-Antimony Cells  
 (760-1820 Ah)

Rate h	Current A	Capacity to 1.75 VPC Ah	Cell Voltage		Energy Output Wh	Energy Density	
			Initial V	Average V		Wh/lb.	Wh/in <sup>3</sup>
500	3.2	1600	2.07	1.99	3185	19.3	1.29
	3.9	1900			3780	17.0	1.28
	4.6	2300			4580	17.0	1.30
	5.8	2900			5770	17.6	1.33
100	13	1300	2.03	1.95	2535	15.4	1.03
	17	1700			3315	14.9	1.12
	21	2100			4095	15.2	1.16
	26	2600			5070	15.5	1.17
8	95	760	1.98	1.90	1445	8.8	0.59
	152	1210			2300	10.3	0.78
	190	1520			2890	10.7	0.82
	228	1820			3460	10.6	0.80
1	330	330	1.84	1.80	590	3.6	0.24
	528	528			950	4.3	0.32
	660	660			1190	4.4	0.34
	792	792			1425	4.4	0.33

Notes: (1)	Cell Capacity 8-h Rate to 1.75 VPC	Weight lb.	Volume in <sup>3</sup>
	760	165	2470
	1210	223	2960
	1520	270	3520
	1820	327	4345

(2) 1.215 acid specific gravity

(3) Float service life expectancy: 22 years.

(4) Charged and maintained in accord with manufacturer's operating instructions.

TABLE A-6-3

Energy Output, Energy Density vs. Discharge Rate, 25<sup>0</sup>C  
 Tubular Positive Lead-Antimony Motive Power Cells  
 (510-1200 Ah)

Discharge Rate	Discharge Capacity to 1.70 VPC	Energy Output to 1.70 VPC	Energy Density (2)	
			Unit Weight	Unit Volume
h	Ah	Wh	Wh/lb.	Wh/in <sup>3</sup>
72	576	1150	14.7	1.67
	763	1525	14.3	1.74
	957	1915	14.3	1.80
	1150	2300	14.8	1.84
	1340	2680	15.0	1.86
12	525	1020	13.1	1.48
	700	1365	12.8	1.56
	875	1705	12.7	1.61
	1050	2050	13.2	1.64
	1230	2400	13.4	1.67
6	510	970	12.4	1.41
	680	1290	12.1	1.47
	850	1620	12.1	1.53
	1020	1940	12.5	1.55
	1195	2260	12.6	1.57

Nominal Cell Capacity 6-Hour to 1.70 VPC	Cell Weight (1)	Cell Volume
Ah	lb.	in <sup>3</sup>
510	78	687
680	107	875
850	134	1062
1020	155	1250
1195	179	1437

- Notes:
- (1) Weight includes cell share of steel battery tray.
  - (2) Reduce output 25% for operation at 0<sup>0</sup>C and 60% for operation at -18
  - (3) Charged and maintained in accord with manufacturer's operating instructions.



TABLE A-6-4

Wet Life and Cycle Life vs. Depth of Discharge, 25<sup>0</sup>C  
Tubular Positive Industrial Truck Cells

Depth of Discharge %	Cycle Life 2 Cycles per Day (Estimated)	Wet Life (Estimated) 25 <sup>0</sup> C Years	Accumulative Output X Rated Capacity C (Estimated) (1) Ah
6-Hour Rated Capacity 10	4600	7	460 C
30	3400	5	1020 C
50	2450	4	1225 C
80	1500	3	1200 C

Notes: (1) Charged and maintained in accord with manufacturer's operating instructions.