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**ANNUAL REPORT FOR 1980 ON
RESEARCH, DEVELOPMENT, AND DEMONSTRATION
OF NICKEL-ZINC BATTERIES FOR
ELECTRIC-VEHICLE PROPULSION
Contract No. 31-109-38-4448**

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

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Prepared for
The Office for Electrochemical Project Management
Argonne National Laboratory
Under Contract No. 31-109-38-4448

by
Exide Management and Technology Company
Yardley, Pennsylvania

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March 1981

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EXECUTIVE SUMMARY

This is the second annual report on ANL contract No. 31-109-38-4448, summarizing work accomplished in the period 1 Sept. 1979 to 31 August 1980. The end of this reporting period corresponds to 16.5 months after the initial receipt of contract. Work at Exide has been carried out in three main development areas. These are:

- 1) Battery Design and Development
- 2) Nickel Cathode Study
- 3) Electrochemical Studies

A summary of the progress in each major area is given below:

1) Battery design and development concentrated on the optimization of design parameters, including electrode spacing, charging methods, electrolyte concentration, the design and fabrication of prototype cells and modules, and testing to verify these parameters. Initial experiments indicated that an interelectrode spacing of 2.5 mm was optimum when normal (D.C.) charging is used. It was during these experiments that a high rate charging technique (C rate) was developed to deposit a dense active zinc which did not shed during vibration. A 4 cell - 300 Ah experimental module was built and sent to NBTI for testing. Initial testing on this module and a 300 Ah cell are reported. Energy density of 42 Wh/Kg was attained on this early model. A single cell (300 Ah), identical in design to the 4 cell module, is presently on 100% D.O.D. life cycle testing at C/3 discharge rate. After 170 cycles the cell exhibited over 90% of initial capacity and is still running.

Experiments on electrolyte concentration are also described, and the indications are that higher concentrations of KOH (8M, 9M or 10M) are beneficial to capacity maintenance.

A proposed 4-cell baseline module design is presented which incorporates a reduced electrode spacing of 1.5 mm.

2) Available nickel cathodes were evaluated for possible use in the VIBROCEL™. These included pocket, sintered plaque impregnated, nickel plated steel wool impregnated, plastic bonded and CMG (multifoil) electrodes. These electrodes have coulombic densities ranging from 70 Ah/Kg for pocket plates to 190Ah/Kg for CMG electrodes. Detailed test data are presented for each type including rate capability, effect of zincate on performance, and capacity maintenance with cycling.

Initial hardware constructed has used sintered nickel electrodes, since these electrodes were available, and were of rugged construction and had good high rate capability. It is our intent to substitute the lighter CMG nickel electrodes in our later models. Performance data for an early bench model VIBROCEL™ with CMG nickel electrodes is presented.

(3) Work on zinc deposition was continued during this period, emphasizing the special charging technique. This is a deposition using special wave forms of charging current, to deposit dense crystalline zinc on the anode substrate. The special charging technique when coupled with vibration, deposits a denser more active zinc (as compared to D.C. charging), which allows us to reduce the VIBROCEL™ inter-electrode spacing to 1.5 mm. Experiments are described showing the optimum conditions of the special charging technique, its beneficial effect on nickel charge acceptance, and finally its incorporation and performance in laboratory cells with 1.5 mm spacing. Power density of cells with 1.5 mm spacing was shown to improve from about 96 W/Kg to >150 W/Kg.

The elements of zinc corrosion were investigated and found to consist of three types; depolarization of zinc due to oxygen diffusion from the air, galvanic corrosion against the anode substrate, and galvanic action of macro-particles of nickel material dislodged from the positive electrode during charging (vibration). The first mechanism's rate is estimated, and found to be low in a worst case analysis. Galvanic corrosion on the substrate is shown to be reduced by the use of proper plating and additives. Experiments with lead additive are described. The third mechanism, galvanic corrosion caused by nickel particles is shown to be the major cause of zinc capacity loss during charged stand. This requires a modification of nickel electrodes to appreciably reduce the shedding of particulate nickel into the electrolyte.

1.0 INTRODUCTION

The goals of this Research and Development Program are to develop a Nickel/Zinc Battery for electric vehicle propulsion, having the performance characteristics as delineated in ANL Statement of Work C0030-0082-01, Rev. 01, dated 4/9/80. These characteristics are:

1. Battery Capacity ^a (kw-hr)	20-30
2. Battery Dimension (cm H x cm W c cm L)	to be determined
3. Volume (L)	"
4. Weight (kg)	"
5. Installation Voltage ^b	"
6. Volumetric Energy ^a (W-hr/L)	>120
7. Specific Energy ^a (W-hr/kg)	> 70
8. Specific Power (W/kg)	
Peak Battery ^c - 15 sec. avg.	>125
Sustained ^f	> 45
9. Duty Cycle	
Charge (hrs)	4-8
Discharge (hrs)	
10. Lifetime	
Deep Discharges ^d	>400
Wet Life (years)	> 2
11. Price/Energy ^e (\$/kW-hr)	> 75
12. Energy Efficiency (%)	> 60

^aC/3 rate discharge; 8 hour charge; rated at 100% discharge.

^bFor compact passenger car.

^cAt 80% discharge state.

^d80% depth of discharge from rated capacity.

^ePrice delivered to auto manufacturer for production of 10,000 units per year.

^f20 minute sustained power drain after 50% DOD at C/3.

To accomplish the program objectives, a Program Management Plan was prepared. The plan was updated and revised 30 May 1980, to cover the time period ending 30 September 1981. The revised plan was submitted to ANL 7 July 1980, and delineated these four major tasks:

Task 1. Exide No. 6050 - Battery Design and Development

Task 2. Exide No. 6051 - Nickel Cathode Development

Task 3. Exide No. 6052 - Electrochemical Studies

Task 4. Exide No. 6053 - Reports and Documentation.

This report is the Second Annual Report, covering the technical progress in the period 4.5 MACE* to 16.5 MACE*. A summary of work accomplished in this period is presented with specific reference to the program tasks. Results are presented in the form of graphs, data tables, photographs and drawings in a manner to permit an assessment of the degree of accomplishment toward the desired program goals.

* MACE = Months after Contract Execution.

2.0 TECHNICAL PROGRESS IN THE REPORTING PERIOD

2.1 BATTERY DESIGN AND DEVELOPMENT (Exide No. 6050)

(A) Effect of Inter-Electrode Space on VIBROCELTM Performance

Test Cells S/N 006, 007 and 008 were built having inter-electrode spacing of 1.5, 2.5 and 3.5 mm respectively. Design Specification details are included in Tables 1, 2 and 3. (Component details were included in Appendix A of the first Annual Report). A typical cell, in a test station, is shown in Figure 1.

Early in cycling, the charge current was at a constant rate of 40A (approx. 3-hr. rate). It was observed during this time that a considerable amount of spongy zinc eroded from the anodes during charge. This material did not redissolve during the normal course of cycling and resulted in a gradual loss of capacity.

Capacity decreased rapidly to about 75 percent of the nominal rating after only about 5 cycles, at which time a new charging technique was initiated. This involved increasing the charge rate from approx. the 3-hr. rate (C/3) to essentially about the 1-hr. (125-150A) rate (C). This rate was applied only until the "zinc signal" was obtained, at which time the rate was reduced to 30A for the remainder of charge. The "zinc signal" referred to in this report pertains to a small (approximately 0.2 volts) but rapid rise in cell voltage during charge. This signal indicates the depletion of zincate from the electrolyte, essentially the end of zinc electrodeposition, and the onset of hydrogen evolution on the negative (zinc) electrode surface. This technique resulted in an appreciable improvement in capacity, to about 90 percent

Figure 1 - Typical Cell - Test Station

TABLE 1
Experimental Cell - Design Specification Sheet

Cell S/N 006, 7-Plate, Electrode Spacing Test; 1.5mm

Type: Ni-Zn VIBROCELTM 132 Ah Nom.

Positive Electrodes

Type: Matsushita Sinters

No. per Cell: 6

W 6.89 ± .040 in.

H 8.937 ± .040 in.

T 0.064 - 0.067 in.

Wt: 234 ± 2 gm. ea.

6050-0104
 Dwg: 6050-0113

Negative Substrate

Type: Perforated Steel, Cd-Plated

No. per Cell: 3

+ .03
 W 6.875 - .00 in.

+ .00
 H 9.00 - .03 in.

T 0.024 in.

Wt: 449 gm. (Total)

Dwg: 6050-0101

Positive Insulator:

Type: VEXAR netting, Polypropylene, 596V 360 Pan1

11 x 11 mesh, 34-37 mils, applied as per Dwgs. 6050-0104, 6050-0113

Negative Active Material: ZnO, 232 gm

Interelectrode Spacing: 1.5mm

Electrolyte: 6M KOH + 10 g/L LiOH · H₂O

Cell Dimensions (Overall): H: 16.0 in. X W: 7.80 in. X D: 1.81 in.

Cell Wt: Dry - 4050 gm; with electrolyte +ZnO - 5608 gm.

Cell Jar Material: Plexiglas

Vibration Mechanism: Actuator Body - Lucite; Shuttle-Delrin.

Total Amplitude - 0.090 in. Frequency - initial 21 Hz, then 15 Hz; in
further cycling.

TABLE 2

Experimental Cell - Design Specification SheetCell S/N 007, 7-Plate, Electrode Spacing Test; 2.5mmType: Ni-Zn VIBROCELTM 132 Ah Nom.Positive ElectrodesType: Matsushita SintersNo. per Cell: 6W 6.89 ± .040 in.H 8.937 ± .040 in.T 0.064-0.067 in.Wt: 234 ± 2 gm. ea.Dwg: 6050-0104
6050-0113Negative SubstrateType: Perforated Steel, Cd-platedNo. per Cell: 3W 6.875 ^{+ .03} - .00 in.H 9.00 ^{+ .00} - .03 in.T 0.024 in.Wt: 435 gm. (Total)Dwg: 6050-0101Positive Insulator:Type: VEXAR netting, Polypropylene, 596V 360 Panel, 11 x 11 mesh,34-37 mils. Applied as per Dwg. 6050-0104, 6050-0113.Negative Active Material: ZnO, 232 gmInterelectrode Spacing: 2.5mmElectrolyte: 6M KOH + 10 g/L LiOH · H₂OCell Dimensions (Overall): H: 16 in. X W: 7.8 in. X D: 2.05 in.Cell Wt: Dry - 4195 gm; Electrolyte + ZnO - 6062 gm.Cell Jar Material: PlexiglasVibration Mechanism: Actuator Body - Lucite; Shuttle-Rulon.Total Amplitude - 0.090 in. Frequency - initial - 21 Hz; then 15 Hz.

TABLE 3

Experimental Cell - Design Specification SheetCell S/N 008, 7-Plate, Electrode Spacing Test; 3.5mmType: Ni-Zn VIBROCELTM 132 Ah Nom.Positive ElectrodesType: Matsushita SintersNo. per Cell: 6W 6.89 ± .040 in.H 8.93/ ± .040 in.T 0.064 - 0.067 in.Wt: 234 ± 2 gm. ea.Dwg: 6050-0104
6050-0113Negative SubstrateType: Perforated Steel, Cd-platedNo. per Cell: 3W 6.875 ^{+ .03} - .00 in.H 9.00 ^{+ .00} - .03 in.T 0.024 in.Wt: 436 gm. (Total)Dwg: 6050-0101Positive Insulator:Type: VEXAR netting, Polypropylene, 596V 360 Panel, 11 x 11 mesh,34-37 mils. Applied as per Dwg. 6050-0104, 6050-0113.Negative Active Material: ZnO, 232 gmInterelectrode Spacing: 3.5mmElectrolyte: 6M KOH + 10 g/L LiOH · H₂OCell Dimensions (Overall): H: 16 in. X W: 7.8 in. X D: 2.285 in.Cell Wt: Dry - 4297 gm; Electrolyte + ZnO - 6497 gmCell Jar Material: PlexiglasVibration Mechanism: Actuator Body-Lucite; Shuttle-RulonTotal Amplitude - 0.090 in. Frequency; initial - 21 Hz, then 15 Hz.

of rated value, especially for Cells 007 and 008. The improvement was associated with the anodes, since erosion of zinc was virtually eliminated, and more uniform, dense deposits were observed.

The test was terminated after 52 cycles. The capacity of Cells 007 and 008 was about 85 percent of rating, and that of Cell 006 about 75 percent of rating. Inspection of the cells revealed anode "shape change," in which the top 50-60 percent of the area was free of zinc (end of discharge), whereas the bottom 40-50 percent had zinc remaining in a somewhat irregular disposition. In Cell 006 (1.5 mm), there was physical damage to the netting on the nickel electrodes, apparently due to abrasion by heavy deposits of zinc. It is assumed that this condition existed early in cycling before a change to the new charging technique.

Test data for this study are included in Tables 4 and 5 and Figure 2. Specific and volumetric energy densities were generally higher with 2.5 mm spacing than with 1.5 or 3.5 mm gaps; 6-8 percent higher for specific energy density, and 3-13 percent higher for volumetric energy density. However, it should be mentioned that the results of this study do not preclude a further evaluation of smaller (1.5 mm) spacings, especially when using special charging techniques which are expected to deposit a dense layer of zinc. In fact, a re-evaluation of the 1.5 mm spacing is essential, especially in view of the need to reduce weight and volume in order to optimize cell performance (see Section 2.3 C).

(B) Testing a 15-plate, 300 Ah VIBROCEL™ (S/N 009)

A 15-plate, 300 Ah (Nom.) VIBROCEL™ was built, and has been on test since November of 1979. Drawings of the various cell components were included in the First Annual Report. Design specification details of Cell S/N 009 are given in Table 6. Construction features are shown in Figures 3, 4 and 5.

A two-step charging method has been used, in which a 300A (C) rate is applied until a "zinc signal" is reached. Thereafter, the rate is reduced to 70A for the remainder of charge. Thus far, the cell has yielded over 170 cycles, and continues to deliver about 90 percent of the nominal capacity rating. This cell has been cycled longer than any other to date, and will continue in the present regime to failure. Cycling data are shown in Table 7 and Figure 6.

Typical charge and discharge characteristics of this cell, as well as the temperature response in both modes, are shown in Figure 7. The usual cut-off on the high rate portion of charge has been about 2.2 V/cell. Temperatures have reached 40-45°C during charge, and generally, remain in this range during discharge.

Effect of Inter-Electrode Spacing on VIBROCELTM Performance
7-Plate (132 Ah Nom.) Test Cells

Figure 2

TABLE 4

EFFECT OF INTER-ELECTRODE SPACE ON VIBROCEL™ PERFORMANCE

Cycle	Charge		Discharge			
	Rate (A)	Input (Ah)	Rate (A)	006	Capacity (Ah) 007	008
1	40	178	40	126	126	123
5	40	178	40	89.6	85.6	89.6
10	25	206	40	105	98.8	92.5
15	80/30	200	40	105.5	115	117.5
20	80/30	188	40	102	118.4	118.4
25	100/30	188	40	107	125	125
30	100/30	200	40	108	125.5	124.4
36	125/34	175	40	104	114	126
40	125/34	142	40	100	110	116
45	150/30	176	40	102	122	119
52	120/30	180	40	101	118	115.5

TABLE 5

EFFECT OF INTER-ELECTRODE SPACE ON VIBROCEL™ PERFORMANCE

Cycle	Charge		S/N006	(Ah/lb) Cell		S/N006	(Ah/in ³) Cell	
	Rate	Input		S/N007	S/N008		S/N007	S/N008
1	40	178	10.2	9.44	8.6	0.557	0.492	0.431
5	40	178	7.25	6.4	6.25	0.396	0.334	0.314
10	25	206	8.50	7.40	6.46	0.465	0.386	0.324
15	80/30	200	8.54	8.61	8.21	0.457	0.449	0.412
20	80/30	188	8.26	8.87	8.27	0.451	0.463	0.415
25	100/30	188	8.66	9.36	8.73	0.473	0.488	0.438
30	100/30	200	8.74	9.40	8.69	0.478	0.490	0.436
36	125/34	175	8.42	8.53	8.80	0.460	0.445	0.442
40	125/34	142	8.09	8.24	8.10	0.442	0.430	0.407
45	150/30	176	8.26	9.14	8.31	0.451	0.477	0.417
52	120/30	180	8.17	8.81	8.07	0.447	0.460	0.405

TABLE 6

Experimental Cell - Design Specification Sheet

Cell S/N 009, 15-Plate, 300 Ah design

Type: Ni-Zn VIBROCEL™Positive ElectrodesType: Matsushita SintersNo. per Cell: 14W 6.89 ± .040 in.H 8.937 ± .040 in.T 0.060-0.067 in.Wt: 234 ± 2 gm. ea.

6050-0104

Dwg: 6050-0113Negative SubstratesType: Perforated Steel, Cd-platedNo. per Cell: 7W 6.875 - .00 in.H 9.00 - .03 in.T 0.024 in.Wt: 1107 gm. (Total).Dwg: 6050-0101Positive Insulator:Type: NALTEX, Case Liner, Polypropylene, 7 mesh, 30 mls thick.Applied as per Dwg. 6050-0104, 6050-0113.Negative Active Material: ZnO, 545 gmsInterelectrode Spacing: 2.5mmElectrolyte: 6M KOH + 10 g/L Li OH · H₂OCell Dimensions (Overall): H: 14.8 in. X W: 8.3 in. X D: 4.4 in.Cell Wt: Dry-7630 gm; filled (Electrolyte + ZnO) - 11,575 gmsCell Jar Material: PlexiglasVibration Mechanism: Actuator Body - PVC; Shuttle-Delrin.

TABLE 7
PERFORMANCE OF A 15-PLATE, 300 Ah VIBROCEL™
TEST CELL S/N 009

CYCLE	CHARGE		DISCHARGE		
	RATE (A)	INPUT (Ah)	RATE (A)	CAPACITY (Ah)	
1	300/70	450	100	296	
10	"	450	"	286	
20	"	450	"	294	
30	"	477	"	280	
40	"	411	"	275	
49	"	501	"	288	NOTE A
60	"	492	"	277	
70	"	450	"	262	NOTE B
80	"	458	"	268	NOTE C
90	"	466	"	285	
100	"	450	"	275	
110	"	469	"	272	
120	"	479	"	275	
130	"	464	"	267	
133	"	495	"	266	NOTE D
140	"	475	"	263	
150	"	475	"	263	
160	"	490	"	273	
170	"	525	"	277	

NOTE A: Inadvertent Reversal at 100A, 16 hrs. (cycle 50)
 B: Dismantled cell, removed nickel oxide sediment
 C: Added 20Ah ZnO, cycle 88
 D: Removed nickel oxides

Fig. 3 - Plate Connector Details
15-Plate VIBROCEL™

Fig. 4 - Assembled 15-Plate Element
300 Ah VIBROCEL™

Fig. 5 - VIBROCELTM - 300 Ah

Performance of a 15-Plate, 300 Ah VIBROCELTM
Test Cell S/N 009

Figure 6

Figure 7
Performance of a 15-Plate, 300 Ah VIBROCEL™
Voltage and Temperature Profiles
Test Cell S/N 009

Performance characteristics at various rates of discharge are shown in Figure 8. Energy density ranged from about 40 W-hr/kg at the 3-hr. (100A) rate, to 36 W-hr/kg at the 1-hr. (300A) rate. Temperature response during discharges over this range are shown in Figure 9. Initial cell temperature shown in Figure 9. Initial cell temperature shown in the temperature immediately following charge. Maximum temperature ranged from about 35°C at the 5-hr. rate, to 45°C at the 2-hr. rate. It increased most rapidly at the 1-hr. rate, reaching about 55°C near the end of discharge.

Peak-power and sustained-power tests were run during cycle 119, using the following technique:

1. Peak-power

With the cell at full charge, an initial discharge rate of 500A was imposed. The rate was then increased in 100A increments until a maximum of 1400A was obtained. Each current was applied for 10 seconds, and the voltage measured at the end of the period. There was an interval of 20 seconds on open circuit between pulses.

2. Sustained-power

Following the peak-power test, the cell was continued on discharge at the 3-hr. (100A) rate for 69 minutes. A total of 141.6Ah was removed (slightly more than 50% cell capacity) before the sustained power test. A sustained drain of 350A was then applied, and the voltage response measured to a cut-off of 0.6V.

Results of the peak-power test are shown in Figure 10. Peak-power was obtained at about 1200A (4C rate), and the specific power at that point was about 97W/kg. It should be mentioned that the cell terminals were under-designed, resulting in a considerable temperature rise, indicating high IR losses. Therefore, an improved terminal design should result in improved peak-power.

A sustained-power (avg) of 35.25W/kg was obtained at 350A for 19 minutes. In Figure 11, "A" designates that portion of the 3-hr. rate discharge immediately preceding the sustained-power test. The anomalous behavior shown at "B" has been attributed to a relatively rapid activation of previously inactive zinc, apparently resulting from the high temperature attained on drain at 350A.

- (C) Fabrication and Testing of a 4-Cell VIBROCEL™ Battery

A 4-cell battery of 300Ah (nom.) rating was built in a monobloc configuration. Each cell comprises 15 electrodes, designed identically to cell S/N 009 (Figures 3 and 4). The monobloc case and cover were hand-fabricated from Plexiglas. Details of the battery construction are shown in Figures 3, 4 and 12.

Effect of Discharge Rate on Performance
VIBROCEL™ S/N G09, 300 Ah, 15-Plate

Figure 8

Performance of VIBROCEL™ S/N 009

15-Plate, 300 Ah

Rate - Temperature Profile

Figure 9

Figure 10

Sustained Power Test; Cell S/N 009

Figure 11

Fig. 12 - VIBROCEL™ Battery, 4 Cell,
300 Ah (Nom.)

A weight break-down of various cell and battery components are included in Tables 8 and 9. Table 9 shows the percentage contribution of each component. The major factors, nickel electrodes and electrolyte, each contribute about one-third of the total weight. The next major factor, case and cover (combined), represents about 15% of the total weight.

Before delivery of this battery to NBTL, it was activated and cycled several times to observe potential problem areas and make corrections if necessary. The battery was tested as follows:

- Charged at 300A (1-hr. rate) to the "zinc signal".
- Reduced charge rate to 70A for remainder of charge, for a total input of generally 450Ah (50% overcharge based on a nominal 300Ah rating).
- After a short period (5-10 minutes) on open circuit, the battery was discharged at 100A (3-hr. rate) to a cut-off of 5.0 Volts.

Data obtained during activation of this battery are shown in Table 10 and Figures 13 and 14. Specific and volumetric energy densities of 42Wh/Kg and 67Wh/L respectively were obtained when discharging at 100A (3-hr. rate). Temperature reached levels of 50-55°C during cycling. A slight modification was made after cycle 4 to correct a minor leakage problem, and also to replace the aluminum bearing blocks with steel blocks. This battery was delivered to NBTL during February of 1980.

While at NBTL, the battery failed due, apparently, to an internal rupture in Cell 15. Failure analysis has not conclusively determined the cause. However, several modifications in design have been made in rebuilding this unit to eliminate potential problem areas where sparks might have been generated. These were:

- Coated top edges of anode substrates with Delta-Bond 152 epoxy to prevent sparks due to possible contact between anode and cathode groups.
- Replace stainless steel bearing holders with glass reinforced epoxy laminate, an insulating material.
- Used positive locking devices in all positive and negative element assemblies to avoid loosening that might be caused by vibratory motion.

In addition to these modifications, two new cathode groups replaced these in Cells 14 and 15. Cell 15 was replaced before re-activating the battery, and Cell 14 after 8 cycles.

TABLE 8

WEIGHT BREAKDOWN ANALYSIS

Four-Cell, 300 Ah VIBROCELTM Battery (Monobloc Design)

Component Weights, Individual Cells (Grams)

	<u>Cell No.</u>			
	<u>012</u>	<u>013</u>	<u>014</u>	<u>015</u>
Cathodes (8)	3670	3680	3680	3695
Anodes (7)	960	952	940	945
Cathode Hardware	344	344	343	343
Anode Hardware	289	289	289	289
Activator and Shuttle	55	55	55	55
Zinc "Getter"	95	95	95	95
Slotted Retainers	207	206	197	193

Four-Compartment Monobloc Case	- 4365 grams
Monobloc Cover	- 803 grams
Bearing Holder and Cover Hold Downs (5)	- 666 grams
Braided Intercell Connectors (4)	- 358 grams
Overall Battery Weight (Dry)	- 28.850 Kg (63.6 lbs)
Overall Battery Dimensions	- 14.5"L, 8"W, 15.5"H
Initial Fill (Zn-Free), 2636 ml Avg/Cell;	Total 10.545 liters
Battery Weight, Initial Fill	- 42.05 Kg (92.7 lbs)
ZnO Added/Cell (ZnO + Zincate Sol'n)	- 600 grams (2400 grams)
Total Battery Weight Activated	- 44.45 Kg (98 lbs) est.

TABLE 9

WEIGHT FACTORS IN FOUR-CELL VIBROCELTM BATTERY

<u>Component</u>	<u>Weight (grams)</u>	<u>Percent of Total</u>
Nickel Electrodes	14,725	33.13
Anode Substrates	3,797	8.54
Cathode Hardware	1,374	3.09
Anode Hardware	1,156	2.60
Case and Cover*	6,351	14.29
Vibration Mechanism**	1,039	2.34
Intercell Conn.	358	0.80
Misc. Hardware	50	0.11
Electrolyte	13,200	29.70
Zinc Oxide	2,400	5.40
TOTAL	44,400	100.0

* Case and Cover includes: Slotted Retainers and "Getters"

** Includes Bearing Holders, Shaft, Eccentrics, Activators and Shuttles

TABLE 10

ACTIVATION OF 4-CELL VIBROCELTM BATTERY
 15-PLATE CELLS, 300 Ah (NOM) RATING

CYCLE	CHARGE		DISCHARGE	
	RATE (A)	INPUT (Ah)	RATE (A)	CAPACITY (Ah)
1	300/70	460	100	272
2	300/70	450	100	283
3	300/70	450	100	280
4	300/70	450	100	285 (NOTE)
5	300/70	450	100	275

NOTE: Repairs and modifications made after cycle 4. Corrected minor leakage problems and replace aluminum bearing blocks with blocks made of steel.

Four Cell, 300 Ah (Nom.) Ni/Zn VIBROCEL™ Battery
Typical Discharge at 100 A

Figure 13

Four Cell, 300 Ah (Nom.) Ni/Zn VIBROCEL™ Battery
Voltage and Temperature Characteristics on Charge

Figure 14

Each cell was filled with an electrolyte having the composition: 6MKOH + 10g/L LiOH.H₂O. 562 g. of ZnO was added to each cell, partly as zincate and partly as ZnO in a slurry in the electrolyte.

The battery was given several "run-in" cycles to determine its characteristics before delivery to NBTL. The data obtained are shown in Table 11 and a photograph of the rebuilt battery in Figure 15. The battery was delivered to NBTL during the last week of August, 1980.

(D) Effect of Electrolyte Concentration on VIBROCELTM Performance

A study is being conducted to evaluate the effect of electrolyte concentration on VIBROCELTM performance. Cells of 7-plate design, identical to these previously made (section 2.1(A) with 2.5 mm spacing) were used throughout. Design specifications are described in Tables 12, 13 and 14.

Cells S/N 018, 019 and 020 were filled with respectively 6M, 7M, and 8M KOH solutions, each containing 10g/L LiOH.H₂O. A total of 245g of ZnO were slurried in the electrolyte for each cell. The test regimen was as follows:

- Charged (D.C.) at 125A (approx. 1-hr. rate) to the "zinc signal".
- Reduced charge rate to 30A for remainder of charge, for a total input of about 200Ah.
- After a short period of open circuit (5-10 min.), discharge was conducted at 40A to a cut-off of 1.25V/Cell.

Figure 16 and Table 15 show the performance obtained with 6, 7, and 8M electrolytes after 61 cycles. Generally, performance increased as concentration increased. This became more pronounced after Cycle 26 when the nickel oxide sediment was removed from the cells. At first, there was a rather rapid decrease in capacity following this treatment, but there was a gradual increase thereafter. The improvement was accelerated by the addition of ZnO in Cycle 47. After 61 cycles the performance, in terms of percent of rated capacity, was as follows: 81, 89 and 92 for respectively 6, 7 and 8M electrolytes. This decline is somewhat greater than that experienced in cycling the 300Ah cell, S/N 009. Cell S/N 018 with 6M KOH retained 81% of nominal capacity after 61 cycles, while cell S/N 009 with 6M KOH retained 90% of nominal capacity after 170 cycles. A possible explanation of this is that the laboratory cells (7 plate), as opposed to full size cells (15 plate), are more susceptible to zinc shape change. The shape change phenomenon is attributed to two main differences between the cells. The 15 plate (300Ah) cell contains 6 double nickel electrodes and 2 single (outside) nickel electrodes. The 7 plate (132Ah) cell contains 2 double and two single electrodes. Experience has shown us that current distribution of the nickel electrodes tends to be slightly unequal; i.e., the single electrodes tend to discharge at a slightly lower rate than the

TABLE 11

PERFORMANCE OF REBUILT STATE-OF-THE-ART FOUR-CELL
MODULE (VIBROCELTM - 300 Ah NOM)

CYCLE	CHARGE		DISCHARGE		
	RATE (A)	INPUT (Ah)	RATE (A)	CAPACITY (Ah)	
1	300/70	510	100	270	
2	300/70	454	100	262	
3	300/70	470	100	250	
4	300/70	458	100	268	(A) Cell 014
5	300/70	-	100	261	Limiting
6	300/70	445	100	258	"
7	300/70	455	100	253	"
8	300/70	458	100	277	B
9	300/70	489	100	279	

A - Cell 3 (S/N 014) Limiting Capacity of Battery.

B - Replaced Cathode Group in Cell S/N 014 after
Cycle 7 Discharge

Fig. 15 - Rebuilt 4-Cell, 300 Ah
VIBROCEL™ Battery

TABLE 12

Experimental Cell - Design Specification SheetCell S/N 018, 7-Plate. Electrolyte Concentration Test - 132 Ah NOM;6M KOH + 10 g/L LiOH · H₂OType: Ni-Zn VIBROCELTMPositive ElectrodesType: Matsushita SintersNo. per Cell: 6W 6.89 ± .040 in.H 8.937 ± .040 in.T 0.064-0.067 in.Wt: 234 ± 2 gm. ea.Dwg: 6050-0104
6050-0113Negative SubstrateType: Perforated Steel, Cd-platedNo. per Cell: 3W $\begin{matrix} + .03 \\ 6.875 - .00 \end{matrix}$ in.H $\begin{matrix} + .00 \\ 9.00 - .03 \end{matrix}$ in.T 0.024 in.Wt: 427 gm.Dwg: 6050-0101Positive Insulator:Type: NALTEX Case Liner, Polypropylene applied as per 6050-0104 and
6050-0113Negative Active Material: ZnO, 245 gramsInterelectrode Spacing: 2.5mmElectrolyte. 6M KOH + 10 g/L LiOH · H₂OCell Dimensions (Overall): H 16.0 in. X W: 7.80 in. X D: 2.05 in.Cell Wt: Dry - 4180 gm; Filled (Electrolyte + ZnO) - 5973 gmCell Jar Material: PlexiglasVibration Mechanism: Actuator Body - Shuttle-RulonTotal Amplitude - 0.090 in., Frequency - 15 Hz

TABLE 13

Experimental Cell - Design Specification SheetCell S/N 019, 7-Plate, Electrolyte Concentration Test - 132 Ah NOM;7M KOH + 10 g/L LiOH · H₂OType: Ni-Zn VIBROCEL™Positive ElectrodesType: Matsushita SintersNo. per Cell: 6W 6.89 ± .040 in.H 8.937 ± .040 in.T 0.064 - 0.067 in.Wt: 234 ± 2 gm. ea.Dwg: 6050 - .0104
6050 - 0.113Negative SubstrateType: Perforated Steel, Cd-platedNo. per Cell: 3W 6.875 - .00 in.
+ .03H 9.00 - .03 in.
+ .00T 0.024 in.Wt: 414 gm.Dwg: 6050-0101Positive Insulator:Type: NALTEX Case Liner, Polypropylene applied as per 6050-0104 and6050-0113Negative Active Material: ZnO, 245 gramsInterelectrode Spacing: 2.5mmElectrolyte: 7M KOH + 10 g/L LiOH · H₂OCell Dimensions (Overall): H: 16.0 in. X W: 7.80 in. X D: 2.05 in.Cell Wt: Dry - 4178; Filled (Electrolyte + ZnO) - 6049 gmsCell-Jar Material: PlexiglasVibration Mechanism: Actuator Body - Lucite; Shuttle-RulonTotal Amplitude - 0.090 in. Frequency - 15 Hz

TABLE 14

Experimental Cell - Design Specification SheetCell S/N 020, 7-Plate, Electrolyte Concentration Test - 132 Ah NOM;8M KOH + 10 g/L LiOH · H₂OType: Ni-Zn VIBROCELTMPositive ElectrodesType: Matsushita SintersNo. per Cell: 6W 6.89 + .040 in.H 8.937 ± .040 in.T 0.064 - 0.067 in.Wt: 234 ± 2 gm. ea.6050-0104Dwg: 6050-0113Negative SubstrateType: Perforated Steel, Cd-platedNo. per Cell: 3W 6.875 + .03 - .00 in.H 9.00 + .00 - .03 in.T 0.024 in.Wt: 421 gm.Dwg: 6050-0101Positive Insulator:Type: NALTEX Case Liner, Polypropylene applied as per 6050-0104 and6050-0113Negative Active Material: ZnO - 245 gramsInterelectrode Spacing: 2.5 mmElectrolyte: 8M KOH + 10 g/L LiOH · H₂OCell Dimensions (Overall): H: 16.0 in. X W: 7.80 in. X D: 2.05 in.Cell Wt: Dry-4182 gms; Filled (Electrolyte + ZnO) - 6027 gmsCell Jar Material: PlexiglasVibration Mechanism: Actuator Body-Lucite; Shuttle-RulonTotal Amplitude - 0.090 in. Frequency - 15 Hz

Effect of Electrolyte Concentration on
VIBROCELTM Performance

7-Plate, 132 Ah (Nom.) Test Cells

Figure 16

TABLE 15.

Effect of Electrolyte Concentration on VIBROCELTM Performance

CYCLE	CHARGE		Rate (A)	DISCHARGE (CAPACITY: Ah)		
	Rate (A)	Input (Ah)		S/N018	S/N019	S/N020
1	125/30*	195	40	133.5	136.5	135
5	"	195	"	120.2	120.2	127.3
10	"	215	"	120.2	121.2	122.2
14	"	200	"	116.3	120.2	121.1
21	"	196	"	113.7	115.7	115.7 — A
26	"	200	"	106.3	112.7	117.2 — B
30	"	195	"	92	99.5	107.5
35	"	198	"	98	103	108
40	"	203	"	100	111	110
45	"	204	"	99	108	112.6
47	"	205	"	106.9	117.8	123.2 — C
52	"	216	"	105.2	116	120
57	"	207	"	105.7	114.8	119.8
61	"	203.5	"	103.3	111.8	117.2

Interrupted cycling to modify S/N018 and S/N019.

- * - Charge - 125 A to "Zinc Signal", then 30 A remainder charge
- A - Dismantled cells, removed nickel oxide sediment
- B - Dismantled cells, removed nickel oxide sediment
- C - Added 10 Ah ZnO each cell

double electrodes. This condition leads to some undischarged zinc remaining on the outside faces of two zinc anodes after the cell has reached cut-off voltage. Charging then deposits zinc on top of this remaining deposit, leading to shape change after a number of cycles. This effect is magnified in the lab cells, where half the nickel electrodes are single electrodes, as compared to the full size cell where only $\frac{1}{4}$ of the nickel electrodes are single electrodes. In addition to this, it appears that mechanical vibration of equal frequency and amplitude creates a greater turbulence in the electrolyte of the full cell (300Ah) because of its greater thickness dimension and less restricted flow paths. This in turn tends to deposit zinc during charge in a more uniform manner, reducing a possible second mode of shape change. As can be seen by the data, laboratory cells S/N 019 and S/N 020 with higher concentrations of KOH, more nearly approach the performance of cell S/N 009 (300Ah). The higher solubility of zinc in these electrolytes is no doubt also a factor in reducing zinc shape change.

After 61 cycles testing was temporarily interrupted, and cells S/N 018 and S/N 019 were modified. They were rebuilt using the same cathodes, but with new anode substrates. The cells were designated S/N 018M and S/N 019M and were filled with respectively 9M and 10M electrolyte. Again, a total of 245g of ZnO was slurried overnight in each solution before addition to the cells. This approach (modification of used cells) was adopted to expedite an extended evaluation of the parameter, because of a lack of new nickel electrodes. Cell S/N 020 was continued on test without modification.

Cycling was resumed according to the regimen described above. The data obtained thus far, after more than 125 cycles (total), are shown in Table 16 and Figure 17. A new cycling sequence for the rebuilt cells was not used because the cathodes had already received 61 cycles. The increase in performance effected by increasing electrolyte concentration from 6M to 9M (S/N 018M) and 7M to 10M (S/N 019M) was surprisingly large: 43% for a change from 6M to 9M and 33% for a change from 7M to 10M. In fact, performance improved from an average of about 80% of nom. rating to 110% of rating by increasing concentration from 6-7M to 9-10M.

There was a rapid decrease in performance after Cycle 68 (18M and 19M), attributed to a build-up of nickel oxide erosion products. The cells were dismantled after Cycle 71 and the oxides were removed. This treatment, and the addition of ZnO (Cycle 76) effected an improvement in performance. The increase in efficiency with increased electrolyte concentration was observed throughout the test.

TABLE 16

EFFECT OF ELECTROLYTE CONCENTRATION ON VIBROCELTM PERFORMANCE

CYCLE	CHARGE		DISCHARGE CAPACITY (Ah) @ 40A			
	Rate	Input	S/N018	S/N019	S/N020	
57	125/30	207	105.7	114.8	119.8	
61	"	203	103.3	111.8	117.2	
			<u>S/N018M</u>	<u>S/N019M</u>	<u>S/N020</u>	A
62	125/30	234	146.8	148.6	116.8	
65	"	253	146	146	117	
68	"	247	146	144.6	116	
70	"	252	133.5	138	116.4	
71	"	226	124.8	131	115.8	B
76	"	215	133.2	139	114.4	C
79	"	229	135.4	138.4	113.8	
82	"	231	134.3	142.9	114.2	
85	"	231	134.8	142.6	113.6	
88	"	228	136.8	144	112.5	
91	"	230	132.9	139.9	111.6	
94	"	234	130.1	137.8	109.1	
95	"	230	131.2	138.8	118	D
98	"	212	129.6	136.4	116	
101	"	222	128	135	116	
104	"	210	128	134	114	
107	"	227	127.6	133.6	113	
110	"	224	128.6	135.8	113.6	
113	"	213	126	134.5	114.2	
116	"	230	125.6	134	114	
119	"	226	124	133.7	111.5	
122	"	214	122.8	133.8	112.8	
125	"	232	124	134	111	

A - Modified S/N018 and S/N019 by replacing electrolyte and anodes
 Electrolyte replacement: S/N018M - 9M; S/N019M - 10M.

B - Removed nickel oxide sediment - S/N018M and S/N019M only.

C - Added 10Ah ZnO - S/N018M and S/N019M only.

D - Added 10Ah ZnO - S/N020 only.

Effect of Electrolyte Concentration on VIBROCEL™ Performance

7-Plate, 132 Ah (Nom.) Test Cells

△ S/N 018 (6M)

▲ S/N 18M (9M)

□ S/N 019 (7M)

■ S/N 19M (10M)

◇ S/N 020 (8M)

Figure 17

There has been a steady decrease in performance with cycling for all cells, but capacity appears to have stabilized for cell S/N 019M (10M) after about 105 cycles (45 cycles with 10M electrolyte). This cell is performing at about rated capacity.

After 125 cycles, the performance, in terms of percent of nominal rating, was as follows: 84, 94 and 101 for respectively 8, 9 and 10M electrolytes. Although there is an appreciable volume of nickel electrode erosion product, in cells S/N 018M and S/N 019M especially, they have not been removed for more than 50 cycles. The aim has been to determine if capacity will stabilize in the presence of these oxides, as appears to have occurred with S/N 019M. Cycling will continue under the current conditions of testing.

(E) Experimental Baseline Module (VIBROCEL™)

A new experimental baseline VIBROCEL™ module has been designed and built in an effort to match the "footprint" of state-of-the-art lead-acid EV-106 batteries. The final design, for a 6V VIBROCEL™, is expected to be 7"W x 11"L. A nom. capacity of 185 Ah is expected, with 7 positive and 6 negative electrodes per cell.

The first test module comprised only two cells because of the scarcity of new Matsushita sintered nickel electrodes, which were used in the design. Some of the new features, intended to optimize energy density, and improve the mechanical design are:

- Reduction of inter-electrode space from the standard 2.5 mm to 1.5 mm. The aim is to reduce electrolyte volume, and thereby weight, and improve the energy density. A smaller gap should also reduce internal resistance and improve discharge potential.
- The use of a special charging technique. This is required because it produces very dense, adherent zinc deposits, an important factor in closely spaced electrodes.
- Incorporate the internal, flexible type anode current collector. This design eliminates the external vibrating collectors and their susceptibility to damage, especially in a multi-cell battery.

Drawings of the various battery components are included in Appendix A of this report, and a photograph of the final unit in Figure 18. A weight breakdown is shown in Table 17, and the percentage contribution of the major elements in Table 18. The energy density for the two cell module with 1.5 mm spacing and Matsushita sintered nickel electrodes is estimated at about 40 Wh/kg. It should be noted that this module was built with ¼ inch thick acrylic plastic, and the standard hardware of the 300Ah module.

Figure 18 - Two-Cell Baseline VIBROCEL™
Battery

TABLE 17

WEIGHT BREAKDOWN OF EXPERIMENTAL BASELINE MODULE

2-CELL, 185Ah (nom) VIBROCEL™ BATTERY

COMPONENT WEIGHTS, INDIVIDUAL CELLS (GRAMS)

	<u>S/N022</u>	<u>S/N023</u>
Cathodes (7)	2251.5	2266.5
Anodes (6)	569.5	551.5
Cathode Hardware	260.2	261.8
Anode Hardware	336	335.6
Actuator & Eccentric Sceene	76	76
Zinc "Getter"	66.2	74.7
Slotted Guides	124.6	125

Monobloc (2 compt.) - 1615

Monobloc Cover & Hold-downs - 327.4

Bearing Holders and Hold-downs - 458.8

Vent-tubes - 44

Intercell Connector - 37

Drive Shaft - 36

Misc. Hardware - 194

Overall Battery Weight, Dry - 10,088 gm.

Overall Dimensions: L-5.75"; W-7.62"; H-13.5".

Battery Weight, 1330Ml/cell Zn-free Electrolyte - 13,460 gm.

Battery Weight, Activated 318g ZnO/cell - 14,096 gm. (est.)

TABLE 18

WEIGHT FACTORS IN EXPERIMENTAL BASELINE MODULE

COMPONENT	WEIGHT (Grams)	PERCENT OF TOTAL
Nickel Electrodes	4518	32.0
Anode Substrates	1121	8.0
Cathode Hardware	522	3.7
Anode Hardware	672	4.8
Case and Cover*	2377	16.9
Vibration Mechanism**	647	4.6
Intercell Connector	37	0.2
Misc. Hardware	194	1.4
Electrolyte	3372	23.9
Zinc Oxide	636	4.5

* Includes guides, Zn "Getters", cover hold-downs, vent tubes.

** Includes bearing holders, actuators, eccentrics, drive shaft.

From Table 18, it can be seen again, as it was for the large four-cell monobloc (Table 9), that the major weight factors are nickel electrodes, electrolyte and container. In the 2-cell unit, however, the percentage contribution of electrolyte is less than 25%, whereas, in the four-cell monobloc it is close to 30%. This reduction is attributed to the smaller electrolyte volume resulting from a reduced interelectrode gap. The contribution of nickel electrodes, in the weight analysis, is about the same in both units, or approximately one-third the weight of the battery. A weight reduction in this area would appreciably improve the energy density of the battery. Studies are being made to obtain new, lighter, and more energetic nickel electrodes for this purpose. (See Section 2.2.)

A preliminary analysis of the weight savings which could be realized in the design of a 4 cell production module of this size has been made. Using a high energy nickel cathode such as CMG, 1.5 mm spacing, a thin molded plastic monobloc battery jar, and redesigned metal hardware, makes it possible that a battery with an energy density of greater than 55 Wh/kg can be built.

(F) VIBROLINK Assembly

The internal flexible connector to be incorporated in the experimental Baseline Module was included for two reasons. First, it was desirable to eliminate any moving current carrying parts from the outside of the battery for safety reasons. In addition, the flat braided copper cable (previously used) was found to be susceptible to electrolyte corrosion despite its nickel plating. The vibrolink design is a leaf type connector consisting of 35 individually nickel-plated leaves, each 3/4 inches wide x .004 inches thick, fabricated from Glidcop-20, an alloy consisting of a .4% Al_2O_3 dispersion in copper. This alloy has a fatigue strength of 20,000psi at 10^7 cycles, a tensile strength of 77,000psi and an electrical conductivity of 85% IACS. The use of the very thin leaves has enabled the design to eliminate the sliding contact concept, and instead, use a hard mount at each end connection of the flexible connector (Vibrolink). The relatively small displacement encountered during vibration can be taken up by a slight flex in the connector when assembled. This design concept was tested in a model VIBROCELTM for a total of 1800 hrs. of operation, with continuous time periods exceeding 500 hrs. During this period of testing, there was no evidence of mechanical failure or increase in contact resistance.

2.2 NICKEL CATHODE STUDY (Exide No. 6051)

This task has involved the study of commercially available nickel cathodes, their performance and applicability to VIBROCELTM. Nickel cathodes under development, which are considered promising candidates, were also included in the study. Table 19 lists all of the candidates investigated during the program to date, and the Ah/Kg values of each.

TABLE 19

COMPARISON OF VARIOUS NICKEL CATHODES

<u>TYPE</u>	<u>Coulombic Density Ah/Kg @ C/5</u>
Pocket	70
Sintered Plaque	110
Ni-Plated Steel Wool Impreg. (DAUG)	135
Plastic-Bonded (ESB)	145
CMG (Multi-Foil) (INCO)	193

The ideal nickel cathode for VIBROCEL™ should have a high coulombic density, should perform well in the VIBROCEL™ environment (i.e., unsupported structure, concentrated zincate electrolyte, vibration during charge). In addition the cost of nickel cathodes should be compatible with the program economic goals.

(A) Commercially Available Nickel Cathodes

Of the candidate electrodes listed in Table 19, only the pocket and sintered plaque type are commercially available at present, and both are considered to be of too low a coulombic density (Ah/Kg) to be viable in the VIBROCEL™. Use of these electrodes imposes weight and/or volume penalties on VIBROCEL™ batteries (ref. Tables 9 and 18 section 2.1 of this report). Sintered nickel electrodes are rarely manufactured in thicknesses greater than 1.5mm, necessitating the use of two electrodes back-to-back to arrive at the 3mm electrode necessary for VIBROCEL™. Projected costs of sintered nickel electrodes are considered too high to accomplish the cost goals of the program. Both sintered and pocket electrodes were tested and evaluated in the early part of the program, and detailed test data was presented in the first Annual Report. For purposes of continuity, a summary of these results is presented below, along with an overall estimate of the applicability of these electrodes to VIBROCEL™.

• Sintered Plaque Nickel Cathodes

The need for 3mm thick electrodes necessitates the use of two, 1.5mm electrodes back-to-back. A further physical requirement is that both electrodes be riveted together to minimize the warping tendency of unsupported single electrodes in VIBROCEL™. There is little or no measurable expansion of these electrodes after cycling. Electrically, the sintered electrodes give good high rate performance at rates up to

C/2. At the C rate there is additional polarization which reduces the power available. Although the sintered nickel electrode is usually considered a "high-rate" electrode, a 3mm thick electrode seems to have definite rate limitations. Sintered electrodes, in general, have been able to be charged at rates up to C in the excess electrolyte environment of VIBROCEL™. To maintain capacity, overcharge in the range of 25-30% is necessary. In VIBROCEL™, sintered electrodes shed particulate matter due to the washing action of the moving electrolyte during vibration, while on charge. This particulate matter increases the galvanic action on the electro deposited zinc on the negative electrode and limits the stand capability.

In spite of these limitations, the sintered electrode because of its rugged nature has been extremely useful in the building of laboratory cells and demonstration batteries. It will be continued to be used in the development program for the evaluation of cell constructions, charging techniques, heating effects and other electrical and mechanical characteristics.

■ Pocket Nickel Cathodes

Pocket nickel cathodes are also rugged in nature, and no swelling is experienced in the VIBROCEL™. The pocket electrode is more of a "medium rate" electrode and presents an acceptable voltage level at discharge rates up to C/3. At higher rates polarization increases rapidly, drastically decreasing battery energy and power density. Pocket electrodes are about 20% lower than sintered electrodes in coulombic density (Ah/Kg) at low rates. The disparity increases to a 40% differential at the C rate. Pocket plates perform approximately the same as sintered with regard to overcharge, however, one big disadvantage is the increased volume required for pocket electrodes. A 3mm sintered electrode of a given area is replaced by a 5mm pocket electrode of equal area, for equivalent capacity. This added penalty in both volume and weight cannot be tolerated in VIBROCEL™ designs. No further work on pocket electrodes is planned at this time.

(B) CMG Nickel Electrodes

CMG (Controlled Micro-Geometry) or laminar foil nickel electrodes, offer a potential weight savings of 12-15% in VIBROCEL™ and have been evaluated in cells.

● CMG Electrode Bench Testing

A 5-plate (3 Pos/2 Neg) VIBROCEL™ (S/N 021) had been assembled with CMG cathodes (Set W20 + 20% hole area/.020cm hole radius/non-woven polypropylene separator). The test cell was given five formation cycles with zincate-free electrolyte and delivered the expected 50 ampere-hour capacity.

The formation electrolyte was removed from the cell and 450ml of 6M KOH + 10g/L LiOH .H₂O containing 139g/L of ZnO added. The cycling regime was as follows:

Initial Charge - 50 Amps to "Zinc Signal"

Overcharge - 15 Amps until total charge input is 75 Ahr

Discharge - Various rates to 1.0 V cell end point

On the initial charge, at the "zinc signal", 30 grams of ZnO powder was added to the cell to increase zinc capacity. The theoretical value of zinc capacity in the cell was 61.2 Ahr.

To date, the cell has completed 37 cycles. The test results are shown in Figure 19.

1) Cycles 1-6 - During these initial cycles, cell capacity dropped from 50.7 Ahr to 35.3 Ahr.

2) Cycles 7-13 - At the end of the initial charge on Cycle No. 7, 100cc of zincate depleted electrolyte was removed from the cell and replaced with 100cc of zincate-rich electrolyte (9 Ahr - 10 Ahr zinc capacity). The theoretical value of zinc capacity was now approximately 71 Ahr. On discharge, Cell No. 17 yielded 44.3 Ahr. However, on subsequent cycles (#8-#14), the cell capacity again decayed to 40 Ahr.

3) Cycles 14-37 - On Cycle No. 14, the cell was charged using a special charging technique which has been found to deposit a dense zinc plating and increase positive charge acceptance. Overcharge of the nickel electrode employed a slightly different technique without mechanical vibration.

On the discharge following this procedure, the cell delivered a capacity of 48 Ah. On Cycles No. 15-37, the cell capacity has stabilized to a nominal value of between 40-41 Ah. It should be noted that on Cycle No. 21, the zinc electrode again became the limiting electrode.

4) Testing results of CMG electrodes in VIBROCEL™ have shown a drop in both zinc and nickel capacity with cycling. Physically, we have observed a pronounced swelling of the CMG electrodes between the stitching to form bulged pockets. We feel that this condition has resulted in unequal current distribution during charge, causing unequal plating of zinc (shape change). This situation is evidently alleviated somewhat by the special charging technique which enhances positive charge acceptance and provides uniform, dense zinc deposition. When we return to normal charging, however, capacity again falls off.

Figure 19

The bulging effect must be corrected, in order to prevent unequal current distribution, and to permit closer electrode spacing (1.5mm). It has come to our attention that our earliest models of stitched CMG electrodes performed well, and exhibited very little expansion. These electrodes were constructed with a very stiff, heavy plastic mesh (EXPAMET), which was then replaced by a lighter material in an effort to reduce weight. This evidently was the cause of the bulging electrodes later experienced. We are now obtaining sets of CMG electrodes constructed with this stiffer mesh for testing in Cell S/N 021 and the 2-cell baseline module described in Section 2.1(E) of this report.

(C) Exide Plastic-Bonded Cathodes

Early work on the Exide plastic-bonded cathode was reported in the first Annual Report. In summary, the electrodes tested showed a swelling and loss of contact between the active material and grid structure, resulting in a rapid decay of both voltage and capacity when cycled "free standing" as would be experienced in VIBROCEL™ operation. These early results suggested a revised electrode construction, similar to the "stitched" construction of CMG electrode (ref. first Annual Report) might be beneficial to the plastic-bonded cathode. The stitched CMG electrodes gave acceptable performance as a "free standing" cathode for VIBROCEL™ application.

A summary of the construction details of the Exide plastic-bonded cathodes evaluated during this report period is contained in Table 20.

1) Cathodes 4MNP1 - 6MNP1 - These cathodes were hand stitched with nylon monofilament, the difference between them being the stitching pattern used on each cathode. The quarter inch stitching interval for both horizontal and vertical (6MNP1) seemed to reduce the amount of cathode swelling. Coulombic densities at the C/5 discharge rate (Table 19) were acceptable, but at discharge rates greater than C/3, the electrodes exhibited severe polarization. Normal procedure is to cycle all electrodes for a minimum of 100 cycles. A cycle consists of 100% overcharge and 100% depth of discharge at the 5 hour rate. During the course of the 100 cycle regime, each electrode was re-characterized at the various discharge rates at 20-30 cycle intervals. As cycling proceeded, the effect of polarization became more pronounced. Again, it appeared that there was loss of contact with the supporting or conducting grid.

2) Cathode 7MNP1 - In an effort to increase the contact area between the supporting or conducting grid and the plastic-bonded active material, the 7MNP1 cathode was constructed with three 40 x 40 square mesh nickel grids. The nickel wire was .007 in. diameter. The perforated nickel foil, Pellon 2506 (non woven nylon felt), and polypropylene netting were deleted. Cathodes 4MNP1 and 6MNP1 were hand stitched with nylon filament, while cathode 7MNP1 was machine stitched (commercial sewing machine) with bonded nylon thread.

TABLE 20

EXIDE PLASTIC BONDED CATHODES - CONSTRUCTION DETAILS

<u>Materials</u>	<u>Electrode Size 6.5"W x 9.5"H</u>					
	<u>4MNP1</u>	<u>6MNP1</u>	<u>7MNP1</u>	<u>8MNP1</u>	<u>9MNP1</u>	<u>10MNP1</u>
Active Material Sheets	2	2	2	2	2	2
Percent Binder	1	1	1	2	1	1
Current Collector or Supporting Grid (3)	Distex 5Ni 17 3/0	Distex 5Ni 17 3/0	40 x 40 Square Mesh Nickel - .007" Dia Wire	Distex 5Ni 17 3/0	Distex 5Ni 17 3/0	Distex 5Ni 17 3/0
Perforated Nickel foil-U Shape	1	1	not used	1	1	1
Non-Woven Pellon 2506 BAG	1	1	not used	1	1	1
Polypropylene U-Shape Netting	1	1	not used	1	1	1
<u>Stitching Pattern</u>						
1)Vertical Interval	1/2"	1/4"	1/4"	1/2"	1/2"	1/2"
2)Horizontal Interval	1/2"	1/4"	1/4"	1/4"	1/4"	1/4"
Stitching Method	hand	hand	machine	machine	machine	machine
Stitching Material	nylon monofilament .015" dia	nylon monofilament .015 dia	bonded nylon 90 denier .012" dia	bonded nylon 69 denier .012" dia	bonded nylon 90 denier .012" dia	316 SS. thread .012" dia 27 strands
WEIGHT (grams)	241.7	244.9	248.0	249.0	217.0	219.0
DRY THICKNESS	.178"	.185"	.160"	.194"	.184"	.179"

Cathode 7MNP1 exhibited a maximum thickness increase of 42% after 21 cycles. The coulombic density at the C/5 rate (Table 19) was acceptable, but at 1C discharge rate was poor. As seen with other plastic-bonded cathodes (free standing), performance deteriorated as we approached 100 cycles.

3) Cathodes 8MNP1, 9MNP1 and 10MNP1 - Electrodes 9MNP1 and 10MNP1 were identical in construction except that cathode 10MNP1 was sewn with 316 stainless steel thread (.012" dia., 27 strands) instead of bonded nylon thread. It was felt that the stainless steel wire would improve the resistance to swelling during cycling. Test results for both electrodes are contained in Table 21. Results indicated a 55% increase in electrode thickness for both cathodes. The coulombic densities at C/5 discharge rate were good, but there was a drastic "fall off" at the C rate.

The 8MNP1 cathode showed the most promise as a "free standing" plastic-bonded cathode during this report period. The main changes in the fabrication of this electrode were the increase in the amount of binder from 1% to 2% and a new proprietary process for fabricating the active material mix. At the C/5 discharge rate, the cathode yielded 183 Ah/Kg, at C/3-157 Ah/Kg and at the 2C rate-85 Ah/Kg. These figures are an improvement over previous test results. A typical set of discharge curves at the various rates are shown in Figure 20. These results are comparable to those obtained from two 1.5mm sintered type electrodes back-to-back. The test results are after 20 cycles and will be reevaluated at 20 cycle intervals.

A redesign of the Exide plastic-bonded electrodes is planned, based on the 8MNP1 construction. Redesign will include modification of the active formulation as well as the use of the very stiff, heavy plastic mesh (EXPAMET), which has been used successfully in preventing the expansion or thickening of the CMG nickel cathodes. The Exide plastic-bonded electrode, in the entire program, has exhibited little or no shedding of active material; due to the use of PTFE binder. This offers the advantage of better compatibility with the zinc electrode in VIBROCEL™, in the area of limiting the presence of particulate matter.

(D) DAUG Sintered Nickel Wool Cathodes

Prior to the contract inception, Exide evaluated several DAUG nickel cathodes (5.9 in. W x 7.5 in. L x .2 in.Th. - 253 grams). These cathodes delivered acceptable coulombic densities - 133 Ah/Kg. - at the C/5 discharge rate.

TABLE 21

PERFORMANCE OF EXIDE PLASTIC BONDED CATHODES

<u>Performance Parameters</u>	<u>4MNP1</u>	<u>6MNP1</u>	<u>7MNP1</u>	<u>8MNP1</u>	<u>9MNP1</u>	<u>10MNP1</u>
Maximum or Final Wet Thickness	.329"	.292"	.227"	.316"	.285"	.275"
Charge - Discharge Cycle To Achieve Maximum Thickness	29	12	21	28	28	30
Percent Increase from Dry Thickness	80	58	42	63	55	55

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COULOMBIC DENSITYAhr/KG

C/5 Discharge Rate	145	163	161	183	180	159
1C Discharge Rate	-	-	36	85	41	28

Performance of Exide Plastic
Bonded Cathode - 8MNP1

Figure 20

Later, during the contract period we received several new DAUG cathodes for evaluation (6.8 in. W x 8.75 in. H x .2 in. Th. - 322 grams). The length and width dimensions were applicable to our full size lab cell VIBROCELTM design. Although the coulombic densities were excellent - 162 Ah/Kg at the C/5 discharge rate, there were severe polarization problems particularly at the C/2 and C discharge rates. Various positions of a Hg/HgO reference electrode during discharge indicated a non-uniform potential over the surface of the cathode.

The indications are that the second sample of these electrodes was not the equal of the originals submitted. In any case, the DAUG electrode, because of its voluminous nature (for example: a given size DAUG electrode of 5mm thickness has a capacity equal to a 3mm sintered or CMG electrode of the same size), would require VIBROCELTM volume to be increased appreciably to accomodate this electrode. Any weight savings that DAUG electrodes offer would be offset by the additional electrolyte required to fill the voids in these electrodes. No further work on DAUG electrodes is planned at this time, for these reasons. An overall evaluation of the different nickel cathodes considered for use in the VIBROCELTM has been made and the merit factors are summarized in Table 22. At this time the CMG cathodes appear to offer the best combination of these characteristics.

(E) Active Material Barrier for VIBROCELTM Cathodes

One of the problems encountered in cycling sintered nickel cathodes, free standing in the VIBROCELTM configuration, is the shedding of surface active material. The nickel oxide particulate matter affects the performance of the VIBROCELTM by increasing galvanic corrosion of the zinc.

In an attempt to minimize the amount of particulate matter in the electrolyte, several full size sintered nickel electrodes were "bagged" in Celgard 3501 barrier material. Celgard is a microporous polypropylene film used as a separator in alkaline batteries.

The Celgard 3501 film used for this test contained a wetting agent to render the film hydrophilic. One control electrode and two electrodes "bagged" in Celgard 3501 were given ten characterization cycles at various discharge rates. Performance curves at the C/5 and C discharge rates are shown in Figure 21. Electrodes with the Celgard barrier exhibited an appreciable increase in polarization at the C (45 amps) discharge rate.

TABLE 22

SUMMARY OF MERIT FACTORS OF NICKEL CATHODES

TYPE	Ah/Kg @C/5	Ah/cc @C/5	Swelling(1) Factor	Shedding (2) Factor	Rate Capability (3)	Est. \$/Ah (4)
Pocket	70	.17	A	XX	C/5	.08
Sintered Plaque	110	.38	A	XX	C/2	.16
Nickel Plated Steel Wool - Impreg. DAUG	135	.27	E	XXX	C/3	.16
Plastic Bonded ESB	145	.23	D	X	C/3	.08
CMG (Multi-Foil) INCO	193	.36	B	XX	C/2	.12

NOTES:

- 1) A Swells less than 10%
 B Swells 10-25%
 C Swells 25-50%
 D Swells 50-75%
 E Does not swell, but blisters occasionally
- 2) X - Little or no shedding
 XX - Moderate shedding requiring occasional clean-up
 XXX - Excessive shedding

- 3) Maximum Discharge Rate with acceptable nickel polarization for a 3 mm thick electrode, except DAUG for which the basis is a 5 mm thick electrode.
- 4) Cost of Manufacture - Based on materials and rough estimates of labor and equipment required.

Performance of Matsushita Cathodes with CELGARD Barrier

Figure 21

After characterization tests, the three electrodes were subjected to a shallow "depth of discharge" life cycle.

Charge - 9 amps - .6 hr. (50% overcharge)

Discharge - 9 amps - .4 hr.

The three test cells were removed from life cycling after 200 cycles. The cells were then discharged at 9 amps to 0 V versus Hg/HgO reference. The two electrodes with the Celgard barrier exhibited severe polarization at C/5 (9 amps) discharge rate. All three electrodes were then given several additional cycles at the normal characterization rates.

Charge - 9 amps - 10 hrs.

Discharge - 9 amps - 0 Volts

Even at the full depth of discharge and 100% overcharge, the Celgard wrapped electrodes exhibited poor voltage levels at the 9 amp discharge. A typical set of discharge curves is shown in Figure 22. The severe polarization is quite apparent. On this particular cycle, the electrode discharges were continued to -.500 V versus the Hg/HgO reference in order to distinguish the "knee of the curve" for each electrode. To the -.500 V end point the electrode capacities were very uniform. Prior to the 200 cycles, the cathode voltages were acceptable particularly at the C/5 (9 amps) discharge rate (Fig. 21). In comparing the 9 amp discharge curves in Figure 21 and Figure 22, the effect of the Celgard barrier after cycling is quite evident.

The Celgard barrier did minimize the amount of particulate matter in the electrolyte but the polarization effect was prohibitive. We do not feel that a barrier material, as such, is the solution to minimizing the active material shedding in the VIBROCEL™. We are considering machine brushing the cathode surfaces to remove any loose particles, followed by the application of a porous inert coating directly to the cleaned surface. Other electrode types such as CMG, would have to incorporate a coating or binder in the manufacturing process to achieve the same results.

(F) Effect of Zincate on Nickel Cathode Performance

Throughout the program there has been some concern as to whether KOH solutions containing zincate detrimentally affect the performance of the nickel cathode.

We have devised a test cell that allows the nickel cathode to be cycled in zincate-rich electrolyte during both the charge and discharge modes. Having the nickel cathode in zincate-rich electrolyte at all times should accelerate any effect the zincate may have on the nickel electrode being tested.

Performance of Matsushita Cathodes with CELGARD Barrier
After 200 Cycles

Figure 22

Normally, in the characterization of nickel cathodes in KOH solutions, nickel sheet anodes would be used. The use of nickel anodes with zincate electrolyte would result in the depletion of zincate from the solutions by the process of plating zinc on the nickel sheet anodes during charge. Our test cell substituted porous carbon anodes for the nickel sheet anodes. The use of these carbon anodes eliminates the zincate depletion problem since carbon has a low hydrogen over-voltage and will evolve hydrogen in preference to the zinc plating reaction.

The following is an outline of the test plan (including test results) to determine the effect of zincate on the performance of the nickel cathode, in this case, a Matsushita sintered nickel electrode (6 in. H x 3 in. W x .065 in. Th.). The test regime, unless otherwise noted:

Charge - 1 amp - 10 hrs. (40% overcharge)

Stand - $\frac{1}{4}$ hour

Discharge - 1.7 amps to 0 V vs. Hg/HgO ref.

Electrolyte was 6M KOH + 10g/L LiOH .H₂O unless otherwise noted.

All cycle references are contained in Figure 23.

1) Cycles 1-10 - The use of nickel sheet is our normal method of determining cathode performance in zincate free electrolyte. The 10 cycles yielded a normal capacity of 7.1 Ah.

2) Cycles 11-21 - The carbon anodes were to be used in determining the cathode performance in zincate rich electrolyte. Rather than go directly to the zincate rich electrolyte, it was decided to cycle the cathodes against carbon in zincate free electrolyte. After 11 cycles, the cathode had nominal capacity of 6.4 Ahr. This represented a 10% loss in capacity in going from the nickel sheet anodes to carbon anodes. The reason for this reduction is not apparent, however, the 6.4 Ah point was now considered the base starting point.

3) Cycles 22-38 - The cathode was given a total of 17 cycles in the zincate rich electrolyte (161g/L ZnO). After 17 cycles, the cathode had a nominal capacity of 5.6 Ahr. This represented a 21 percent loss in capacity since being cycled against nickel sheet anodes and a 12.8 percent from the 6.4 Ahr base level established with the carbon anodes.

4) Cycles 39-43 - The cathode was removed from the carbon anode cell containing the zincate rich electrolyte and blotted dry. It was then returned to the cell containing nickel sheet anodes and fresh zincate free electrolyte. After 5 cycles the nominal capacity remained at 5.6 Ahr even in the zincate free electrolyte. On each cycle some residual zinc was plated out on the nickel sheet anodes. A sample of electrolyte was analyzed and indicated 4.5g of ZnO in the 700ml of electrolyte. At this point, it appeared the zincate had permanently affected the sintered cathode.

Effect of Zincate on Nickel Cathodes (Matsushita)

Figure 23

5) Cycles 43-48 - Since the standard electrolyte did not restore the cathode to its original capacity, it was decided to vary the concentration of electrolyte. A high concentration of electrolyte would provide more solubility for any zincate in the cathode but is also known to have the detrimental effect of increased corrosion of the sintered nickel cathode. The first electrolyte was a dilute solution (3MKOH + 5g/L LiOH .H₂O). The lower concentration did not improve capacity. An analysis of the electrolyte yielded 0.7g ZnO in 700ml.

6) Cycles 48-54 - The low concentration electrolyte was replaced with 10M KOH. The initial cycle yielded 6.0 Ahr. a slight increase over the previous cycle. As expected, there was some corrosion as evidenced by a slight sediment of nickel oxide at the bottom of the cell. On the next cycle (#49), the cathode yielded the original 7.2 Ahr nominal capacity. On the subsequent 5 cycles (50-54), the cathode was able to maintain a nominal capacity of 7.15 Ahr. It was expected, at this higher electrolyte concentration, that any ZnO remaining in the cathode would go into solution, but there appeared to be no zinc plating out on the nickel sheet anode. Analysis of the electrolyte yielded only a trace amount of ZnO.

7) Cycles 55-61 - After re-establishing initial capacity (7.2 Ahr) in the 10M electrolyte, it was replaced with the original concentration of electrolyte (6M KOH + 10 g/L LiOH). Cycles 55 and 56 were performed with the nominal 40% overcharge per cycle and the capacity dropped to 6.0 Ahr. With 100% overcharge, the capacity increased to 6.5 Ahr.

Zincate solutions appear to affect the performance of sintered nickel cathodes but the exact mechanism is not known.

A new test cell has been devised to determine the effect of zincate on the nickel cathode. The new cell uses platinized Titanium anodes rather than carbon anodes to prevent plating of zinc from zincate rich electrolytes. The platinized Titanium anodes offer the following advantages:

- 1) The test can be performed with larger electrodes.
- 2) The electrode performance can be determined with zincate free and zinc rich electrolytes without changing anodes (previously, nickel anodes were changed to carbon anodes...)
- 3) The electrodes can be characterized at various discharge rates. At high discharge rates, the carbon anodes were susceptible to stress cracking.

The overall test scheme will be similar to that used for the carbon anodes. We also plan to perform some chemical analysis on the sintered nickel cathode to determine if there are any zinc compounds within the cathode structure.

2.3 ELECTROCHEMICAL STUDIES (EXIDE NO. 6052)

(A) Zinc Electrodeposition

1) Special Charging Technique

During this reporting period, experiments have continued to establish the optimum conditions for deposition of a dense crystalline zinc deposit, using the special charging technique. These experiments included tests on 7-plate cells (120Ah) containing industrial size plates, as well as 3-plate lab cells of 6Ah capacity. It was found that an acceptable dense zinc deposit can be obtained at cathodic current densities within the range of 8 - 18 ma/cm². Within this range, zinc grain size is estimated to be less than 200 μ m. The quality of zinc deposit as a function of current density is depicted in Figure 24. A photo micrograph of the dense zinc deposit at 50 X magnification is shown in Figure 25. For our cycling tests in the laboratory, the special charging technique was used, at an average charge current density of 15 ma/cm². During the cycling tests, the quality of the zinc deposition was constantly monitored. Weight variation (as a measure of zinc shape change) and zinc electrode capacity were checked as a function of cycling. After a test of 50 deep cycles, no shape change or loss of capacity were indicated. Visual observations indicated no changes in the zinc morphology over the 50 cycle period. Zinc substrate in these tests was a low carbon steel sheet, cadmium plated.

2) Rotating Disc Experiments

For a better understanding of the mechanism of the special charging technique, a series of experiments was run utilizing a rotating disc of 0.12 cm² diameter and the simplest form of non-direct current charging; i.e., a pulsing current with a frequency of 60 Hz. With this type of investigation, we were able to vary the current density of charge, the intensity of the hydrodynamic disturbance in the electrolyte, and to make a quick analysis of the results. In the experiments, zinc foil counter electrodes were used, keeping the zincate concentration of the electrolyte constant. Conditions of the experiments included an initial electrolyte concentration of 6M KOH + 10 g/L LiOH .H₂O, and a disc rotational velocity of 150 rev./min. Figure 26 depicts the ϕ - I relationship of zinc deposition. It is clear that the pulsing current technique exhibits a lower over-potential than direct current, and that hydrogen evolution occurs at a lower current density with D.C. charging. This increase in over-potential probably affects the quality of the zinc deposit.

Quality of Zinc Deposit - Grain Size vs Current Density
Using Special Charging Technique

Figure 24

Figure 25 - Dense Zinc Deposit 50X

Polarization Curve of Zinc Electrodeposition

Figure 26

The next series of experiments were concerned with the effect of rotational speed on the deposited zinc surface. Galvanostatic measurements (Figure 27) show that zinc polarization (over-potential) decreases with increasing rotational velocities, and that for the same rotational velocity polarization potentials are reduced when pulse charging is used as compared to D.C. charging. Potentiastatic measurements (Figure 28) also confirmed that pulsing current facilitates the process of zincate ion reduction. These results indicate that the application of pulsing current decreases zinc over-potential and affects the quality of the zinc deposited.

To determine this effect a series of experiments were run using the following conditions for each run:

Disc Velocity (ω)	160 rev./min.
C_{ZnO}	150 g/L
Capacity of Zn Deposit	12 mah/cm ²
Temp.	22°C (approx.)
Plating Substrate	Gold Disc-Electrode

The pulsing current of zinc deposition was varied from 0.5 ma/cm² to 150 ma/cm². Surfaces with dense, bright deposits were obtained at pulsing current densities in the range of 4 to 80 ma/cm². Figure 29 depicts a zinc surface of good, dense quality obtained at a current density of 22 ma/cm². A strong solid structure is seen with an average grain size of 5-10 μ .

Next, the effect of zincate concentration was investigated using cathodic pulsing deposition. Galvanostatic measurements of the deposition of zinc at a pulsing current density of 10 ma/cm² as a function of rotational velocity are shown in Figure 30. Two levels of zincate concentration were run; namely, 65 g/L ZnO and 150 g/L ZnO. It is clear from the data that the polarization of the zinc deposition increases as the zincate concentration decreases.

Another set of experiments was run varying the disc rotational velocity at a series of different pulsing current densities. Results show (Figure 31) that zinc deposition over-potential increases with pulse charge current density at a specific zincate starting concentration and in all cases, polarization decreases with increasing rotational velocity. A region of acceptable quality zinc deposit was found. This was at current densities of 4-40 ma/cm², and at rotational velocities of 300-400 rev./min.

Effect of Rotational Velocity on Zinc Polarization
Galvanostatic Measurements

Figure 27

Effect of Rotational Velocity on Zinc Polarization
Potentiostatic Measurements

Figure 28

Figure 29 - Dense Zinc Deposit
Rotating Disc 50X

Effect of Zincate Concentration and Rotational Velocity
on Zinc Polarization

Figure 30

Overpotential of Zinc Electrode vs. Rotational Velocity

Figure 31

The efficiency of zinc plating was also measured by a series of experiments using charge-discharge cycling of a rotating disc electrode, using a fixed rotational velocity of 300 rev./min., a zincate concentration of 65 g/L ZnO, and varying the current density of the pulsing current charge. Table 23 gives the results of these experiments, and as can be readily seen, as current density of charge increases from 30 to 100 ma/cm², charge efficiency decreases from 99.6% to 88.6%. This inefficiency is attributed to hydrogen evolution becoming more favored at the higher current densities.

TABLE 23
EFFECT OF PULSING CURRENT DENSITY
ON ZINC CHARGE EFFICIENCY

Current Density (ma/cm ²)	Capacity (mah/cm ²)		Efficiency %
	Charge	Discharge	
30	12.0	11.95	99.6
40	12.0	11.92	99.3
60	12.0	11.71	97.6
80	12.0	11.10	92.5
100	12.0	10.60	88.3

It should also be mentioned that electrodeposition efficiency decreases as the zincate concentration decreases. Since the over-potential of zinc deposition increases as zincate concentration decreases, then this inefficiency will be seen as hydrogen evolution. As shown in Figure 31, in depleted solutions (10 g/L ZnO), increasing the rotational velocity does not reduce polarization appreciably below 1.4 volts (Vs Hg/HgO) unless current density of deposition is 5ma/cm² or less. Table 24 gives a summary of all these data.

Anodic pulsing current (discharge) was also evaluated for the zinc electrode. It was found that the use of pulse discharge current increased the efficiency of discharge, and makes the accumulation of passive zinc less likely. Moreover, the potential of the zinc electrode is more electronegative, and the over-potential is lower than when discharging with direct current. This is shown in Figure 32 where a pulsing discharge at 80 ma/cm² is compared with a D.C. discharge at the same current density.

TABLE 24

VARIATION OF ZINC DEPOSITION EFFICIENCY
 AS A FUNCTION OF ZINCATE CONCENTRATION DEPOSITION
 CURRENT DENSITY AND ROTATIONAL VELOCITY

Current Density ma/cm ²	ZnO Conc. g/L	Zinc Deposition Efficiency % Rotational Velocity RPM			
		0	150	800	1500
10	5	86.0	87.9	90.2	-
	10	-	89.6	-	-
	20	89.2	91.4	96.7	98.7
20	5	79.8	80.5	85.4	91.0
	10	80.8	82.6	87.3	-
	20	84.0	88.1	92.7	93.5
40	5	72.5	77.8	86.3	85.2
	10	76.0	80.6	84.1	89.1
	20	79.4	82.5	91.3	92.9
80	5	61.3	72.7	77.2	79.1
	10	66.4	74.3	80.1	84.6
	20	70.8	77.8	82.9	86.9

Zinc Polarization on Discharge

Figure 32

3) Effect of Pulsing Charging on Nickel Electrode

Since it was seen that charging techniques other than D.C. (pulse charging e.g.) gave a better quality of zinc deposit, it was necessary to evaluate this type of charging for its effect on nickel cathodes.

As is well known, the charging of nickel electrodes is accompanied by the undesirable side reaction of oxygen evolution, because of the low oxygen overvoltage on active nickel surfaces for the reaction:

At the end of charge, when most of the NiOOH is formed in the body of the electrode, ohmic resistance increases and the overvoltage increases the rate of oxygen evolution, thus lowering the final charge efficiency of the nickel electrode. Additives, such as cobalt, which increase the oxygen overpotential have been used historically to increase the efficiency of the electrochemical conversion of the active mass. In our experiments, the special charging technique and pulse charging current were used to evaluate their effect on nickel charge acceptance. A nickel electrode with an area of 3.75 mm² and a nominal capacity of 2.3 mah was used, and charged with D.C. pulse current, and the special charging technique. A charge current of 20 ma/cm² was used and the charge acceptance determined. The results are shown in Table 25 for different periods of charge and overcharge. The efficiency of the nickel electrode (capacity out/2.3 mah) is given for each test condition. In each test the pulsing technique yielded the highest charge acceptance.

(B) Zinc Corrosion

1) Types of Corrosion

Zinc electrodes lose capacity during storage. This loss of capacity is actually a corrosion of the active zinc on the negative electrode. Examination of zinc electrodes after storage indicates that the main zone of corrosion is often at the top of the electrode near the liquid surface. This suggests a corrosion mechanism caused by oxygen depolarization at the liquid surface caused by inadequate sealing of the experimental cell. If this is an actual mechanism of capacity loss, it is essential to estimate the rate of corrosion (capacity loss) possible.

Oxygen corrosion of zinc at the liquid surface is well known. It is a homogeneous (not galvanic) corrosion and it is independent of the galvanic corrosion which is hydrogen depolarized. This corrosion occurs due to differences in oxygen concentration at the liquid surface and in the bulk of the KOH solution. The electrolyte forms a meniscus at the electrode surface under action of capillary forces. Oxygen from the air diffuses to that portion of the electrode surface which underlies the meniscus and there undergoes ionization according to the reaction:

TABLE 25

EFFECT OF PULSE CHARGING ON SINTERED NICKEL ELECTRODE
CHARGE ACCEPTANCE

Charge Current Type	Time of Charge	Time of Overcharge	Charge Capacity	Discharge Capacity	Efficiency of Nickel Electrode
	Hours	Hours	mah	mah	%
Direct	3	0	2.28	1.86	81.5
Special Charging Technique	3	0	2.28	1.84	80.7
Pulsing	3	0	2.28	1.90	83.3
Direct	4	1	3.04	1.95	84.7
Special Charging Technique	4	1	3.04	1.91	83.0
Pulsing	4	1	3.04	2.05	89.1
Direct	6	3	4.56	2.10	91.3
Special Charging Technique	6	3	4.56	1.95	84.7
Pulsing	6	3	4.56	2.23	96.9

The zinc immediately adjacent to the reaction site polarizes and provides the electrons for the oxygen ionization as shown by the reaction:

Figure 33 depicts a system of coordinates with the origin at the upper edge of the meniscus. It is further assumed that there is no electrochemical polarization so that the Nernst Equation can be used to calculate the potential drop at the electrode/solution interface in terms of gas concentration, C_1 , at this interface. Since the potential of the metallic electrode is almost independent of y , it follows that the variation of E with y can be represented by the equation:

$$dE = \frac{RT}{2F} d \ln C_1 \quad (1)$$

Letting dr represent the ohmic resistance of a film sector of length dy measured along the y axis, and length unity measured along the three phase boundary, one has:

$$dr = \frac{1}{\mu} \frac{dy}{x_0} \quad (2)$$

μ being the electrical conductivity of the solution and x_0 the film depth.

The linear current density per unit width (one side of zinc electrode), where L is the electrode width.

$$i_e = \frac{I}{L}$$

will then be determined through the equation of Ohm's law

$$i_e = \frac{dE}{dr} \quad (3)$$

from which it follows that

$$i_e = \mu x_0 \frac{RT}{2F} d \frac{\ln C_1}{dy} \quad (4)$$

The quantity of oxygen diffusing to the electrode surface under this film in unit time will be equal to

$$D \left(\frac{C_o}{x_0} - C_1 \right) dy \quad (5)$$

Figure 33

Mechanism of Zinc Corrosion by Oxygen Diffusion

C_1 is the concentration of oxygen at the interface of zinc and electrolyte. This concentration becomes lower with increased depth. D is the oxygen diffusion constant.

The increment of linear current density or contribution of current over each section will then be:

$$d i_e = 2FD \frac{(C_o - C_1)}{x_o} dy \text{ (Fick's first Law) } (6)$$

Multiplying (4) and (6) and then integrating with conditions taken as

$$y = 0 \quad i_e = 0 \quad C_1 = C_o$$

$$i_e = \int_0^y 2 RTDC_o \mu \{ \ln (C_o/C_1) + (C_1/C_o) - 1 \} dy^{1/2} \quad (7)$$

but according to Nernst's Law:

$$\frac{C_1}{C_o} = e^{-\frac{2F\Delta\psi}{RT}} \quad (8)$$

then

$$i_e = \int_0^y 2 RTDC_o \mu \{ (2F\Delta\psi/RT) + \exp(-2F\Delta\psi/RT) - 1 \} dy^{1/2} \quad (9)$$

Taking into consideration that $\Delta\psi$ is the potential drop between two points of the electrolyte where the concentration of oxygen is equal to C_o (at the gas boundary) and in the bulk of the solution $C = C_1$. Usually, such potential differences have been 2-3 mv. Therefore:

$$\frac{2F\Delta\psi}{RT} = \frac{2 \cdot 96 \cdot 500 \cdot 0.003}{1.98 \cdot 295} = 0.29$$

For a case where $\frac{2F\Delta\psi}{RT} < 1$, equation (9) simplifies to

$$i_e = 2F \sqrt{\frac{DuC_o}{RT}} \cdot \Delta\psi \quad (10)$$

According to this equation, we can calculate the linear current density as follows:

$$F = 96,500 \text{ coul./eq.}, \Delta\psi = 3 \text{ mv} = 0.003 \text{ V.}$$

$$D = 10^{-6} \text{ cm}^2/\text{s}; \mu = (1.68 \text{ ohm-cm})^{-1} = 0.6 \text{ ohm}^{-1} \text{ cm}^{-1}$$

$$C_o = 0.0023 \text{ cc/cc} = 1 \times 10^{-7} \text{ moles/cm}^3$$

$$T = 22^\circ\text{C} = 295 \text{ K}$$

$$R = 1.98 \text{ cal/}^\circ\text{C-mole} = 8.314 \text{ J/K-mole}$$

then:

$$i_e = 0.85 \text{ ma/cm}$$

The length of the boundary phase in the experimental cell is equal to 12 cm, and the storage time is 24 hours.

$$0.85 \text{ ma/cm} \times 12 \text{ cm} \times 24 \text{ hr.} = 245 \text{ mah/day.}$$

Capacity of the experimental electrodes is usually equal to 4-5 Ah. Therefore, the loss of capacity is equal to about 5 percent per day due to the oxygen reaction. This calculation is in approximate agreement with experimental results. Furthermore, an additional experiment was run in which the charged electrode was stored in a dessicator containing an Argon atmosphere. Zinc corrosion in this case was only approximately 1.5%/day. Extrapolating these results to a 7 plate 130 Ah laboratory cell with full size electrodes (approx. 6.9 x 9.0 inches) indicated that a loss of 2.6 to 3.0 Ah/day (approx. 2 to 2.5%) is possible even if the electrodes are completely covered with electrolyte, but the cell seal allows air to enter and diffuse oxygen into the electrolyte.

2) Charged Stand Testing

In order to evaluate zinc corrosion in a practical way, a number of charged stand tests were run on the 7 plate 130 Ah (S/N 016) VIBROCEL™ with 2.5 mm spacing. One of the significant results observed was that capacity losses (corrosion) are less when the cell is not fully charged and contains a higher concentration of zincate than a fully charged cell. When the electrolyte is depleted of zincate (fully charged) corrosion rates are the highest. In general, the corrosion of zinc in the VIBROCEL™ can be considered to be one of three types. These are:

- Self dissolution of zinc due to oxygen diffusion and depolarization of zinc. Dependent upon oxygen concentration.
- Dissolution of zinc due to hydrogen evolution as a result of galvanic action with substrate. Dependent on type of substrate material.
- Dissolution of zinc due to hydrogen evolution as a result of galvanic action of macro-particles absorbed on the surface of zinc during charge. Particles are the result of shedding of the nickel electrode during charge (washing action of electrolyte).

The last type is considered to be the most harmful since it increases as the amount of particulate material in the electrolyte increases. This is usually a function of the number of charge cycles. This is shown graphically in Figure 34 where the % capacity loss of cell S/N 016 per 24 hrs. is plotted VS. no. of cycles. At the start of the test, the capacity loss was 1.5% per day, while after 30 cycles capacity loss was over 5% per day. As a confirmation of this theory, the electrolyte was filtered of particulate matter, and returned to the cell. Capacity loss per day fell to 1.5% (the initial value) immediately. Thus, it appears essential to develop a non-shedding nickel cathode for VIBROCEL™.

Other work of notice in this area concerns a comparison of zinc capacity loss of cells charged with D.C. as compared to the special charging technique or pulse charging. Test results indicate that zinc capacity losses of cells charged with pulsing current (and also the special charging technique) are approximately half that of cells charged with D.C. The explanation for this is that the dense zinc deposited by the special charging techniques is more stable in KOH than the mossy D.C. zinc deposits. Equilibrium potential of the dense zinc deposits for the reaction

is more positive by about 9 mv than that of the mossy zinc deposits of D.C. charging. An example of this is given in Figure 35 where a plot of % capacity loss is given VS storage time. The upper curve represents D.C. charging, while the lower curve is pulse charging. The pulse charging consistently shows stand losses about half that of the D.C. charging.

3) Additives for Corrosion Inhibition

The use of additives to inhibit zinc corrosion in alkaline batteries is well documented in the literature. Of particular interest are the inorganic additives such as lead and mercury. These additives, if incorporated on the substrate surface layer, have the property of increasing hydrogen over-potential.

Our experiments were started with lead additives. Various concentrations of lead were evaluated, and it was found that at a concentration of $8.0 \times 10^{-5} \text{M/L Pb}^{++}$, a dense good quality zinc deposit was obtained on a rotating disc electrode, using the special charging technique. This is shown in Figure 36.

Figure 34

Capacity Loss of Zinc Electrodes

Figure 35

Fig. 36 Zinc Deposit with Lead Additive

A - Zinc Deposit X1000, 6M KOH + 150 g/L ZnO
Pb (8.0×10^{-5} M/L)

B - Zinc Deposit X5000, 6M KOH + 150 g/L ZnO
Pb (8.0×10^{-5} M/L)

In order to determine the long term effect of lead additives, two experiments were conducted using lead additives:

- o The over-potential of hydrogen evolution was measured after each zinc deposition on a rotating disc electrode. (Pb^{++} concentration $8 \times 10^{-5} M/L$.)
- o Measurements of zinc corrosion rates (capacity loss) were made on 3 plate (6 Ah) laboratory cells containing $4 \times 10^{-5} M/L$ Pb^{++} .

The results of the first experiment are shown in Figure 37 where increased hydrogen over-potentials were measured, and stability over a number of cycles was indicated. The testing of the 6 Ah laboratory cells showed an increased zinc corrosion resistance as compared to cells without this additive.

(C) Effect of Cycle Testing and Special Charging Technique in Cells with Reduced and Normal Electrode Spacing

For purposes of evaluating the special charging technique, its effectiveness with closer electrode spacing, and performance over an extended number of cycles, test VIBROCELTM S/N 016 and 017 were used. These were 7 plate laboratory cells containing full size industrial electrodes (approximate size 6.9 inches x 9.0 inches) with a nominal rating of 130 Ah. Cell S/N 016 has an interelectrode spacing of 2.5 mm, while cell S/N 017 has a spacing of 1.5 mm. Extensive cycling tests were run utilizing a charging mode of the special charging technique at an average current of (40A) C/3 until the depletion of zinc (as signaled by hydrogen over-potential being reached), followed by an overcharge at C/6 (20A) average, using pulsing currents. The value of the pulsing current overcharge for nickel capacity maintenance has been demonstrated on small nickel electrodes. Figure 38 illustrates the effect of various periods of overcharge on cell S/N 017, with pulsing currents of 20 A. Nominal capacity is reached with slightly over 4 hrs. of overcharge at $\frac{C}{6}$, or about 50% overcharge.

The capacity variation of cell S/N 017 with cycling is presented in Figure 39. The tendency for capacity fall-off is restored periodically by an extended overcharge using pulsing current.

To determine long term effects of the special charging technique, cell S/N 017 was dismantled after Cycle 85 discharge and the negative substrates examined. A photograph of the negative assembly at this time is shown in Figure 40. As can be seen, there is no evidence of shape change, or passivated zinc adhering to the anode substrate. The extended cycling with 1.5 mm spacing and the special charging technique seems to deposit a uniform dense zinc which also discharges in a uniform manner.

Hydrogen Overpotential as a Function of Cycle Number
with Lead Additive

Figure 37

Cell S/N 017 - Variation of Capacity with Pulsing
Overcharge Time

Figure 38

Cell S/N 017 Capacity vs Cycles

Figure 39

Figure 40 - Negative Assembly Cell S/N 017
Cycle 85

To estimate one of the advantages of the closer spacing of cell S/N 017, a power density curve was run on this cell. This data is depicted in Figure 41. Also, indicated in Figure 41, is similar data obtained from cell S/N 009, a 300 Ah - 15 plate cell with 2.5 mm spacing (ref. Figure 10). For purposes of comparison, discharge currents of the cells were normalized based on the actual electrode areas of each cell. The data indicates a significant advantage in power density for cell S/N 017, due to the closer spacing (and lower IR losses) as well as the densely deposited zinc, and its lower polarization during discharge. It should be noted that this power density data represents performance of cells initially at a full state of charge.

2.4 REPORTS AND DOCUMENTATION (EXIDE NO. 6053)

Monthly progress reports have been prepared giving an update of technical progress for the period September 1979 (No. 5) to July 1980 (No. 15). In addition, the Milestone Schedule and Status Report (DOE Form 535), the Manpower Management Report (DOE Form 534M), and Cost Management Report (DOE Form 533M) have been prepared for each of these reporting periods, as well as for August 1980. This "Second Annual Report" is a summary of the technical progress in the period September 1, 1979 to August 31, 1980.

The Program Management Plan, originally submitted in May 1979, was updated and resubmitted in May 1980.

△ S/N 017 - 7 Plate VIBROCEL™, 130 Ah, 1.5mm Spacing

○ S/N 009 - 15 Plate VIBROCEL™, 300 Ah, 2.5mm Spacing

Comparison of Power Densities

Figure 41

APPENDIX A

DETAILED VIBROCELTM DRAWINGS

DETAILED VIBROCELTM DRAWINGS

Drawing No.

SK 6050-4027	Experimental Baseline Module - Two Cell
SK 6050-4000	Two Cell Monobloc Case
SK 6050-4001	Cover, Monobloc
SK 6050-4002	Guide Rails, VIBROCEL TM
SK 6050-4003	Positive and Negative Connectors
SK 6050-4004	Bearing, Linear
SK 6050-4005	Negative Terminal
SK 6050-4006	Bearing Holder
SK 6050-4007	Hold Down, Cover
SK 6050-4008	Sleeve, Eccentric
SK 6050-4009	Actuator and Shuttle
SK 6050-4010	Double Plate Cathode - 30 Ah
SK 6050-4011	Single Cathode and Support
SK 6050-4012	Substrate, Anode
SK 6050-4013	Clamp, Cover
SK 6050-4014	Hardware, Miscellaneous
SK 6050-4015	Nut, Anode Group
SK 6050-4016	Nut, Positive Group
SK 6050-4017	Vent Tube
SK 6050-4018	Flexible Negative Connector
SK 6050-4019	Intercell Connector
SK 6050-4020	Stud and Sleeve, Positive Group

DETAILED VIBROCELTM DRAWINGS (cont'd)

Drawing No.

SK 6050-4021	Stud, Negative Group
SK 6050-4022	Netting, Double Plate Cathode
SK 6050-4023	Zinc Getter
SK 6050-4024	Gasket, Cover
SK 6050-4025	Shaft, Actuator Drive
SK 6050-4026	Seal, Bellows

NO.	DESCRIPTION	DWG. NO 6050-
1	TWO-CELL "MONOBLOC" CASE	4000
2	" " " COVER	4001
3	GUIDE RAILS	4002
4	POSITIVE CONNECTOR	4003
5	NEGATIVE GROUP CONNECTOR	4003
6	" " SPACER	4003
7	LINEAR BEARING	4004
8	NEGATIVE TERMINAL	4005
9	BEARING HOLDER	4006
10	COVER HOLD-DOWN	4007
11	ECCENTRIC SLEEVE	4008
12	ACTUATOR AND SHUTTLE	4009
13	DOUBLE-PLATE CATHODE	4010
14	SINGLE-PLATE CATHODE	4011
15	ANODE SUBSTRATE	4012
16	COVER CLAMP	4013
17	MISC. HARDWARE	4014
18	NUT, ANODE GROUP	4015
19	NUT, POSITIVE GROUP	4016
20	VENT TUBE	4017
21	FLEXIBLE NEG. CONNECTOR	4018
22	INTERCELL CONNECTOR	4019
23	POS. GROUP STUD & SLEEVE	4020
24	NEGATIVE GROUP STUD	4021
25	ZINC GETTER	4023
26	COVER GASKET	4024
27	SHAFT (ACTUATOR DRIVE)	4025
28	BELLOWS SEAL (NEUPRENE)	4026

DESIGNED BY		DATE		5/1/80		SCALE		FULL	
CHECKED BY		DATE				BY		DATE	
APPROVED BY		DATE				BY		DATE	
AT PASADENA DO NOT SCALE DRAWING 01/80 01/80									
ESB INCORPORATED TECHNOLOGY CENTER YARDLEY, PENNSYLVANIA EXPERIMENTAL BASELINE MODULE TWO-CELL BATT (VIBROCEL) SK 6050-4027

TWO-CELL BATTERY CASE (MONOBLOC)
FOR EXPERIMENTAL BASELINE MODULE
OF 185 AH (NOM) RATING, AND STD
EV FOOTPRINT

MAT'L: ACRYLIC, 2 REQ'D

DESIGN/RELEASE APPROVALS		DESIGN BY	JLE	DATE	7/2/74	ESB INCORPORATED TECHNOLOGY CENTER VANDLEY, PENNSYLVANIA
APPROVED BY	DATE	ENGINEER	NAME	FULL		
		DESIGNER		NAME		TWO-CELL MONOBLOC CASE EXP. BASELINE MOD VIBROCEL™
		NAME				
		PROJECT		NAME		SK 605U-4
		NAME				
		PROJECT		NAME		C
		NAME				

0.290
0.280

2.40
2.39

0.290
0.280

A ←

2.685
2.675

←

←

A

5.87
5.85

SECTION A-A

MAT'L: ACRYLIC
REQ'D - 2

DESIGN/RELEASE AUTHORITY		VJ3		5/1/72		ESB INCORPORATED	
APPROVED BY		DATE		FULL		TECHNOLOGY CENTER	
						VARELEY, PENNSYLVANIA	
		AS SPECIFIED		DO NOT SCALE DRAWING		COVER (MUNICIPAL) EXPERIMENTAL	
						BASELINE MODULE (VARELEY)	
		11/80		01/80		5K 6050 - 4001	

C

PROPRIETARY RIGHTS ARE CLAIMED IN THE
SECTION ENCLOSED ON THIS DRAWING.

INSPECTION SPECIFICATION

REV.	DATE	ALTERATION	BY	APP.
TITLE: VIBROCEL™ GUIDE RAILS EXP. BASELINE MODULE (TWO-CELL BATT.)				
MATERIAL: ACRYLIC 8-REQ'D		NEW SOURCE SETTING ENGINEERING DEPT. - DESIGN DIVISION WOODHALL, PA 15068 SCALE: DATE 1/12/70 DRAWN VJS CHECK APP. THIS DWG. SUPERSEDES SK 6057-4002 MADE IN U.S.A.		

POSITIVE CONNECTOR

POSITIVE
CONNECTOR
REQ'D - 4

0.34

POS. & NEG.
SPACERS
(SEE TABLE
AT RIGHT)

A +0.000
-0.002

B

NEGATIVE CONNECTOR STUD, 4 REQ'D

REQUIREMENTS ARE BASED ON THE
GENERAL DIMENSIONS OF THIS DRAWING.

SECTION SPECIFICATION

SPACERS

TYPE	A	B	M. REQ'D
POSITIVE	0.340	0.38 0.35	24
NEGATIVE	0.344	0.32 0.33	20

NEG. CONNECTOR STUD, 4 REQ'D

REV.	DATE	ALTERATION	BY	APP.
TITLE: POSITIVE AND NEGATIVE CONNECTORS EXP. BASELINE MODULE, VIBROCEL™				
MATERIAL: C.R. STEEL				
DESIGNED BY: [Signature]				
SCALE: 1/15				
DATE: 9/11/50				
THEORY: [Signature]				
SK 6030 - 4003				
MADE IN U.S.A.				

BEARING RETAINER

MAT'L:
ACRYLIC
4 R29'0

BEARING INSERT

4 R29'0

MAT'L - RULON

SYL	DATE	REVISION	CK	DRAWN BY	DATE	ESB INCORPORATED TECHNOLOGY CENTER YARLEY, PENNSYLVANIA
				CHECKED	SCALE		
				MATERIAL			
				DO NOT SCALE DRAWING			
				TOLERANCE			
				FRACTION	DECIMAL	ANGLES	
				±1/64	±0.001	±1/4°	
DRAWING NO.						A	
5X 656-4004							

LINEAR BEARING
EXP. BASELINE MODULE, VIRRUCET™

PROPRIETARY RIGHTS ARE CLAIMED IN THE
MATERIAL DISCLOSED ON THIS DRAWING

NEGATIVE TERMINAL

MAT'L :
C.R. STEEL
FINISH : N. PLATE

NEGATIVE TERMINAL; EXP. BASELINE MODULE (VIBROCEL™)

EXIDE

DESIGN ENGINEERING
MORSHAM, PA. 19044

SCALE FULL DATE 8/18/80

DRAWN VJS CHKD. APPD.

REV.	DATE	ALTERATION	BY	APP.

THIS DWG.
SUPERSEDES

SK 6050-4005

MADE IN U.S.A.

BEARING HOLDER AND COVER HOLD-DOWN

MAT'L: GLASS REINFORCED EPOXY LAMINATE
 APPROX $\frac{3}{8}$ THICK
 NO. REQ'D - 3 PER TWO-CELL MODULE (TOTAL - 6)

BEARING INSERT

MAT'L: PULON
 NO. REQ'D = 6

DESIGN/RELEASE APPROVALS		DRAWN BY VJS		DATE 5/1/80		ESB INCORPORATED	
APPROVED BY	DATE	CHECKED	SCALE	FULL		TECHNOLOGY CENTER	
						YARLEIGH, PENNSYLVANIA	
		P.O. DESCRIBED				BEARING HOLDER	
		DO NOT SCALE DRAWING				EXP. BASELINE MODULE	
		FRACTION				DRAWING NO.	
		1/8" X 2 1/2" X 2 1/2"				SK 6050-4006	
		1/8"				C	

COVER HOLD-DOWN

12 REQ'D
MAT'L: C.R.S.

SYL	DATE	REVISION	CK	DRAWN BY VJS	DATE 5/1/86	ESB INCORPORATED TECHNOLOGY CENTER YARDLEY, PENNSYLVANIA		
				CHECKED	SCALE TWICE			
				MATERIAL C.R.S. ; NO REQ'D - 8		COVER HOLD-DOWN EXP. BASELINE MODULE (VIBROCEL™)		
				DO NOT SCALE DRAWING				
				TOLERANCE		DRAWING NO. SK 6050-4007		
				FRACTION ±1/64	DECIMAL .XX ±.010 .XXX ±.005			
						A		

ECENTRIC SLEEVE

MAT'L: C.R.S.; NICKEL PLATE NO. REQ'D - 4

SYL	DATE	REVISION	CK	DRAWN BY	DATE	ESB INCORPORATED	
				VJS	4/15/80	TECHNOLOGY CENTER	
				CHECKED	SCALE	YARLEY, PENNSYLVANIA	
				MATERIAL	TWICE	ECCENTRIC SLEEVE	
				C.R.S.; FINISH NICKEL PLATE		EXP. BASELINE MODULE (VIBROLOC™)	
				DO NOT SCALE DRAWING		DRAWING NO.	
				FRACTION	DECIMAL	ANGLES	
				±1/64	±.010	±1/4°	SK 6050-4008
					±.008		A

ACTUATOR

MAT'L: ACRYLIC ; 4 REQ'D

PROPRIETARY RIGHTS ARE CLAIMED IN THE MATERIAL DISCLOSED ON THIS DRAWING.

INSPECTION SPECIFICATION

SHUTTLE
MAT'L: RULON
2 REQ'D

REV.	DATE	ALTERNATION	BY	APP.
TITLE: ACTUATOR AND SHUTTLE EXP. BASFLINE MODULE (VIBROCEL™)				
MATERIAL:		KIDS POWER SYSTEMS DIVISION ENGINEERING DEPT. - DESIGN DIVISION WORMHAM, PA. 19044 SCALE FULL DATE 5/13/74 DRAWN VJS CHD. APP.		
AS SPECIFIED		THIS DWG. SUPERSEDES SK 6050-4009 MADE IN U.S.A.		

DATE	REVISION	BY	CHK

MODEL 202 N "MATSUSHITA"

SIM TAREO. NICKEL PLATES (2), CUT DOWN

LOADING NIKKEC HYDRAK-JE. (1.28 g/cc approx)

DESIGN/RELEASE APPROVALS		DATE	4/21/20	REVISION	1	DATE	4/21/20	REVISION	1
APPROVED BY	DATE	AS SPECIFIED	DO NOT SCALE DRAWING	DATE	4/21/20	REVISION	1	DATE	4/21/20
ESB INCORPORATED		TECHNOLOGY CENTER		TAMLETT, PENNSYLVANIA		DOUBLE PLATE CATADROP, 30 AL		EVP, CASE LINE NO.	
SK 6030		VIBROCEL		VIBROCEL		VIBROCEL		VIBROCEL	

MODEL 202N MATSUSHITA SINTERED
NICKEL CATHODE (1), CUT DOWN
LOADING, NIBB) - 1.285/4 APPROX

A - EDGES OF NETTING SHOWN ON
OUTSIDE SURFACE OF CATHODE

SINGLE, OUTSIDE, CATHODE, WITH SUPPORT

CATHODE (SINGLE, OUTSIDE) SUPPORT MEMBER

RIVET SUPPORT TO OUTSIDE SURFACE OF SINGLE
OUTSIDE CATHODE AS SHOWN AT LEFT.

MATL: 0.024 GAGE CARBON STEEL, PREPARED
32% HOLE DR. - 0.045, STAGGERED
0.080 - NICKEL PLATE FINISH

DESIGN/RELEASE APPROVALS		DESIGNED BY VJS	DATE 2/10/90	ESB INCORPORATED	
APPROVED BY	DATE	ENGINEER	DATE FULL	TECHNOLOGY CENTER	
		DRAWN		VANDLEY, PENNSYLVANIA	
		AS SPECIFIED		SMALL CATHODE AND SUPPORT	
		DO NOT SCALE DRAWING		EXP. BASELINE MODEL (VIBROCEL™)	
		PROJECT	NUMBER	DRAWING NO.	
		11/84	SR 2310	5K 60SU - 40 11	
		REV 2	01/84

MAT'L: 0.024 GAUGE CARBON STEEL
 PERFORATED 32%
 HOLE DIA. - 0.085"
 SPACER - 0.080
 FINISH: CADMIUM PLATE - 1 MIL
 NO KEY - 6 PER CELL

DESIGN/RELEASE APPROVALS		DESIGNED BY: J. J. J.	DATE: 4/29/80	ESB INCORPORATED TECHNOLOGY CENTER YAROLEY, PENNSYLVANIA
APPROVED BY:	DATE:	DESIGNED BY:	DATE:	
		AS DESIGNED		ABOVE SUBSTRATE EXP. BACKLINE MODULE (VIBRACEL™)
		DO NOT SCALE DRAWING		
		PRODUCTION	APPROVED	DRAWING NO. SK 6050-4012
		1/1/84	1/1/84

APPLIED

NO. REG'D - 10

SYL	DATE	REVISION	CL	DRAWN BY	DATE	ESB INCORPORATED	
				UJS	5/2/60	TECHNOLOGY CENTER	
				CHECKED	SCALE	YARDLEY, PENNSYLVANIA	
				MATERIAL		COVER CLAMP	
						EXP. BASELINE MODULE (VIBROCEL™)	
				TOLERANCE		DRAWING NO.	
				DO NOT SCALE DRAWING		SK 6050 - 4013	
				FRACTION	DECIMAL	ANGLES	A
				±1/64	XX ±.010 XXX ±.008	±1/4°	

HEX NUTS

SIZE	A	B	C
3/8-24 UNF	0.56	0.65	0.227
1/2-20 UNF	0.75	0.866	0.323
5/8-18 UNF	0.93	1.083	0.387

PROPRIETARY RIGHTS ARE CLAIMED IN THE
MATERIAL DISCLOSED ON THIS DRAWING.

INSPECTION SPECIFICATION

WASHERS

FLAT / LOCK

SIZE	A	B	C
3/8	1.0 .688	.438 .382	.071 .094
1/2	1.25 .879	.562 .509	.112 .125
5/8	1.75 1.086	.688 .653	.112 .156

HEX NUT

FLAT WASHER

LOCK WASHER

REV.	DATE	ALTERATION	BY	APP.
<p>TITLE: MISC. HARDWARE</p> <p>EXP. BASELINE MODULE (VIRACEL™)</p>				
<p>MATERIAL:</p> <p>C.R. STEEL</p> <p>FINISH: NICKEL PLATE</p>		<p>KENEC POWER SYSTEMS DIVISION 1800 WILSON AVENUE MORGANTOWN, PA. 15044</p> <p>SCALE: DATE 5/12/81 DRAWN VJS CHECKED APP.</p>		
<p>THIS DWG. SUPERSEDES</p> <p>SK 6050-4014</p> <p>MADE IN U.S.A.</p>				

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MAT'L: S.P. STEEL, CADMIUM PLATED
NO. REQ'D - 8

NUT ; ANODE GROUP

EXP. BASELINE MODULE (VIBRUCEL™)

EXIDE

DESIGN ENGINEERING
HORSHAM, PA. 19044

SCALE FULL

DATE 5/2/80

DRAWN VJS

CHKD.

APPD.

REV.

DATE

ALTERATION

BY

APP.

THIS DWG.
SUPERSEDES

SK 6030-4015

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MAT'L: C.P. STEEL

FINISH: NIKEL PLATE

NO. REQ'D - 8

NUT, POS. GROUP

EXP. BASELINE MODULE (VIBRICEL™)

EXIDE POWER SYSTEMS DIVISION
253 UNDEVELOPED
ENGINEERING DEPT. - DESIGN DIVISION
PHILADELPHIA, PA. 19130
SCALE FULL DATE 5/2/50
DRAWN VJS CHKD. APPD.

REV.	DATE	ALTERATION	BY	APP.

THIS DWG.
SUPERSEDES

SK 6058-4016

MADE IN U.S.A.

VENT TUBE

4 REQ'D

SYN.	DATE	REVISION	CX	DRAWN BY VJS	DATE 5/1/80	ESB INCORPORATED TECHNOLOGY CENTER YARDLEY, PENNSYLVANIA
				CHECKED	SCALE FULL	
				MATERIAL		
				ACRYLIC		VENT TUBE EXP. BASELINE MODULE (VIBROCEL™)
				DO NOT SCALE DRAWING		
				TOLERANCE		DRAWING NO. SK 6050-4017
				FRACTION	DECIMAL	
				±1/64	.XX ±.010 .XXX ±.005	ANGLES ±1/4°
						A

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APPLICATION OF FLEXIBLE
CONNECTOR -
APPROX. 35 LEAVES / CELL

FLEXIBLE CONNECTOR
MATERIAL: GLIDCOP-20 COMPOSITE
4 MIL THICK

FINISH: Ni FOLLOWED BY Cd PLATE

FLEXIBLE NEGATIVE CONNECTOR; EXP. BASELINE MODULE (VIBROCEL™)

EXIDE

DESIGN ENGINEERING
HORSHAM, PA. 19044

SCALE FULL DATE 8/16/80
DRAWN VJS CHKD. APPD.

REV.	DATE	ALTERATION	BY	APP.

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SUPERSEDES

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MAT'L: COPPER

FINISH: NICKEL PLATE

NO. REQ'D - 6

INTERCELL CONNECTOR; EXPERIMENTAL BASELINE MODULE (VIBROCEL™)

EXIDE

DESIGN ENGINEERING
MORSHAM, PA. 19044

SCALE FULL

DATE 5/13/80

DRAWN VJS

CHKD.

APPD.

REV.

DATE

ALTERATION

BY

APP.

THIS DWG.
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POSITIVE GROUP STUD

NO. REG'D - 4

POSITIVE GROUP SLEEVE

MAT'L: S.P. STEEL ; FINISH - NICKEL PLATE

POSITIVE GROUP STUD AND SLEEVE

EXIDE

DESIGN ENGINEERING
HORSHAM, PA. 19044

SCALE FULL DATE 5/13/80
DRAWN VJS CHKD. APPD.

REV.	DATE	ALTERATION	BY	APP.

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MAT'L: C.R. STEEL
FINISH: CADMIUM PLATE
NO. REQ'D - 4

NEGATIVE GROUP STUD

EXIDE

DESIGN ENGINEERING
HORSHAM, PA. 19044

SCALE FULL DATE 5/13/80

DRAWN VJS CKD. APPD.

REV.	DATE	ALTERATION	BY	APP.

THIS DWG.
SUPERSEDES

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NETTING FOR DOUBLE PLATE CATHODE; EXP. BASELINE MODULE (VIBROCEL™)

EXIDE

DESIGN ENGINEERING
HORSHAM, PA. 19044

SCALE ~

DATE 5/13/80

DRAWN VJS CHKD.

APPD.

REV.

DATE

ALTERATION

BY

APP.

THIS DWG.
SUPERSEDES

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MAT'L: "PURE CARBON" POROUS FC-13 2 REQ'D

ZINC GETTER; EXP. BASELINE MODULE (VIBROCEL™)

EXIDE

DESIGN ENGINEERING
HORSHAM, PA. 19044

SCALE FULL DATE 5/13/80

DRAWN VJS CKED. APPD.

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INSPECTION SPECIFICATION

2 REQ'D

REV.	DATE	ALTERATION	BY	APP.
TITLE: COVER GASKET				
EXP. BASELINE MODULE (VIBRACEL™)				
MATERIAL:				
NEOPRENE, 0.055 T				
ENGINEERING DEPT. - DESIGN DIVISION				
HONOLULU, HI. 96844				
SCALE Full DATE 5/13/80				
DRAWN VJS CHN. APP.				
THIS DOC. SUPERSEDES				
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SHAFT (ACTIVATOR DRIVE)

EXP. BASELINE MODULE (VIBROCEL™)

EXIDE

DESIGN ENGINEERING
MORSHAM, PA. 19044

SCALE FULL DATE 5/30/80

DRAWN VJS CHED.

APPD.

REV.

DATE

ALTERATION

BY

APP.

THIS DWG.
SUPERSEDES

SK6050-4025

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MATL: NEOPRENE

BELLOWS SEAL

EXP. BASELINE MODULE (VIBROCEL™)

EXIDE

DESIGN ENGINEERING
MORSHAM, PA. 19064

SCALE TWICE DATE 5/30/70

DRAWN VJS CHED. APPD.

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