

**Space Station Freedom NiH₂
Cell Testing Program**

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1. SUMMARY

a. Testing for the Space Station Freedom Nickel Hydrogen Cell Test Program began in 1990 at Crave Division, Naval Surface Warfare Center. The program has included receipt inspection, random vibration, acceptance, characterization, and life cycle testing of Ni-H₂ cells in accordance with the NASA LeRC Interagency Order C-31001-J.

b. A total of 400 Ni-H₂ cells have been received at NAVSURFWARCENDIV Crane from three separate manufacturers; Yardney Technical Products (Yardney), Eagle Picher Industries (Eagle Picher), and Gates Energy Products (Gates). Of those, 308 cells distributed among 39 packs have undergone life cycle testing under a test regime simulating low earth orbit conditions. As of 30 September 1993, there are 252 cells assembled into 32 packs still on life cycle test.

c. Since the beginning of the program, failed cells have been detected in all phases of testing. The failures include the following; seven 65 AmpHr and 81 AmpHr Yardney cells were found to be leaking KOH on receipt, one 81 AmpHr Eagle Picher cell failed the acceptance test, one 65 AmpHr Gates cell failed during the characterization test, and six 65 AmpHr Gates cells failed the random vibration test. Of the 39 life cycle packs, testing on seven packs, 56 cells, has been suspended because of low end of discharge voltages. All of the failed life cycle packs were cycled at 60% depth of discharge.

2. INTRODUCTION

a. Initial funding for the Space Station Freedom Nickel Hydrogen Cell Test Program was received at Crane Division, Naval Surface Warfare Center (NAVSURFWARCENDIV) in March 1987 under NASA LeRC Interagency Order C-31001-J. The first cells were received in April 1990. Cell testing began in May 1990 with the first LEO life cycle testing starting in July 1990. The last scheduled life cycle pack was started in February 1993.

b. The purpose of the cell test program is to develop a statistically significant Ni-H₂ database on representative cell from U.S manufacturers and to establish facilities which can perform special testing in support of Space Station Freedom. The major test objective is to evaluate cell life at 35% and 60% Depth of Discharge (DOD) and -5°C and 10°C. The goal of the life cycle testing is to reach 20,000 cycles at 60% DOD and 33,000 cycles at 35% DOD.

3. TEST PLAN

a. The cells were from three different manufacturers; Yardney Technical Products, Eagle Picher Industries and Gates Energy Products. Different designs from each manufacturer were used in the tests including variations in plate arrangement, separator type, use of catalyzed walls, KOH concentration and the nickel plate manufacturing process, Table I.

b. The cell test program included receipt inspection, random vibration, acceptance, characterization, and LEO life cycle testing. Receipt inspection consisted of a visual inspection plus measuring physical and electrical characteristics such as dimensions, weight, internal impedance, insulation resistance between the cell wall and the mounting flange, and a phenolphthalein leak test. Following the receipt inspection, all of the cells were cycled under various temperatures to determine if they met the capacity and voltage performance requirements in the acceptance test. Based on the data from the acceptance test, the cells were assigned to life cycle test packs or storage groups. Before the life cycle packs were assembled and started, 20% of the cells from each pack were subjected to random vibration testing. An equal number of cells went through characterization testing where they were cycled under various charge/discharge rates and temperatures to provide fundamental efficiency and operation characteristics. The cells were then assembled into LEO life cycle packs of 4 to 10 cells or the storage groups based on the test matrix shown in Table II.

c. A standard LEO life cycle test consisted of dividing each group or lot of cells into four separate packs. Of the four packs, two were tested at a DOD of 35% at 10°C and -5°C. The

		Yardney			Eagle Picher			Gates		
		65 AmpHr-Standard	65 AmpHr-Advanced	81 AmpHr-Advanced	65 AmpHr-Standard	65 AmpHr-Advanced	81 AmpHr-Advanced	65 AmpHr-Standard	65 AmpHr-Advanced	81 AmpHr-Advanced
Stack Arrangement	Recirculating	X								
	Back-To-Back		X	X	X	X	X		X	X
Stack Type	Dual	X	X	X	X	X	X			
	Single							X	X	X
Separator Material	Zircar	X	X	X	X ²	X	X	X ²	X ²	X ²
	Asbestos	X	X	X		X	X			
	Serrated		X	X						
KOH Concentration	26%		X	X					X ³	
	31%	X			X	X	X	X	X ³	X
Wall Recombination	Yes		X	X		X	X			
	No	X			X			X	X	X
Ni Electrode	Slurry	X	X	X ¹	X	X	X			
	Dry Sinter							X	X	X

(1) Ni Electrode is thinner than the 65 AmpHr advanced design.

(2) Separator is two layers of Zircar.

(3) Half of the cells are 26% KOH and half are 31% KOH.

Table I. Ni-H₂ Cell Design Matrix

remaining two packs were tested to a DOD of 60% at 10°C and -5°C. The charge/discharge regime varied from group to group. Most packs used a test regime that discharged the specified DOD in .6 hours. The discharge was followed by a high rate charge for .6 to .667 hours (36 to 40 minutes) that put 95% of the discharged Amp-Hours back into the pack. Following the high rate charge, a low rate charge for .233 or .3 hours brought the pack to a constant recharge rate that varied from 101% to 107%. Table III shows a summary for a typical test regime used with the 81 AmpHr Gates cells.

d. Some of the packs used variances to the standard charge/discharge regime. They included varying the state of charge (SOC) at the beginning of the test, the use of a taper charge, a single step charge, and a trickle charge at the end of the charge step. For the Gates 65 AmpHr cells, 3600G through 3604G and Eagle Picher 3600X through 3605X, different SOC were used. SOC tests are set by starting the LEO cycle tests with the cells at a specific SOC. Currently, these packs are being run at 90%, 94% and 100% SOC.

	Temp	Yardney		Eagle Picher			Gates		
		65 AmpHr Standard	81 AmpHr Advanced	65 AmpHr Standard	65 AmpHr Standard	81 AmpHr Advanced	65 AmpHr Standard	65 AmpHr Standard	81 AmpHr Standard
35% DOD LEO Test	-5°C	10 5635W	5 5735W	10 3835Y	0	5 5735E	10 3835E	10 3635G	10 3835G
	10°C	10 5631W	5 5731W	10 ⁽²⁾ 3831Y	24 ⁽⁴⁾ 360xX	5 3731E	10 3831E	10 3631G	12 ⁽⁹⁾ 360xG
60% DOD LEO Test	-5°C	10 ⁽¹⁾ 5665W	5 ⁽¹⁾ 5765W	0	0	5 ⁽¹⁾ 3765E	10 3865E	0	10 3865G
	10°C	10 ⁽¹⁾ 5661W	5 ⁽¹⁾ 5761W	20 ⁽³⁾ 386xY	24 ⁽⁵⁾ 360xX	5 3761E	10 3861E	20 ⁽⁷⁾ 366xG	8 ⁽¹⁰⁾ 360xG
Storage		10	0	17	2	0	17 ⁽⁶⁾	10 ⁽⁸⁾	0
Shipped to GSFC for Additional Testing		0	0	3	0	0	3	0	3
On Test at Crane Under Another Project		0	0	0	0	0	0	0	10

(1) These packs have failed and have been discontinued.

(2) One cell was removed from the pack of 10 when it failed.

(3) Split between two 10 cell packs, 3861Y and 3865Y.

(4) Split between three 8 cell packs, 3600X, 3601X, and 3602X.

(5) Split between three 8 cell packs, 3603X, 3604X, and 3605X.

(6) One of these 17 cells failed during characterization testing.

(7) Split between two 10 cell packs, 3661G and 3665G.

(8) Seven of this group of 10 cells have failed. One failure occurred during acceptance testing. The remaining 6 cells failed during vibration testing.

(9) Split between three 4 cell packs, 3600G, 3602G and 3603G.

(10) Split between two 4 cell packs, 3601G and 3604G.

TABLE II. Ni-H₂ Cell Test Matrix

e. In addition to using varying SOC, the Eagle Picher 65 AmpHr cells in packs 3600X through 3605X are using single step, and taper charges. The six packs are all running at 10°C. Three packs are operating at 35% DOD and three at 60% DOD. In each DOD group, the packs were started at 100%, 94%, or 90% SOC. The 100% SOC tests use a taper charge at the end of the high rate charge. When the tests were first started, the charge regime

	Discharge Regime	Charge Regime		Temp °C
		Hi Rate for	Lo Rate for	
3831G	35%DOD in .6Hr	.600Hr	.300Hr	10
3835G	35%DOD in .6Hr	.600Hr	.300Hr	-5
3861G	60%DOD in .6Hr	.667Hr	.233Hr	10
3865G	60%DOD in .6Hr	.667Hr	.233Hr	-5

All tests are 10 cells per pack

TABLE III. Gates 81 AmpHr Test Regime Summary

included a 2 Amp trickle charge at the end of the charge. This reflected the trickle charge that was part of the charge profile for Space Station Freedom (SSF). When the trickle charge was dropped from the SSF charge profile, the test profile for the six Eagle Picher packs was also modified to reflect the difference. A summary of the 65 AmpHr Eagle Picher charge/discharge profiles are shown in Table IV.

	Cycle Range	Discharge Regime	Charge Regime			State of Charge
			Hi Rate	Taper	2 Amp Trickle	
3600X	1-2727	35%DOD in .6Hr	Hi Rate	Taper	2 Amp Trickle	100%
	2738-8694	35%DOD in .6Hr	Hi Rate	Taper		
3601X	1-2749	35%DOD in .6Hr	Hi Rate		2 Amp Trickle	94%
	2758-8746	35%DOD in .6Hr	Hi Rate			
3602X	1-2736	35%DOD in .6Hr	Hi Rate		2 Amp Trickle	90%
	2748-8575	35%DOD in .6Hr	Hi Rate			
3603X	1-2752	60%DOD in .6Hr	Hi Rate	Taper	2 Amp Trickle	100%
	2758-8297	60%DOD in .6Hr	Hi Rate	Taper		
3604X	1-2724	60%DOD in .6Hr	Hi Rate		2 Amp Trickle	94%
	2730-8249	60%DOD in .6Hr	Hi Rate			
3605X	1-2668	60%DOD in .6Hr	Hi Rate		2 Amp Trickle	90%
	2678-8122	60%DOD in .6Hr	Hi Rate			

All tests are 8 cells per pack at 10-C

TABLE IV. Eagle Picher 65 AmpHr Test Regime Summary

4. TEST EQUIPMENT

a. All of the cyclic testing has been done on one of two automated test systems that have been developed and built at NAVSURFWARCENDIV Crane. Each system is built around a Hewlett Packard HP1000 mini computer. The computers use Hewlett Packard HP3497 Data Acquisition/Control units and HP3456 Digital Voltmeters to monitor and control process functions. All of the equipment is maintained and calibrated to the NAVWPNSUPPCEN Instruction 4355.17K, covering the implementation of the Naval Sea System Command Calibration Program.

b. Each test system is capable of simultaneously controlling and monitoring a variety of test scenarios on up to 40 separate packs. Each pack's charge/discharge current, cell voltage, cycle time, and operational limits are monitored by the test software on a two minute interval. To assure prompt action during test upsets and interruptions, the test labs are staffed 24 hours a day, 7 days a week.

c. A recent upgrade to the test system capabilities has been to add a centralized database of all of the test data at Crane. Access is available through phone in connections to all

NASA customers at this time. Data base users have access to any data that is part of their project. Security is provided by a user/password entry during login. All of the automated test systems that are operated by the Aerospace Power Systems Branch are interfaced to the database via network connections. A diagram of the test systems, database, and remote access interconnection are shown in Figure 1.

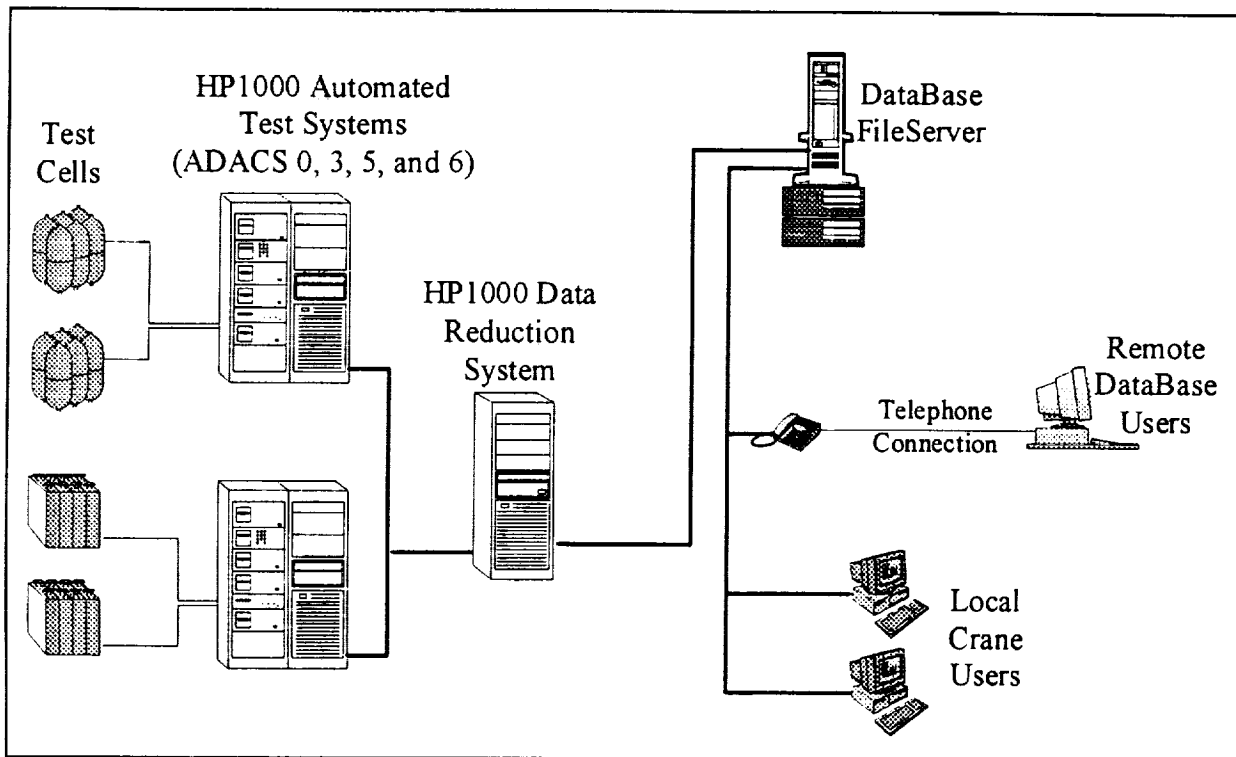


Figure 1. Automated Test System Configuration

5. TEST RESULTS

a. Seven cells showed signs of KOH leakage around one or both terminals during the initial receipt inspection. Leaks were discovered in two 65 AmpHr Yardney cells and five 81 AmpHr Yardney cells. All of the leaking cells were returned to Yardney for repair. When they were received back at NAVSURFWARCENDIV, no KOH leakage was detected. The two 65 AmpHr cells were put in a storage group. The 81 AmpHr cells were placed into LEO life cycle packs, 3831Y and 3865Y. Of the three that were put in pack 3831Y, one was removed at cycle 3199 because of low EOD voltages. At cycle 6440, all of the cells in the pack were rechecked for leaks. The failed cell in 3831Y showed signs of KOH at both terminals. The remaining cells did not appear to have any leaks.

b. One 65 AmpHr Gates cell failed acceptance testing when it showed little to no capacity in the first cycle. The cell was shipped to Gates where a Destructive Physical Analysis (DPA) was

performed. The cause of failure was determined to be a twisted cell stack from the assembly process.

c. An 81 AmpHr Eagle Picher cell failed during characterization with a gradual loss of capacity after 15 deep cycles to .5 volts. The cell was DPA'd at Crane. The cause of failure was determined to be shorting of the positive plates to the case.

d. Six of the eight 65 AmpHr Gates cells that were subjected to vibration testing failed. One of the cells showed signs of leaking immediately after the vibration test. A subsequent capacity check of the cells showed little capacity, 1 to 5 AmpHr, on four cells and a reduced capacity on one more cell. The four cells with little capacity showed signs of leaking after the capacity test. The final cell showed signs of leaks prior to beginning life cycle testing 5 months later. The two cells that passed the vibration test are currently life cycle packs 3661G and 3635G. Their EOD voltages compared to the pack average voltage are 1.158V/1.162V and 1.224V/1.226V respectively.

e. During the program, a total of 39 packs, 308 cells, have been cycled under a LEO test regime. Currently there are 32 packs, 252 cells still under test. Figures 2, 3, and 4 represent the cycling history and current status of the LEO packs for each of the three manufacturers. For the SSF test program.

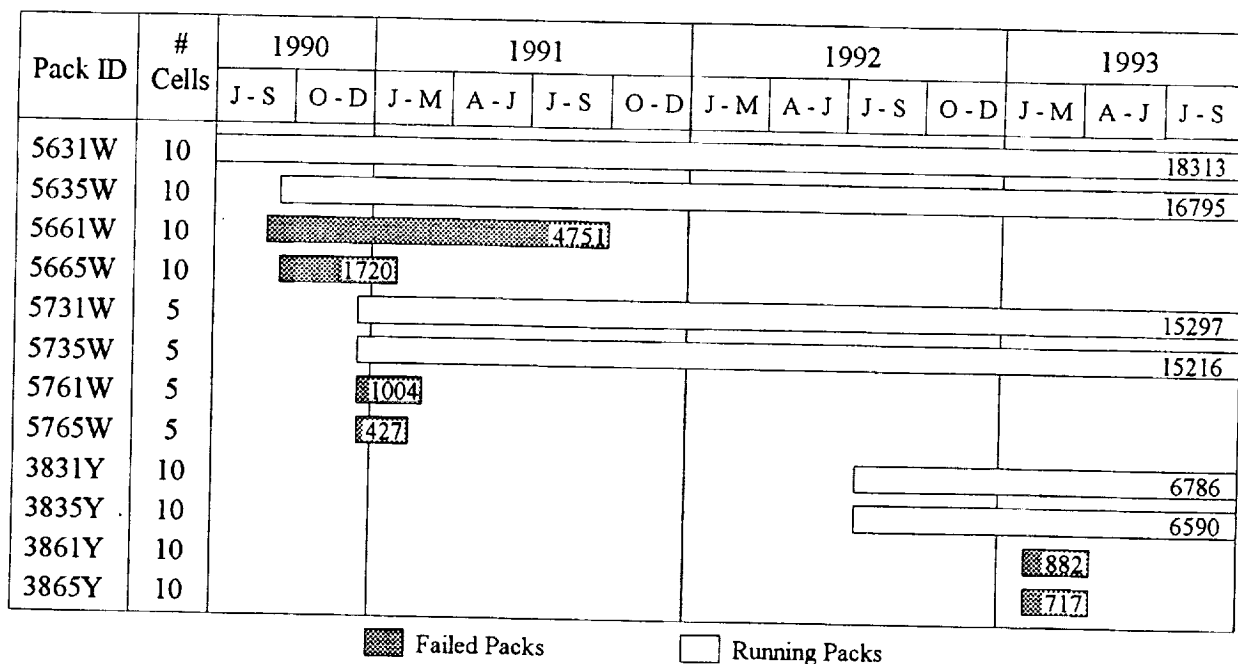


Figure 2. Yardney Life Cycle Test Summary

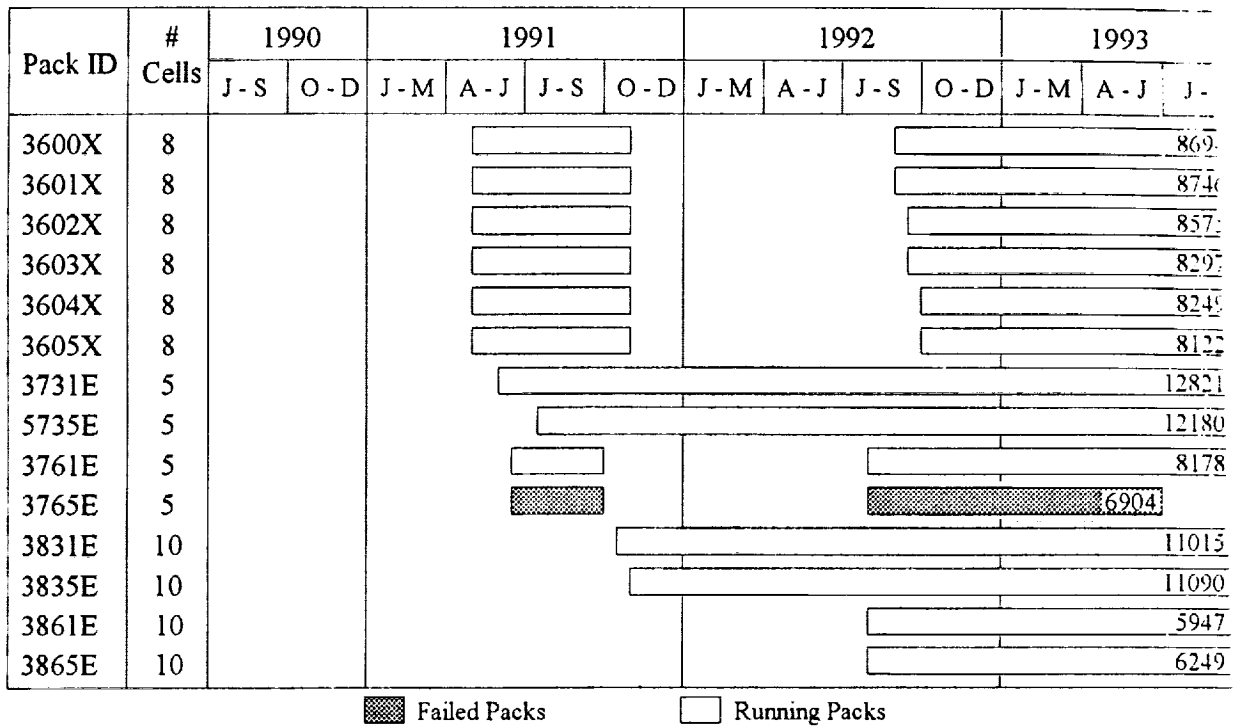


Figure 3. Eagle Picher Life Cycle Test Summary

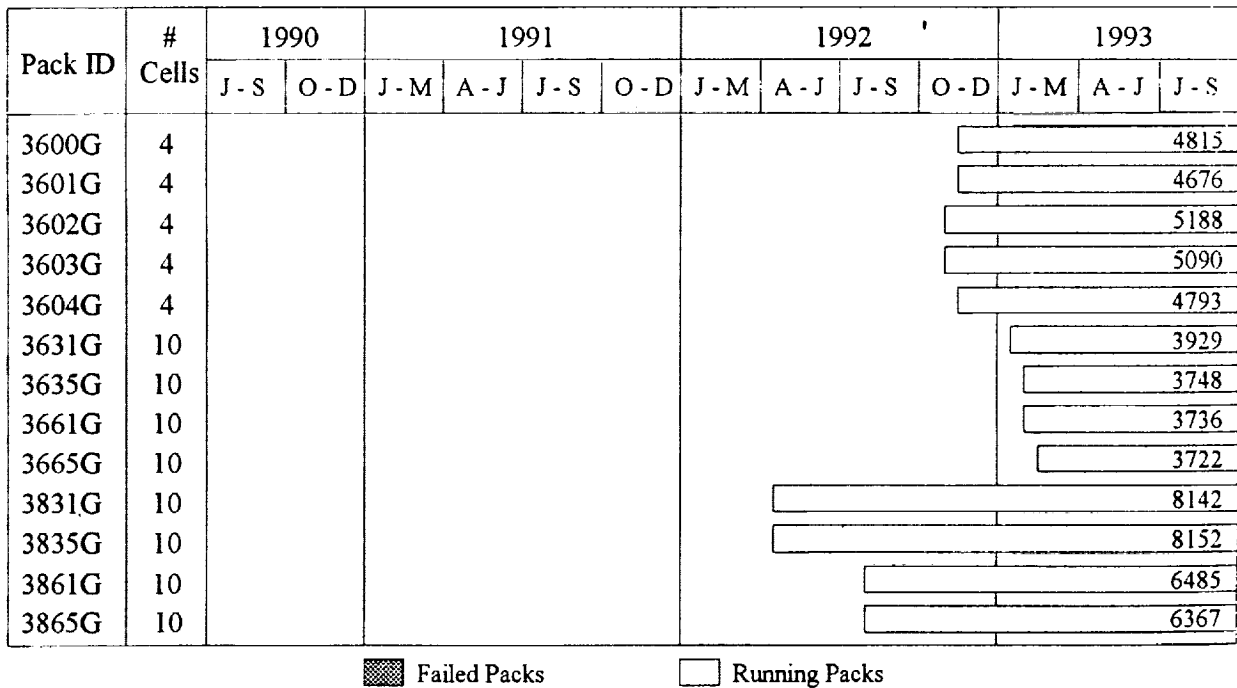


Figure 4. Gates Life Cycle Test Summary

life cycle failure occurs when the majority of the cells in a pack fall below EOD voltage of 1.0V.

f. Four Yardney 65 AmpHr packs that started LEO testing early in the program, failed after 427 to 4751 cycles. Post LEO capacity tests showed a variance of 58% to 83% of the original capacities, Table V. All of the cells were cycling at 60% DOD.

g. Two packs that were started at 60% DOD, 3861Y and 3865Y, dropped below the 1.0V EOD limit after 882 cycles and 717 cycles respectively. Post LEO capacity testing showed little capacity loss, Table V. The post life cycle capacity of 3861Y was measured to be 73 AmpHrs, a 2.6% loss from the 75 AmpHrs measured before life cycle testing began. Similarly, the post life cycle capacity of 3865Y was measured to be 67 AmpHr, a 6.9% capacity loss. Both packs have been considered as failed and testing has been discontinued.

h. A more recent failure is the -5°C, 60% DOD 65 AmpHr Eagle Picher pack, 3765E. It failed at 6904 cycles. Post LEO capacity was measured at 43% of the original value, Table V. The 10°C, 60% DOD pack, 3761E, that is from the same lot as 3765E, is near failure. One cell dropped below an EOD voltage of 1.0V at 6171 cycles. At 7927 cycles the same cell was removed from the pack when the cell EOD voltage dropped to 0.0V. At 8178 cycles, the average EOD voltage of the remaining 4 cells in the pack is 1.038V.

Pack Capacities to 1.0V				
PACK	Number of Cycles	Pre L.C. Capacity (AmpHr)	Post L.C. Capacity (AmpHr)	Discharge Rate
5661W	4751	67	39	C
5665W	1720	72	52	C
5761W	1004	60	50	C
5765W	427	66	50	C
3861Y	882	75	73	C/2
3865Y	717	72	67	C/2
3765E	6904	79	34	C

TABLE V. Pre and Post Life Cycle Failure Capacities

i. In addition to the cells already mentioned, there are some packs that have EOD voltages that are approaching levels of concern. The 81 AmpHr, 60% DOD Eagle Picher pack, 3865E is running with an EOD voltage of .995 at 6249 cycles. Four of ten cells have fallen below the 1.0V EOD value. Two 60% DOD 81 AmpHr Gates packs have cells that are approaching 1.0V at EOD. 3861G has one cell that has dropped to .940V while the pack average is still 1.085V. 3865G has three cells below 1.0V with a pack average of 1.095V.

6. PRELIMINARY FINDINGS

a. Even though the majority of the life cycle testing is still ongoing, some early conclusions can be made. The testing has provided a method to test the feasibility of a state of charge test. Of the six 65 AmpHr Eagle Picher packs, 3600X - 3605X, four are being operated at less than 100% SOC. So far the lower SOC has not resulted in large voltage dispersions.

b. Cells with the double layer Zircar separators have performed better than the asbestos or asbestos-Zircar combination in 60% DOD tests. Of the 39 life cycle packs tested during the program, 19 were at 60% DOD. So far, seven of the 19 packs have failed. All of the failed packs have had the asbestos-Zircar separator combination and had a completed cycle range from 717 to 6904. There are still three packs with the asbestos-Zircar separators running with a completed cycle range of 5947 to 8178. Of those, two are expected to fail within the next 1000 cycles. The remaining nine packs have a double layer Zircar separator with a completed cycle range from 3722 to 8297. None of them are in any immediate danger of failing.

c. Identical cells run at higher pressures at -5°C vs 10°C when cycled at 35% DOD. Cells run at 60% DOD also run at higher pressures than cells run at 35% DOD. The Eagle Picher 81 AmpHr packs 3831E, 3835E, 3861E, and 3865E are an example of the pressure differences. The 35% DOD packs 3831E (10°C) and 3835E (-5°C) have EOD/EOC pressures of 410/640 psi and 550/770 psi respectively. The 60% DOD packs, 3861E (10°C) and 3865E (-5°C) have EOD/EOC pressures of 430/840 and 420/790 psi.

d. At 60% DOD, cells perform better at 10°C than at -5°C . In all life cycle failures so far, packs running at -5°C completed fewer cycles than identical packs that ran at 10°C . The colder temperature and higher current result in undesirable voltage performance. The performance at 60% DOD has fallen short of anticipated life cycle expectancy.

Appendix A

Life Cycle Trend Plots

NSWC Crane

Pack ID 3600X

8 cells

Voltage/Pressure/Recharge EOC/EOD Trend Plot

04/28/91 - 09/28/93

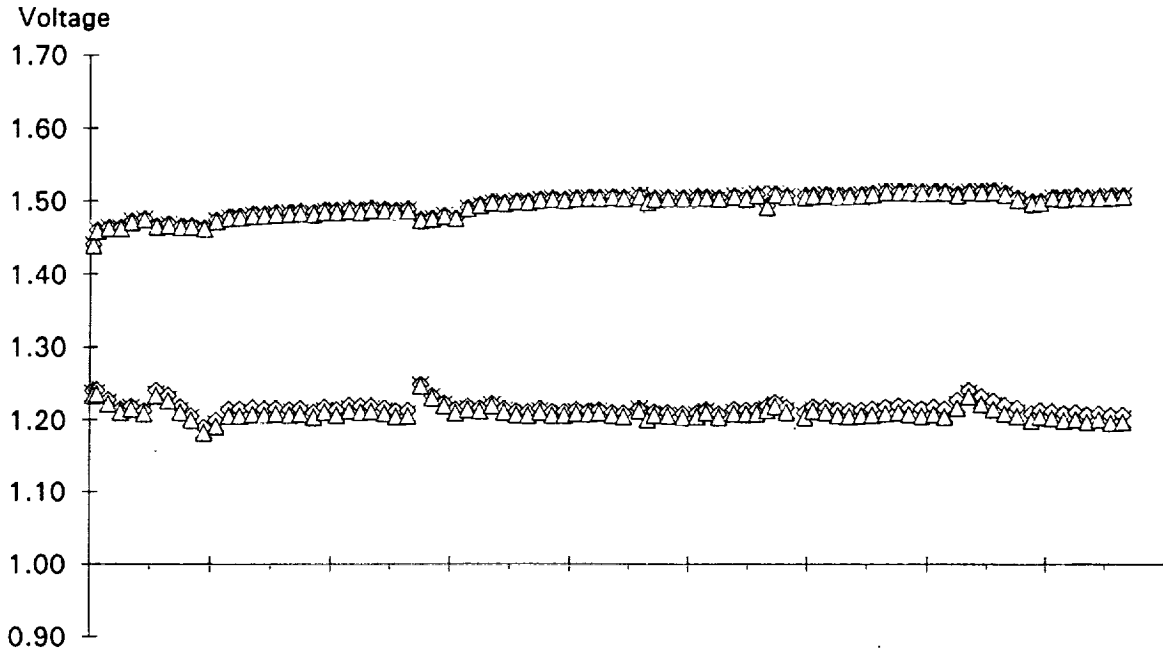
Eagle Picher 65 AmpHr

35% DOD

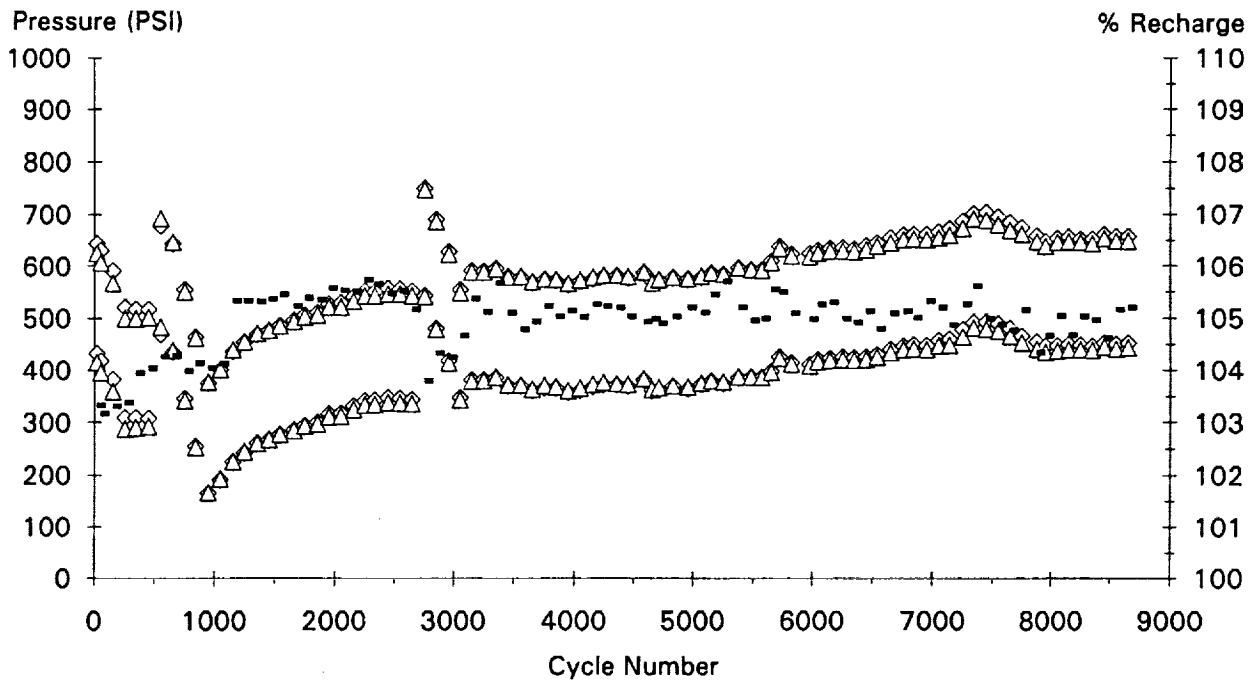
10 Deg C

Taper Chg

× V-avg ◇ Hi Voltage △ Lo Voltage



◇ P1:1 △ P1:2 - %Rchg



Note. Cycles 1-2727 display the total Recharge rate, including the .73% from the 2.0A trickle charge at the end of the charge cycle. The target recharge rate does not include the 2.0A trickle charge.

Cycle 1. Started Life Cycle Test.

-37.92A for .6Hr ; 31.42A for .6Hr ; 30.575 to 8.703A Taper for .233 Hr ; 2.0A for .083Hr
Rchg = 103.0%

Cycle 492. Power Supply failure during discharge caused pack to be overcharged.

Cycle 1287. Raised Rchg from 103.0% to 104%.

-37.92A for .6Hr ; 31.42A for .6Hr ; 30.645 to 10.584A Taper for .233Hr ; 2.0A for .083Hr

Cycle 2727. 11/01/91. Halted test for evaluation. Cells were left in a discharged state.

Cycles 2728 - 2737. These cycles were used for capacity testing.

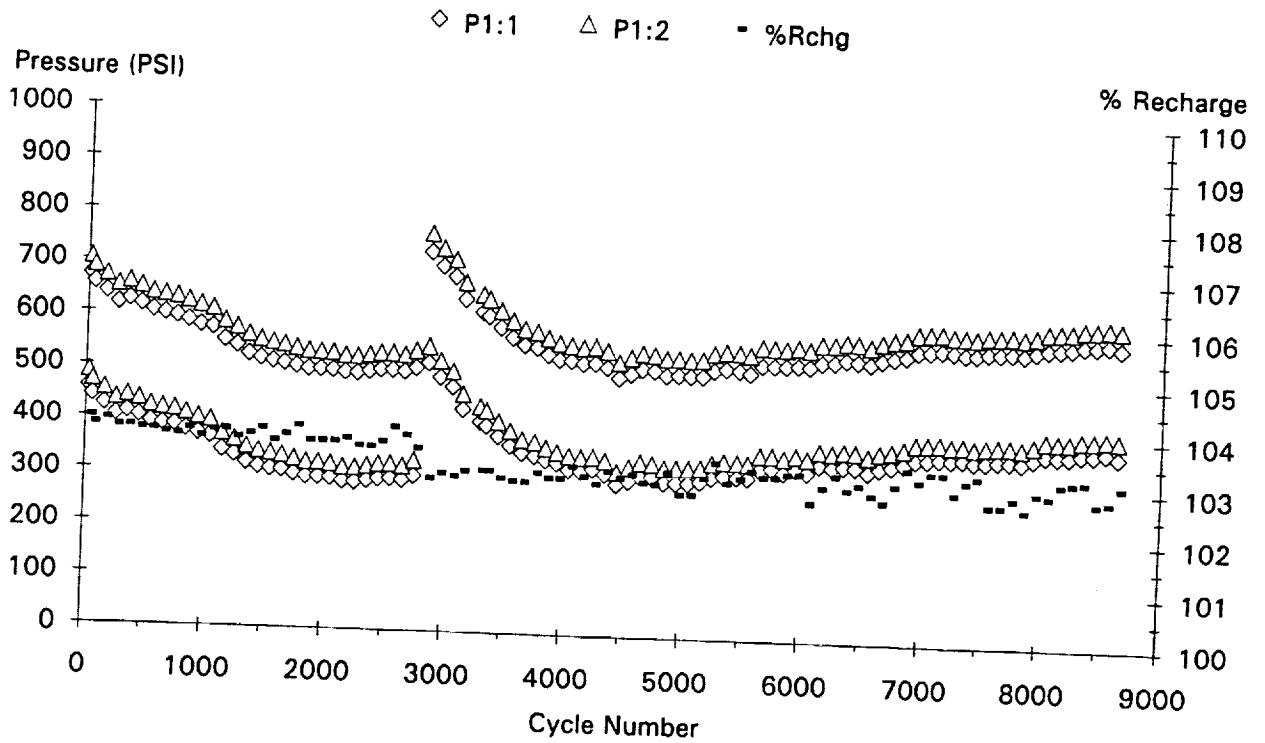
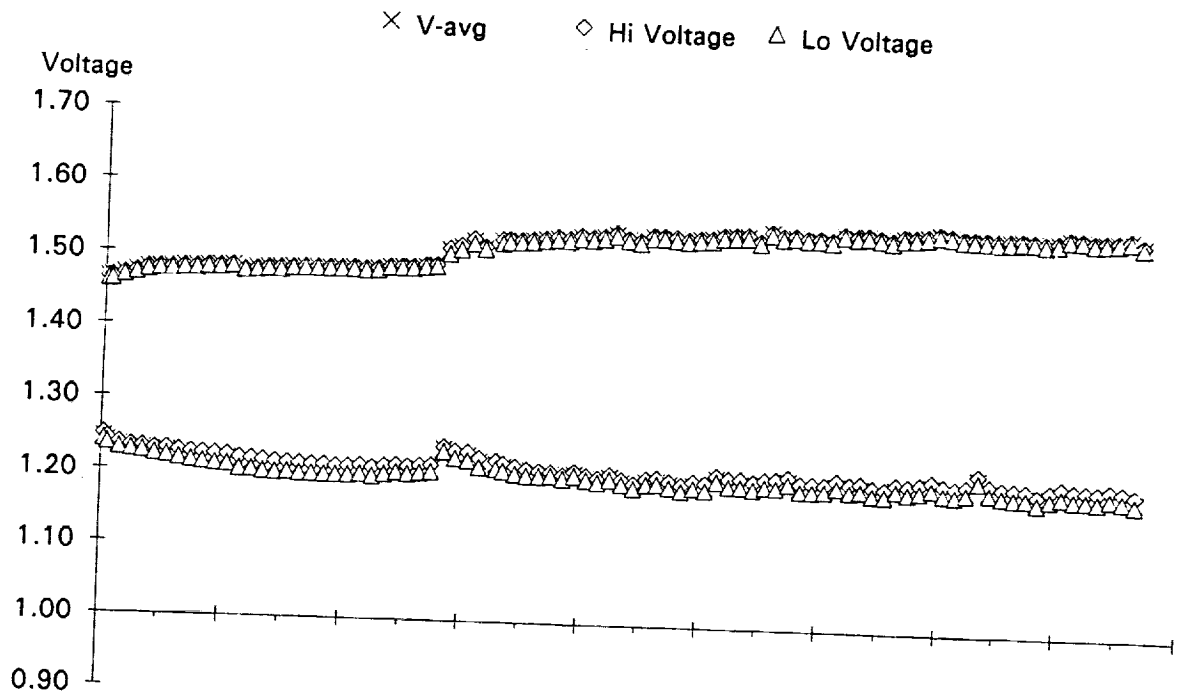
Cycle 2738. Pack restarted under a new test regime.

-37.92A for .6Hr ; 29.76A for .633Hr ; 29.03 to 7.045A Taper for .266Hr ;
Rchg = 104.0%

Cycle 3154. Raised Rchg from 104.0% to 105.0%.

-37.92A for .6Hr ; 29.76A for .6Hr ; 29.084 to 8.698A Taper for .266Hr

NSWC Crane **Pack ID 3601X** **8 cells**
 Voltage/Pressure/Recharge EOC/EOD Trend Plot 04/25/91 - 09/25/93
 Eagle Picher 65 AmpHr 35% DOD 10 Deg C 94% SOC



Note. Cycles 1-2749 display the total Recharge rate, including the .73% from the 2.0A trickle charge at the end of the charge cycle. The target recharge rate does not include the 2.0A trickle charge.

Cycle 1. Started Life Cycle Test.

-37.92A for .6Hr ; 26.52A for .883Hr ; 2.0 A for .083 Hr ; Rchg = 103.0%

Cycle 2749. 11/25/91. Halted test for evaluation. Cells were left in a discharged state.

Cycles 2750 - 2757. These cycles were used for capacity testing.

Cycle 2758. Pack restarted under a new test regime.

-37.92A for .6Hr ; 26.04A for .9Hr ; 103.0% Rchg

NSWC Crane

Pack ID 3602X

8 cells

Voltage/Pressure/Recharge EOC/EOD Trend Plot

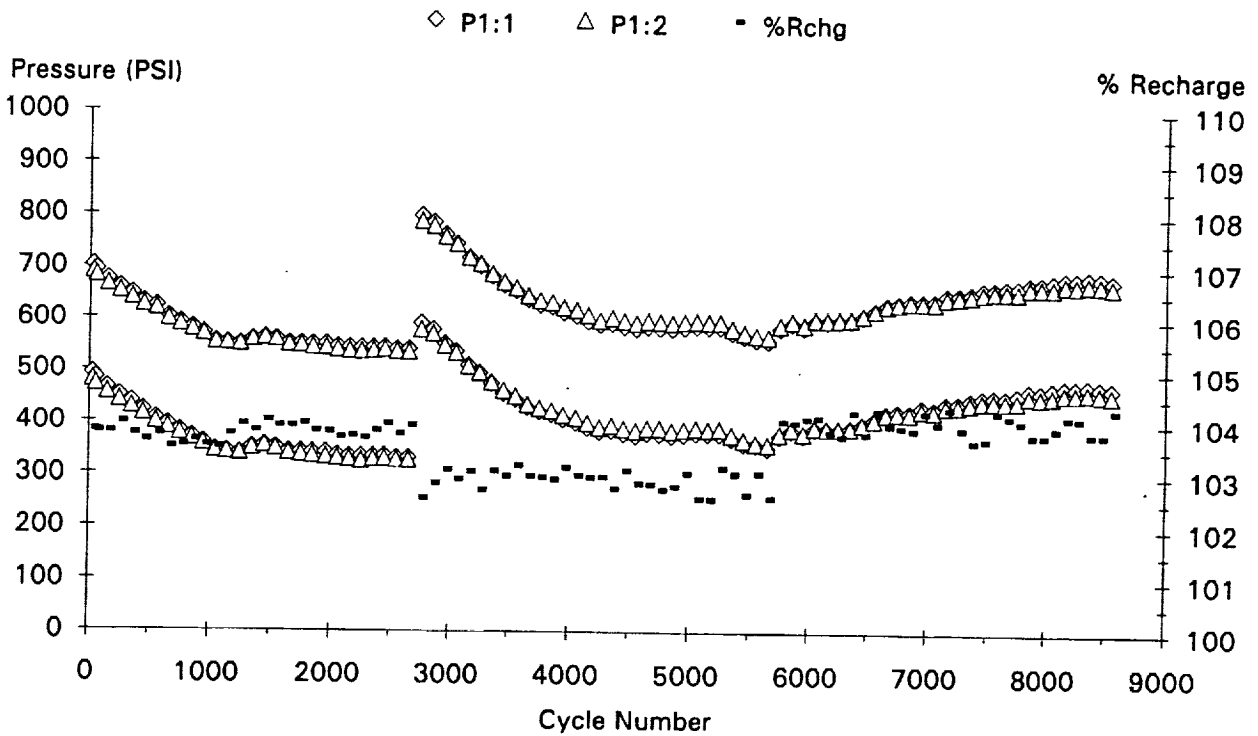
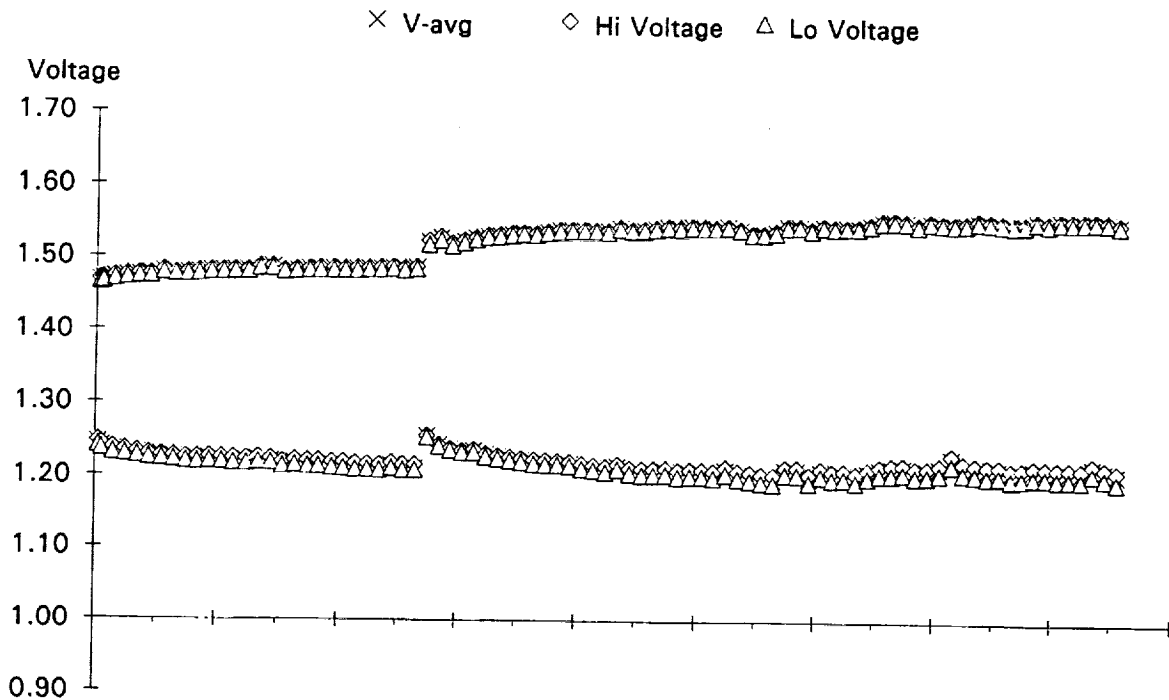
04/25/91 - 09/29/93

Eagle Picher 65 AmpHr

35% DOD

10 Deg C

90% SOC



Note. Cycles 1-2736 display the total Recharge rate, including the .73% from the 2.0A trickle charge at the end of the charge cycle. The target recharge rate does not include the 2.0A trickle charge.

Cycle 1. Started Life Cycle Test.

-37.92A for .6Hr ; 26.52A for .883Hr ; 2.0A for .083Hr ; Rchg = 103.0%

Cycle 2736. 10/24/91. Halted test for evaluation. Cells were left in a discharged state.

Cycles 2737 - 2747. These cycles were used for capacity testing.

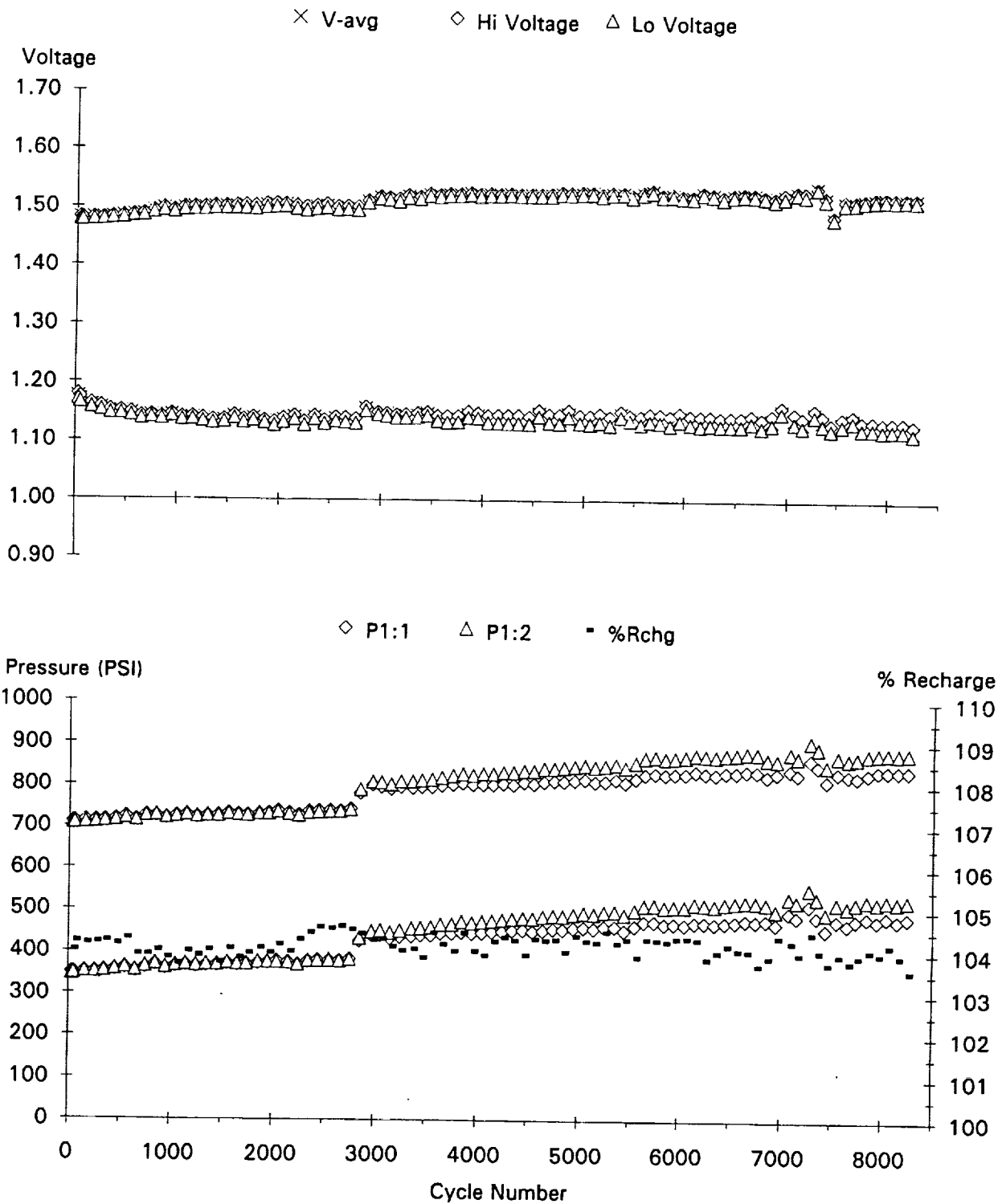
Cycle 2748. Pack restarted under a new test regime.

-37.92A for .6Hr ; 26.04A for .9Hr ; Rchg = 103.0% Rchg

Cycle 5698 Raised Rchg from 103.0% to 104.0%.

-37.92A for .6Hr ; 26.28A for .9Hr

NSWC Crane **Pack ID 3603X** **8 cells**
 Voltage/Pressure/Recharge EOC/EOD Trend Plot 05/03/91 - 09/27/93
 Eagle Picher 65 AmpHr 60% DOD 10 Deg C Taper Chg



Note. Cycles 1-2752 display the total Recharge rate, including the 1.0% from the 2.0A trickle charge at the end of the charge cycle. The target recharge rate does not include the 2.0A trickle charge.

Cycle 1. Started Life Cycle Test.

-65.0A for .6Hr ; 54.0A for .65Hr ; 45.435 to 14.129A Taper for .183Hr ; 2.5A for .2Hr ;
Rchg = 104.0%

Cycle 630. Corrected Taper Charge.

-65.0A for .6Hr ; 54.0A for .65Hr ; 45.435 to 14.129A Taper for .183Hr ; 2.0A for .2Hr ;
Rchg = 104.0%

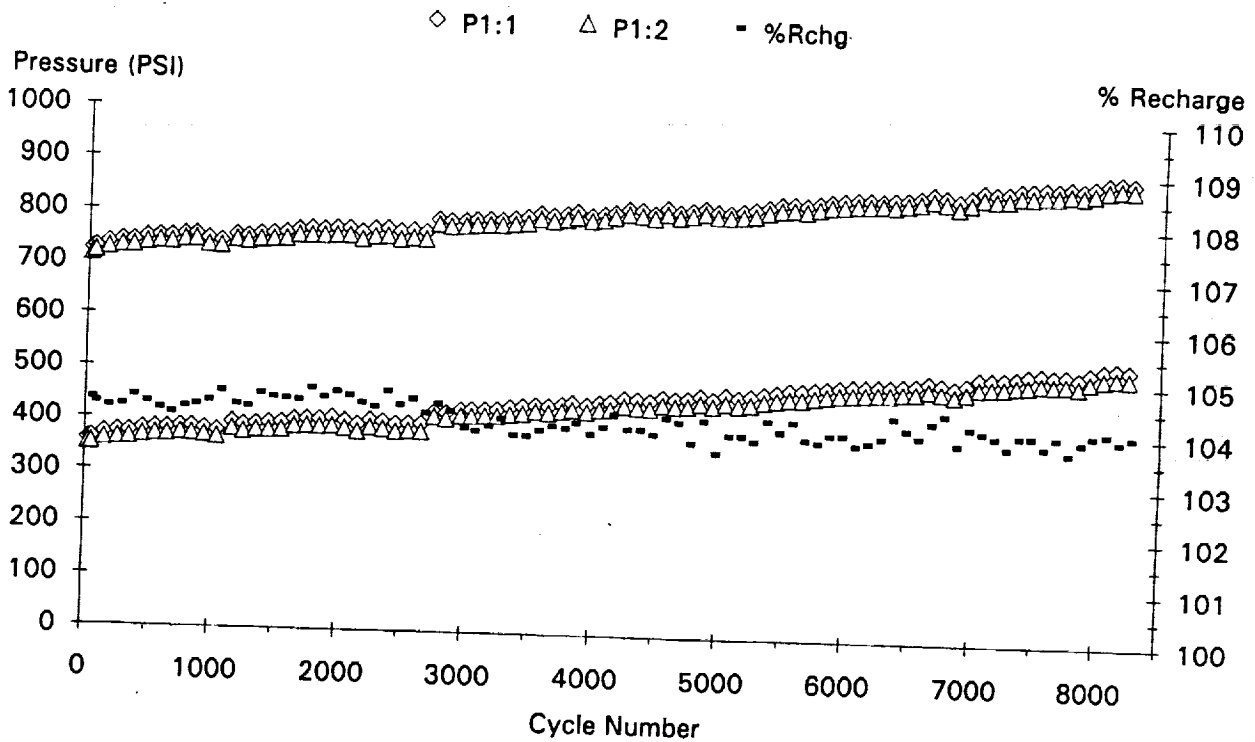
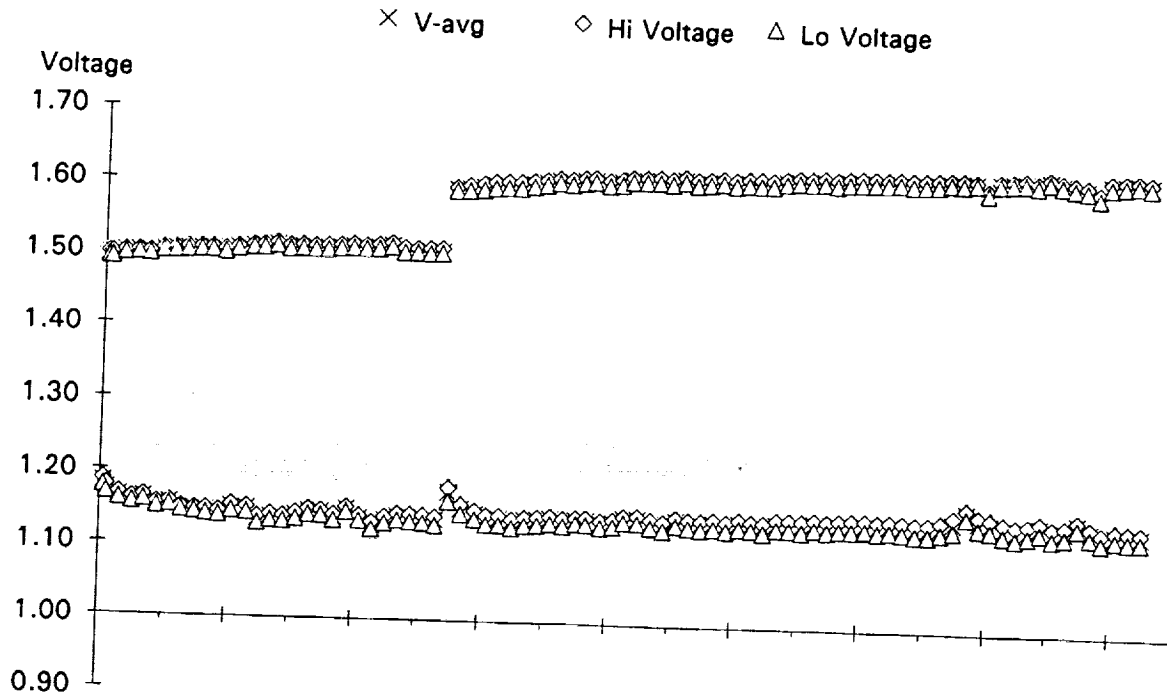
Cycle 2752. 11/01/91. Halted test for evaluation. Cells were left in a discharged state.

Cycles 2753 - 2757. These cycles were used for capacity testing.

Cycle 2758. Pack restarted under a new test regime.

-65.0A for .6Hr ; 50.14A for .7Hr ; 48.237 to 6.363A Taper for .2Hr ; Rchg = 104.0%

NSWC Crane **Pack ID 3604X** **8 cells**
 Voltage/Pressure/Recharge EOC/EOD Trend Plot 04/25/91 - 10/01/93
 Eagle Picher 65 AmpHr 60% DOD 10 Deg C 94% SOC



Note. Cycles 1-2754 display the total Recharge rate, including the .425% from the 2.0A trickle charge at the end of the charge cycle. The target recharge rate does not include the 2.0A trickle charge.

Cycle 1. Started Life Cycle Test.

-65.0A for .6Hr ; 45.93A for .883Hr ; 2.0A for .083Hr ; Rchg = 104.0%

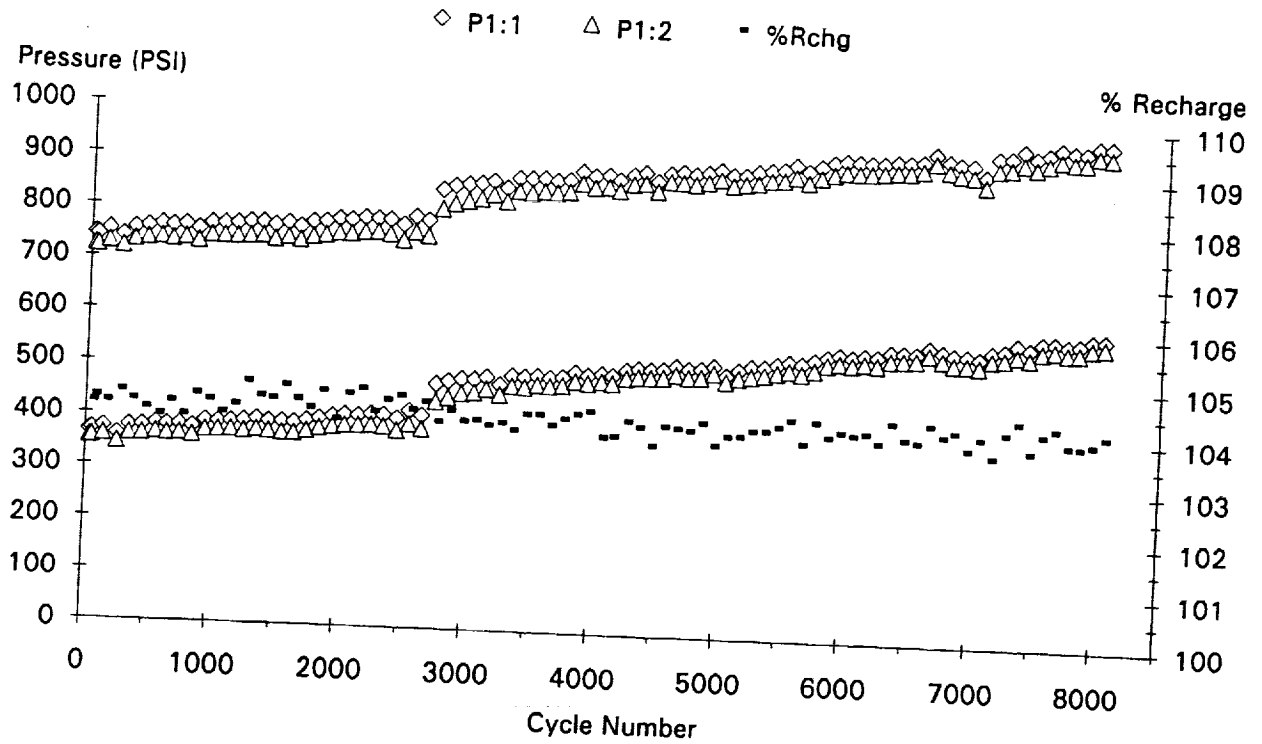
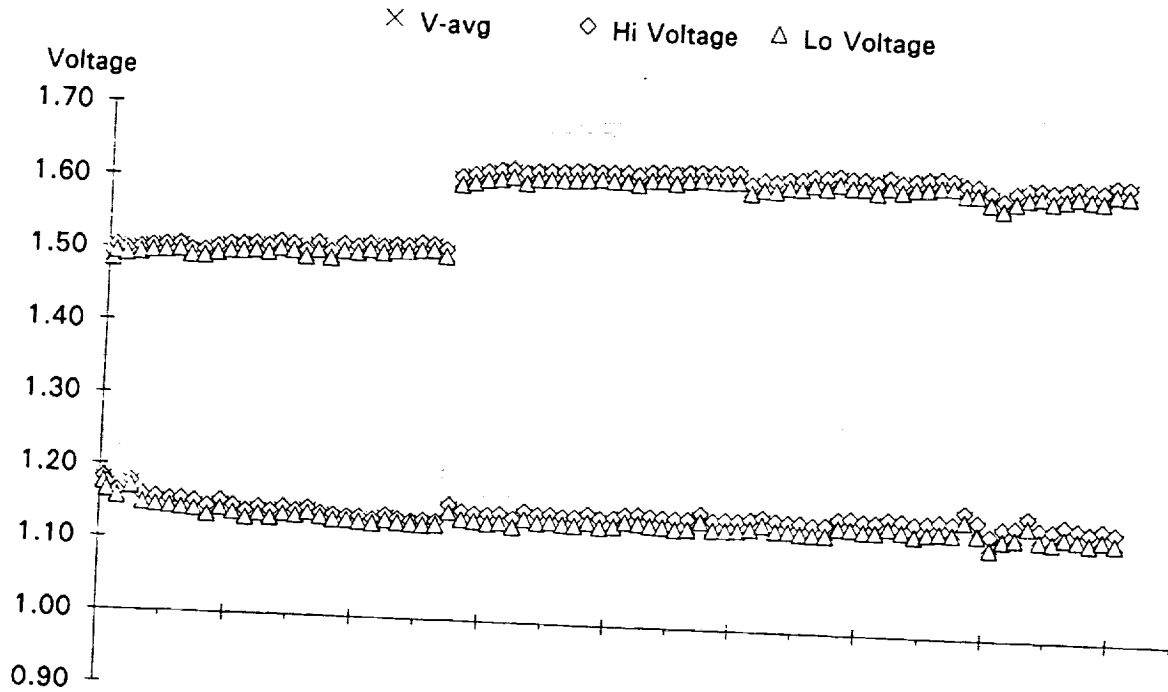
Cycle 2724. 11/08/91. Halted test for evaluation. Cells were left in a discharged state.

Cycles 2725 - 2729. These cycles were used for capacity testing.

Cycle 2730. 09/30/92. Pack restarted under a new test regime.

-65.0A for .6Hr ; 45.07A for .9Hr ; Rchg = 104.0%

NSWC Crane **Pack ID 3605X** **8 cells**
 Voltage/Pressure/Recharge EOC/EOD Trend Plot 04/26/91 - 09/26/93
 Eagle Picher 65 AmpHr 60% DOD 10 Deg C 90% SOC



Note. Cycles 1-2668 display the total Recharge rate, including the .425% from the 2.0A trickle charge at the end of the charge cycle. The target recharge rate does not include the 2.0A trickle charge.

Cycle 1. Started Life Cycle Test.

-65.0A for .6Hr ; 45.93A for .883Hr ; 2.0A for .033Hr ; Rchg = 104.0%

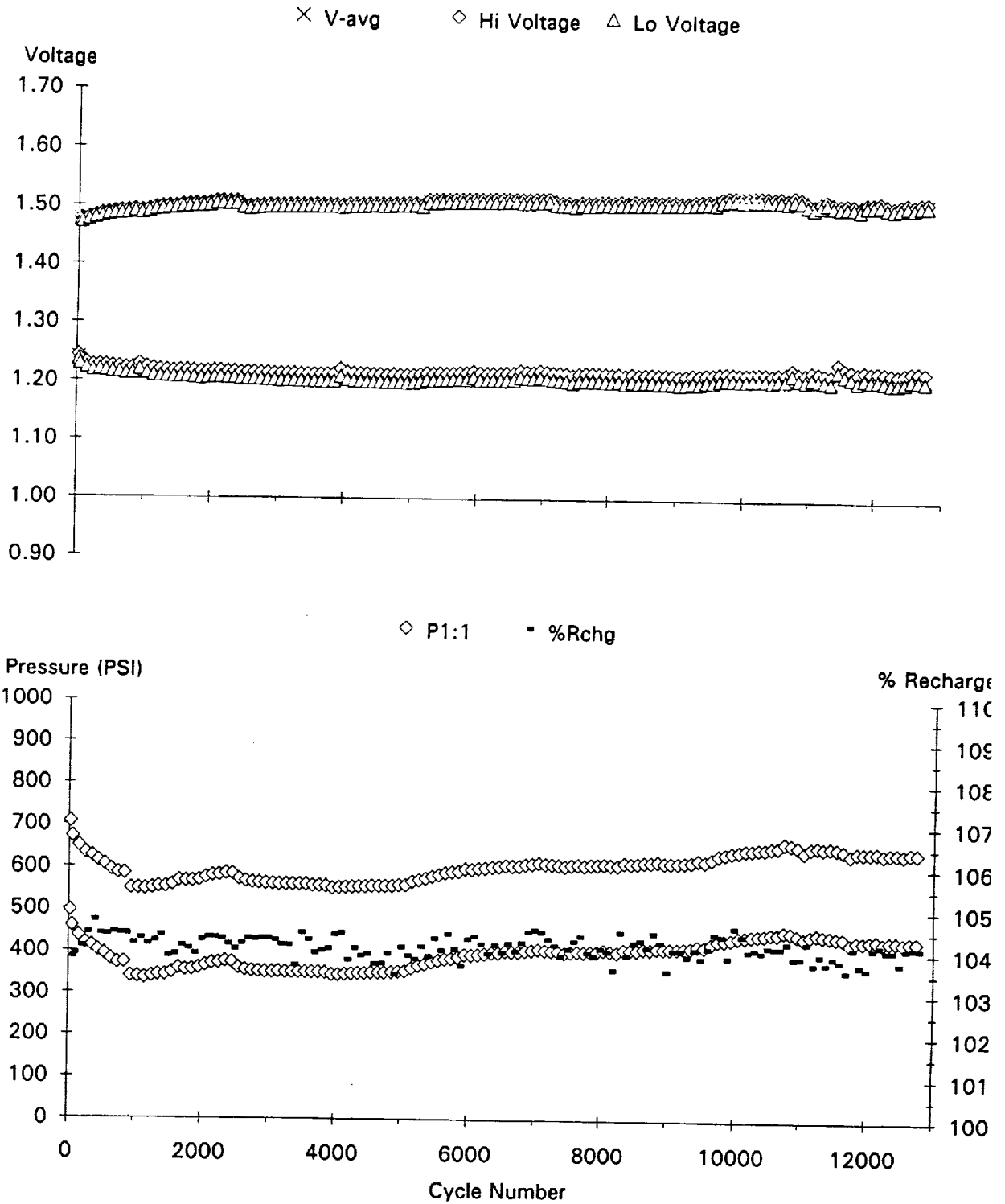
Cycle 2668. 11/08/91. Halted test for evaluation. Cells were left in a discharged state.

Cycles 2669 - 2677. These cycles were used for capacity testing.

Cycle 2678. 09/24/92. Pack restarted under a new test regime.

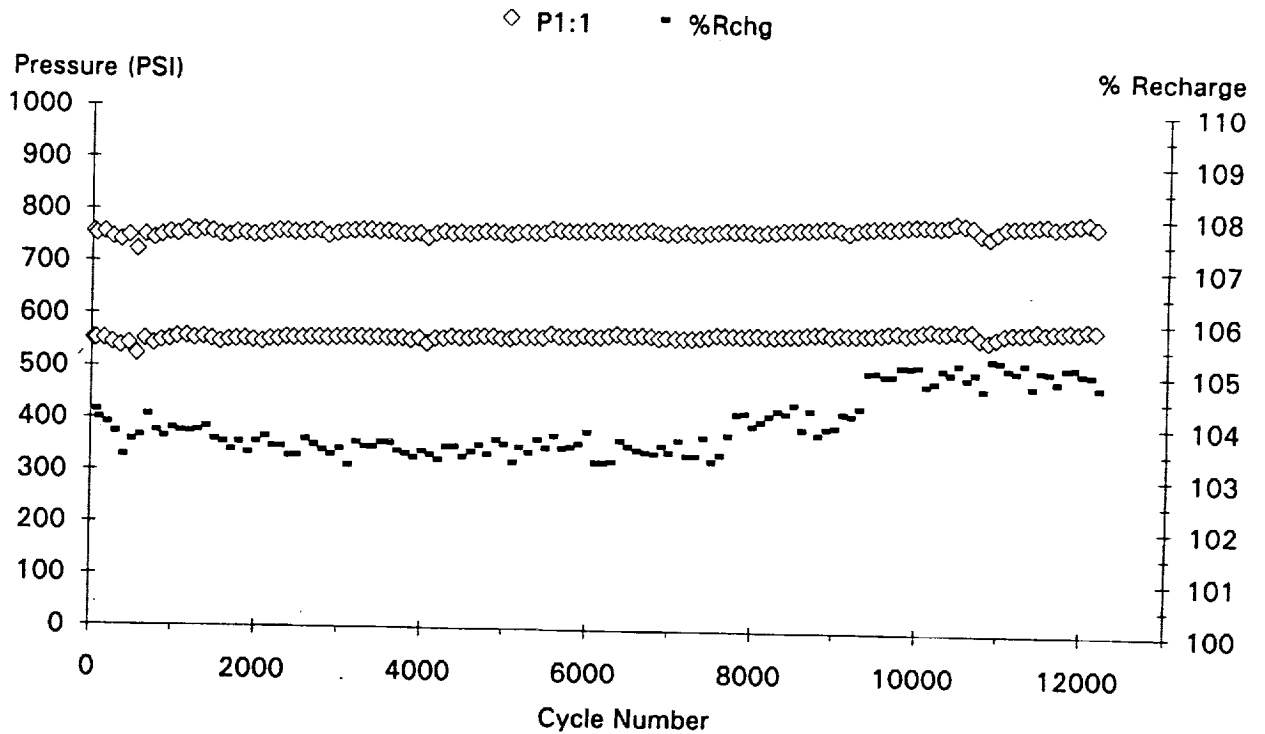
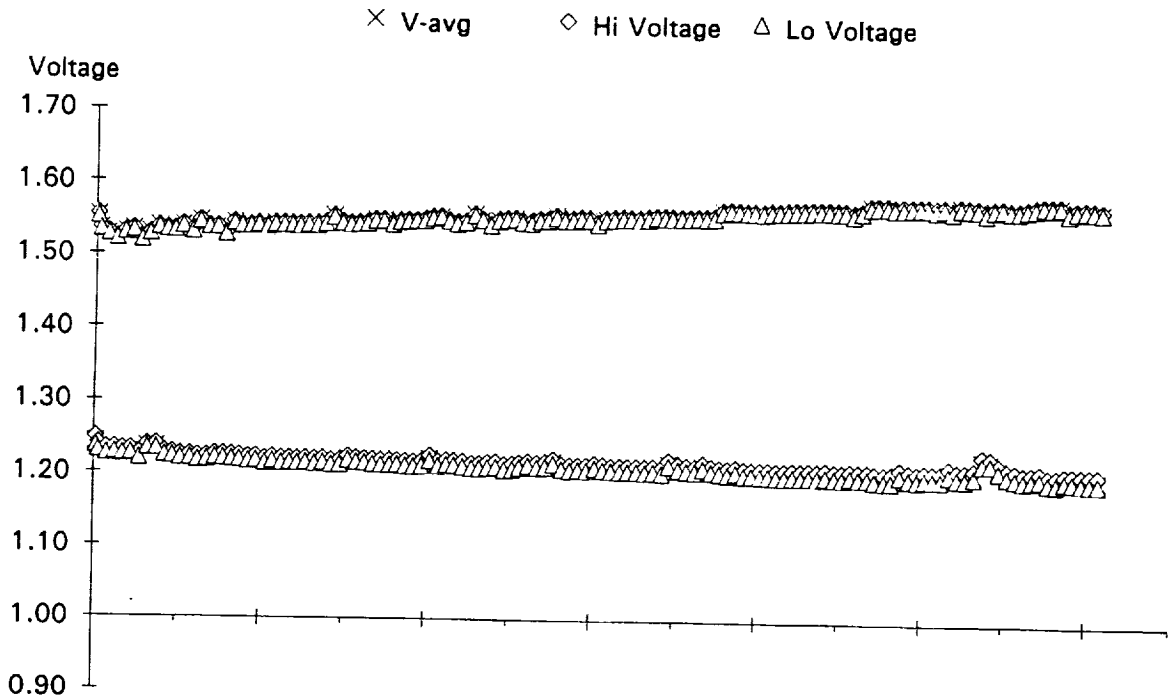
-65.0A for .6Hr ; 45.07A for .9Hr ; Rchg = 104.0%

NSWC Crane **Pack ID 3731E** **5 cells**
 Voltage/Pressure/Recharge EOC/EOD Trend Plot 06/22/91 - 09/26/93
 Eagle Picher 65 AmpHr 35% DOD 10 Deg C



Cycle 1. Started Life Cycle Test.

-37.9A for .6Hr ; 36.0A for .6Hr ; 6.82A for .3Hr ; Rchg = 104.0%



Cycle 1. Started Life Cycle Test.

-37.9A for .6Hr ; 36.0A for .6Hr ; 6.49A for .3Hr ; Rchg = 103.5%

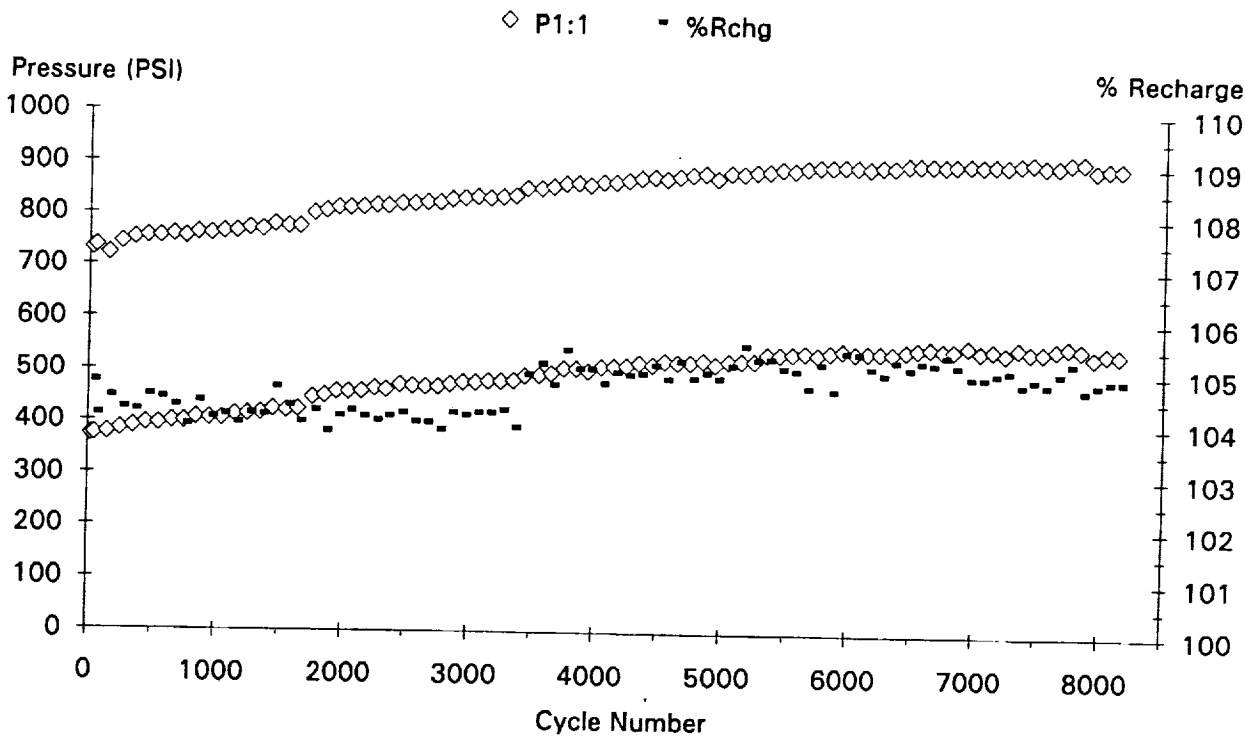
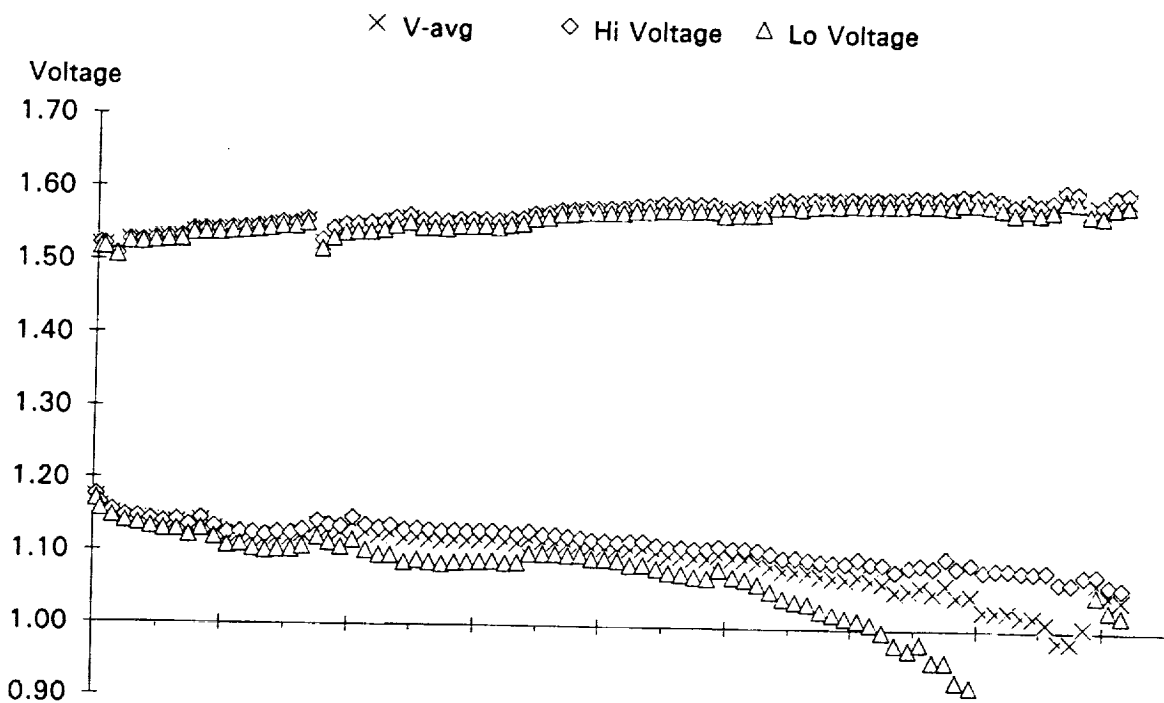
Cycle 7491. Raised Rchg from 103.5% to 104%.

-37.9A for .6Hr ; 36.0A for .6Hr ; 6.87A for .3Hr

Cycle 9347. Raised Rchg from 104% to 105%.

-37.9A for .6Hr ; 36.0A for .6Hr ; 7.63A for .3Hr

NSWC Crane **Pack ID 3761E** **5 cells**
 Voltage/Pressure/Recharge EOC/EOD Trend Plot 06/22/91 - 09/29/93
 Eagle Picher 65 AmpHr 60% DOD 10 Deg C



Cycle 1. Started Life Cycle Test.

-65.0A for .6Hr ; 61.75A for .6Hr ; 11.7A for .3Hr ; Rchg = 104.0%

Cycle 1649. Pack removed from testing. 10/07/91.

Cycle 1660. Pack restarted L.C. testing. 07/27/92.

-65.0A for .6Hr ; 61.75A for .6Hr ; 11.7A for .3Hr ; Rchg = 104.0%

Cycle 1784. Test regime modified to;

-65.0A for .6Hr ; 55.57A for .667Hr ; 15.06A for .233Hr ; Rchg = 104.0%

Cycle 3392. Raised Rchg from 104.0% to 105.0%

-65.0A for .6Hr ; 55.57A for .667Hr ; 16.74A for .233Hr ; Rchg = 105.0%

Cycle 6171. Cell #4 (SN22) hit 1.0V at EOD. Pack average voltage was 1.063V.

Cycle 7582. Pack average EOD voltage fell below 1.0V. EOD voltage of cell #4 was .7325V. The EOD voltage of the remaining 4 cells ranged from 1.036V to 1.068V.

Cycle 7927. Cell #4 removed from pack. EOD voltage dropped to 0V. Capacity testing was run on this cell under the Pack ID of 3761X.

NSWC Crane

Pack ID 3765E

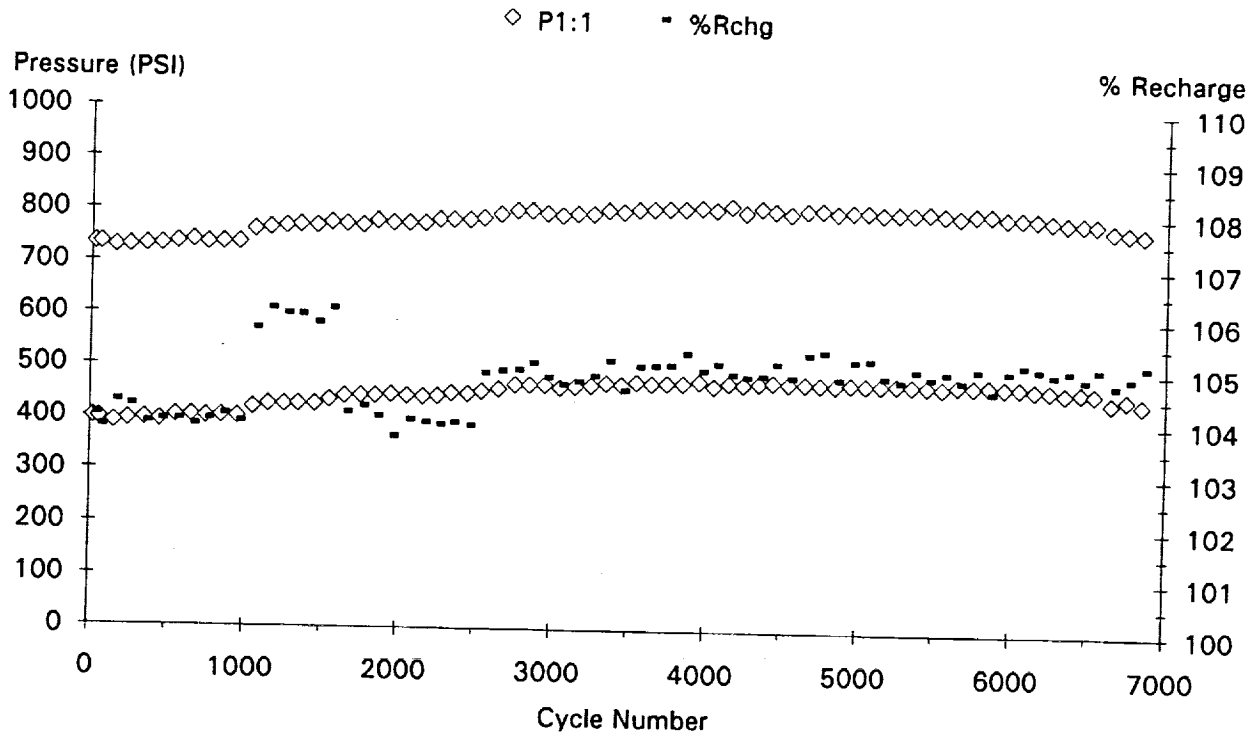
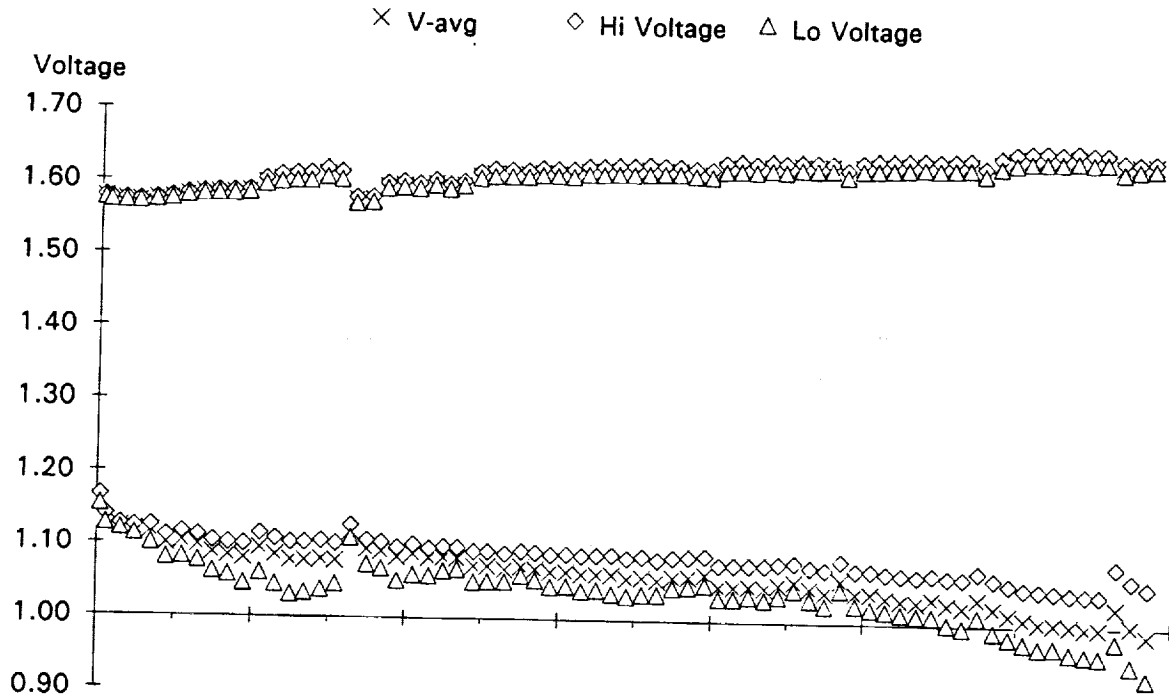
5 cells

Voltage/Pressure/Recharge EOC/EOD Trend Plot

06/22/91 - 07/10/93

Eagle Picher 65 AmpHr 60% DOD -5 Deg C

Test Ended at Cycle 6904



Cycle 1. Started Life Cycle Test.

-65.0A for .6Hr ; 61.75A for .6Hr ; 11.7A for .3Hr ; Rchg = 104.0%

Cycle 1091. Raised Rchg from 104.0% to 106.0%.

-65.0A for .6Hr ; 61.75A for .6Hr ; 14.3A for .3Hr ; Rchg = 106.0%

Cycle 1604. Pack removed from testing. 10/07/91.

Cycle 1615. Pack restarted L.C. testing. 07/27/92.

-65.0A for .6Hr ; 61.75A for .6Hr ; 11.7A for .3Hr ; Rchg = 104.0%

Cycle 1723. Test regime modified to;

-65.0A for .6Hr ; 55.57A for .667Hr ; 15.06A for .233Hr ; Rchg = 104.0%

Cycle 2536. Raised Rchg from 104.0% to 105.0%

-65.0A for .6Hr ; 55.57A for .667Hr ; 16.74A for .233Hr ; Rchg = 105.0%

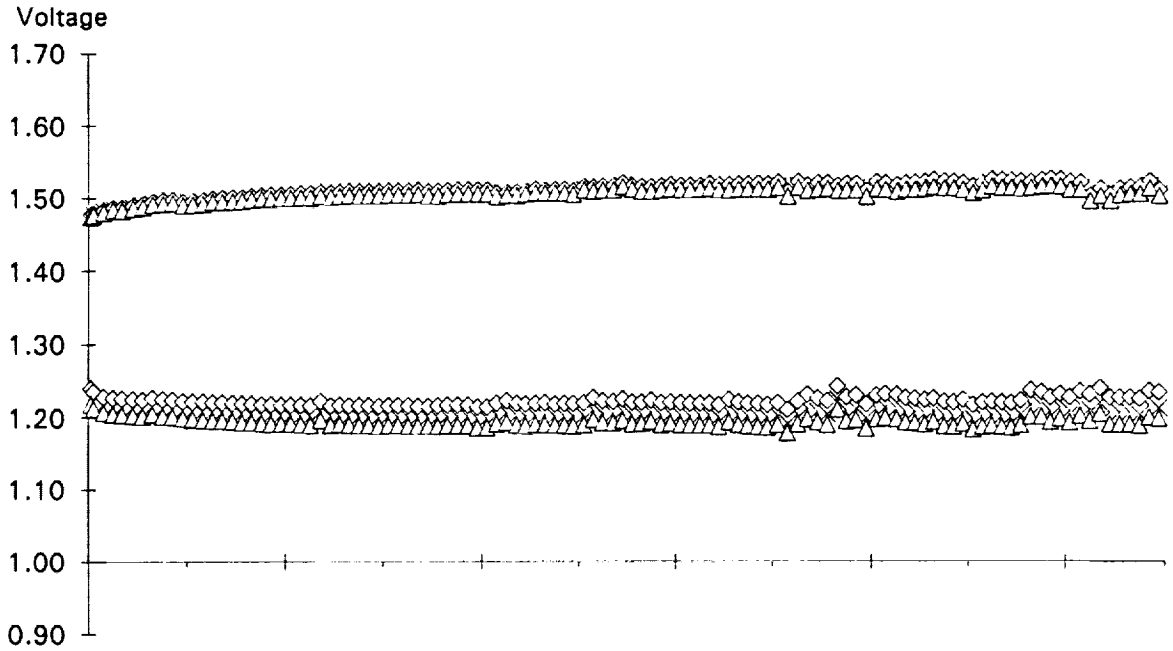
Cycle 6904. Pack removed from Life Cycle testing. End of discharge voltages fell below 1.0V.

Cycles 6910 - 6929. Cycles used to run capacity tests on cell number 4.

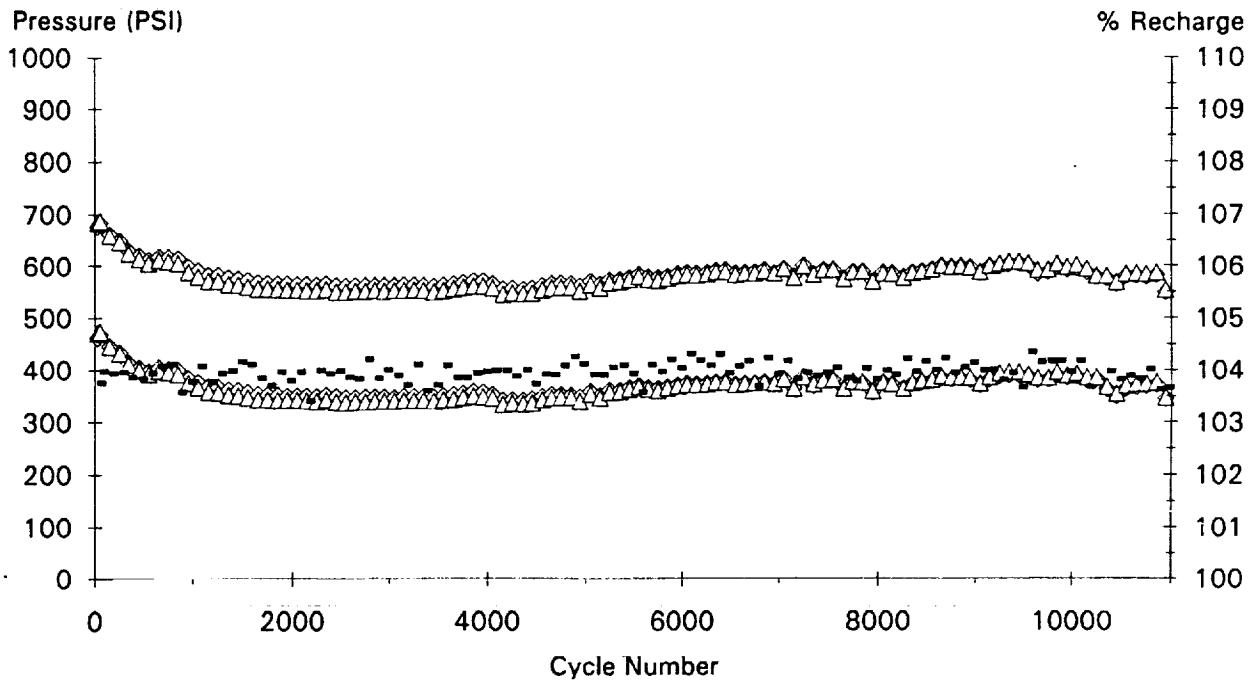
Cycles 6930 - 6948. Cycles used to run capacity tests on cell number 5.

NSWC Crane **Pack ID 3831E** **10 cells**
 Voltage/Pressure/Recharge EOC/EOD Trend Plot 10/08/91 - 09/26/93
 Eagle Picher 81 AmpHr 35% DOD 10 Deg C

× V-avg ◇ Hi Voltage △ Lo Voltage



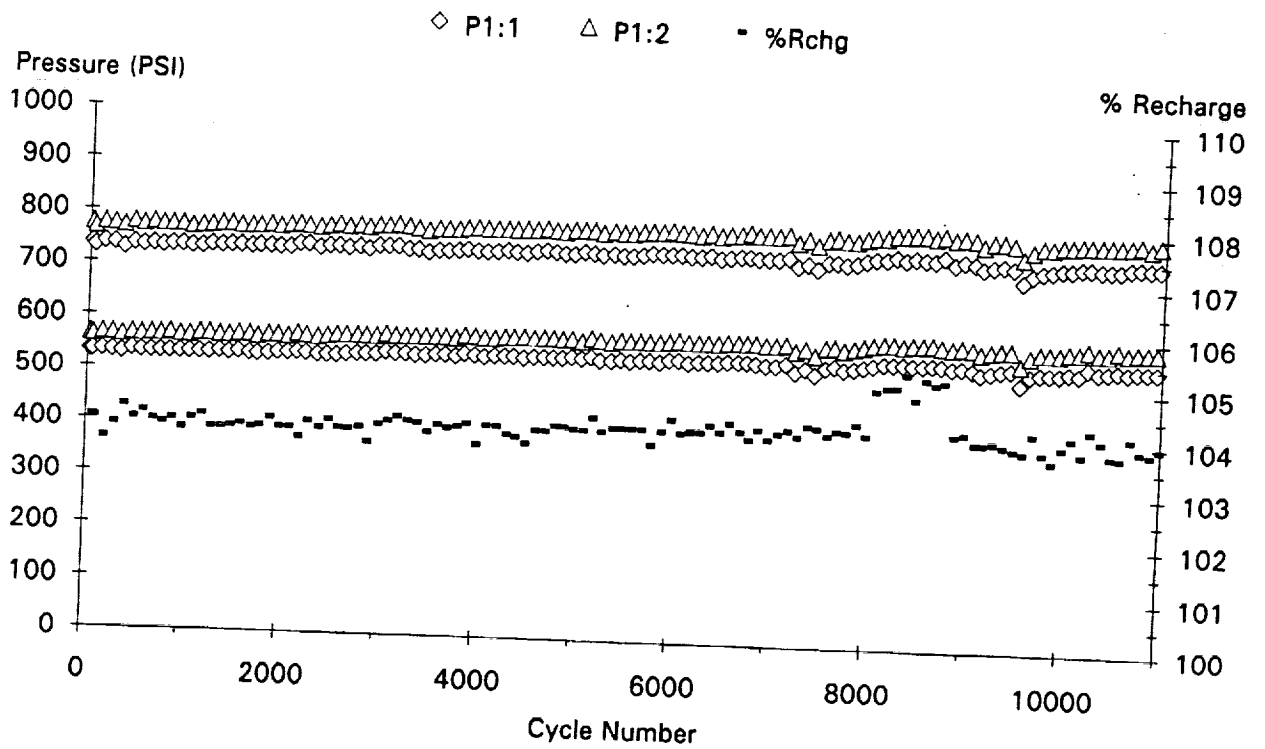
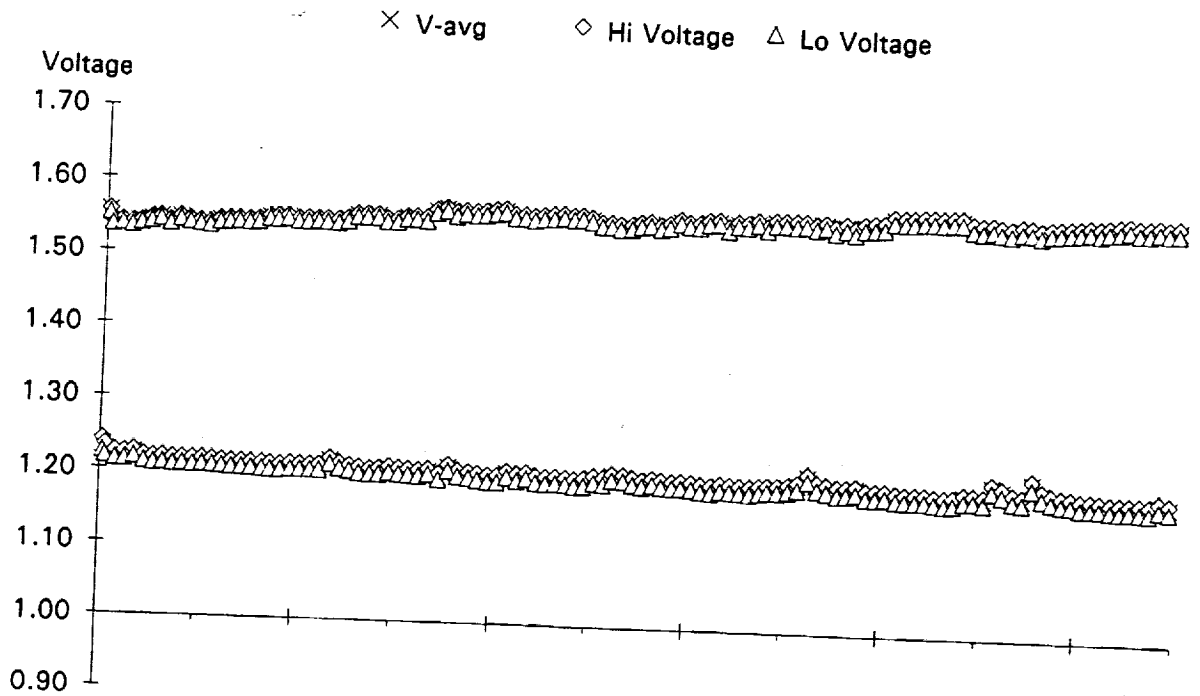
◇ P1:1 △ P1:2 ■ %Rchg



Cycle 1. Started Life Cycle Test.

-47.25A for .6Hr ; 44.89A for .6Hr ; 8.9A for .3Hr ; Rchg = 104.0%

NSWC Crane **Pack ID 3835E** **10 cells**
 Voltage/Pressure/Recharge EOC/EOD Trend Plot 10/12/91 - 09/22/93
 Eagle Picher 81 AmpHr 35% DOD -5 Deg C



Cycle 1. Started Life Cycle Test.

-47.25A for .6Hr ; 44.89A for .6Hr ; 8.5A for .3Hr ; Rchg = 104%

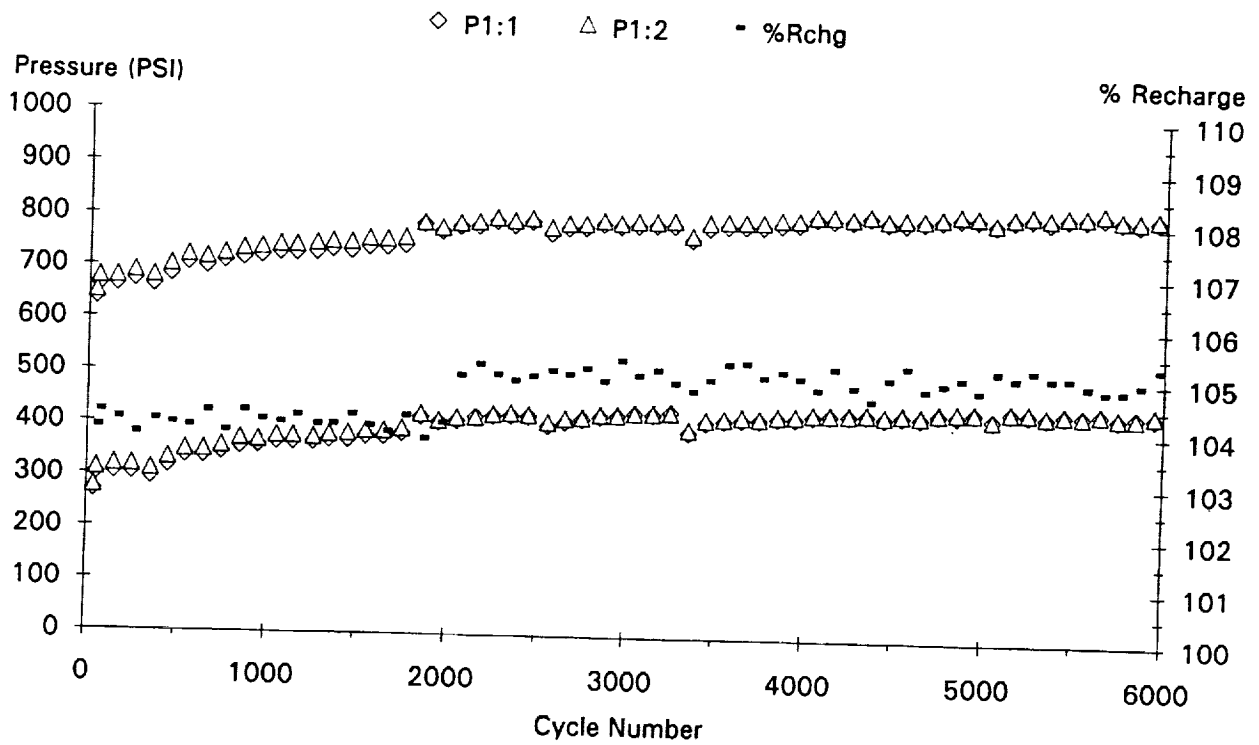
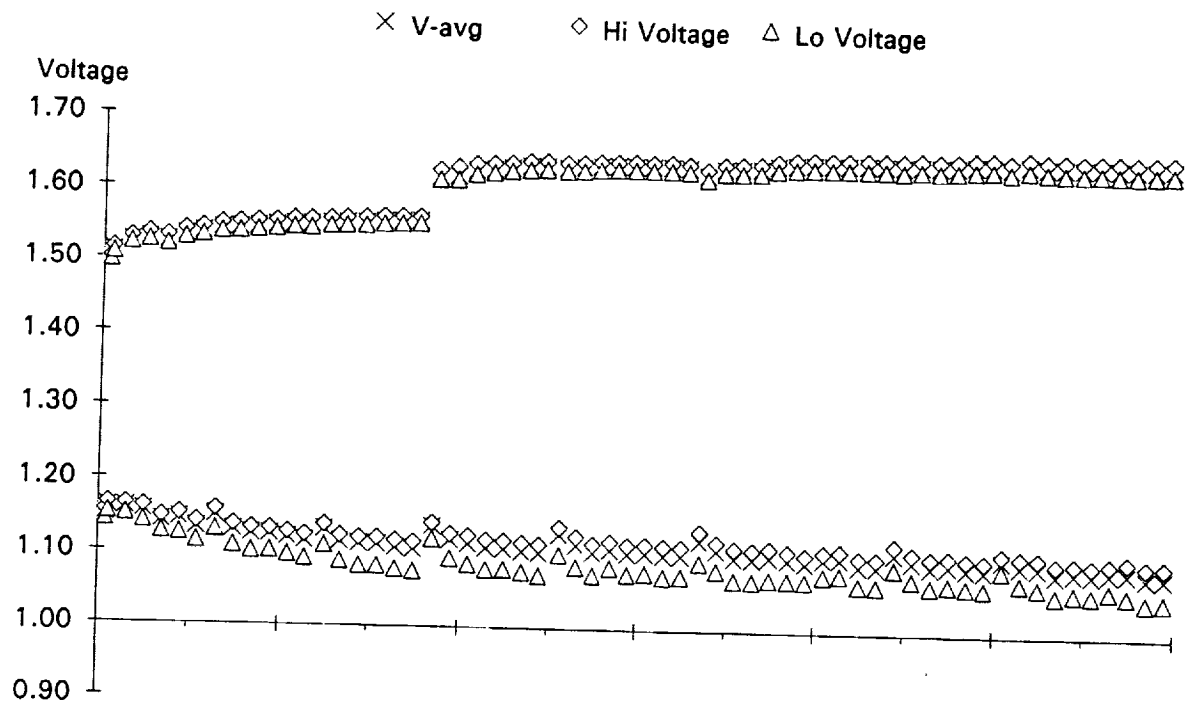
Cycle 7960. Raised Rchg from 104.0% to 105.0%.

-47.25A for .6Hr ; 44.89A for .6Hr ; 9.45A for .3Hr

Cycle 8768. Lowered Rchg from 105.0% to 104.0%.

-47.25A for .6Hr ; 44.89A for .6Hr ; 8.5A for .3Hr

NSWC Crane **Pack ID 3861E** **10 cells**
 Voltage/Pressure/Recharge EOC/EOD Trend Plot 08/07/92 - 10/01/93
 Eagle Picher 81 AmpHr 60% DOD 10 Deg C



Cycle 1. Started Life Cycle Test.

-81.0A for .6Hr ; 69.25A for .667Hr ; 18.77A for .233Hr ; Rchg = 104.0%

Cycles 1818 - 1825. packs were cycled for capacity tests.

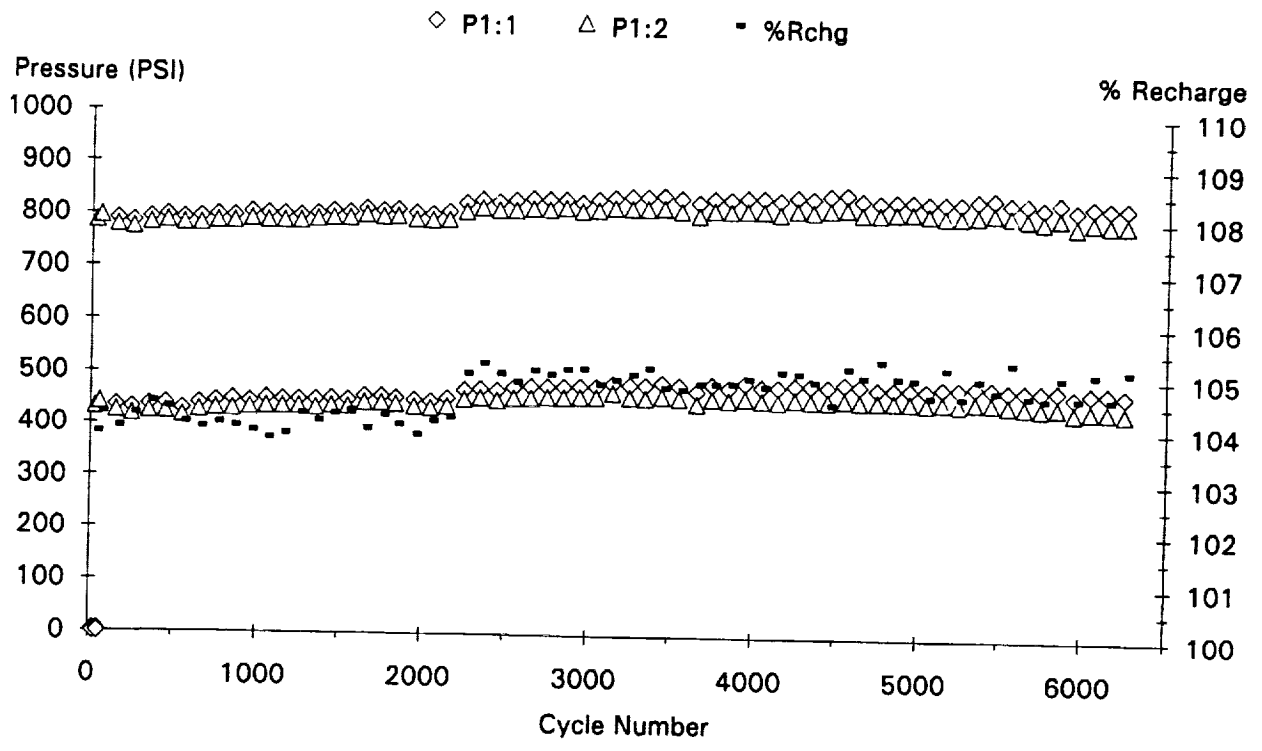
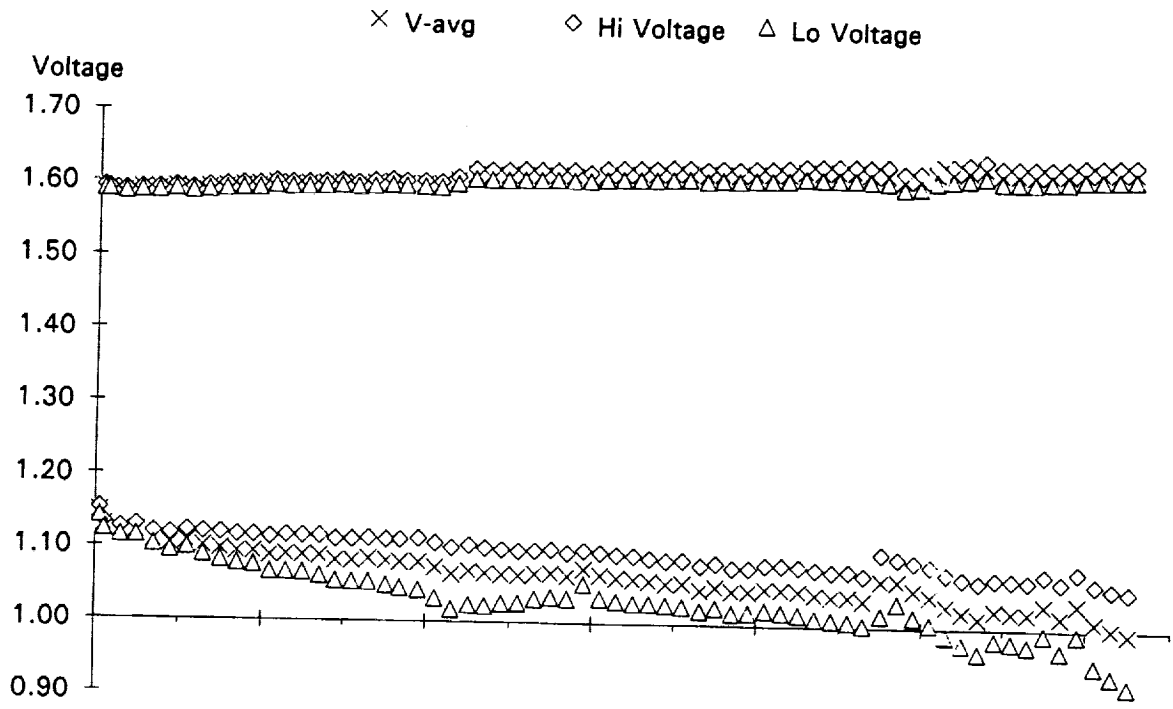
Cycle 1837. Test Regime changed to:

-81.0A for .6Hr ; 56.16A for .9Hr ; Rchg = 104.0%

Cycle 2034. Raised Rchg from 104.0% to 105.0%.

-81.0A for .6Hr ; 56.7A for .9Hr

NSWC Crane **Pack ID 3865E** **10 cells**
 Voltage/Pressure/Recharge EOC/EOD Trend Plot 08/07/92 - 10/01/93
 Eagle Picher 81 AmpHr 60% DOD -5 Deg C Test Ended at Cycle 6538



Cycle 1. Started Life Cycle Test.

-81.0A for .6Hr ; 69.25A for .667Hr ; 18.77A for .233Hr ; Rchg = 104.0%

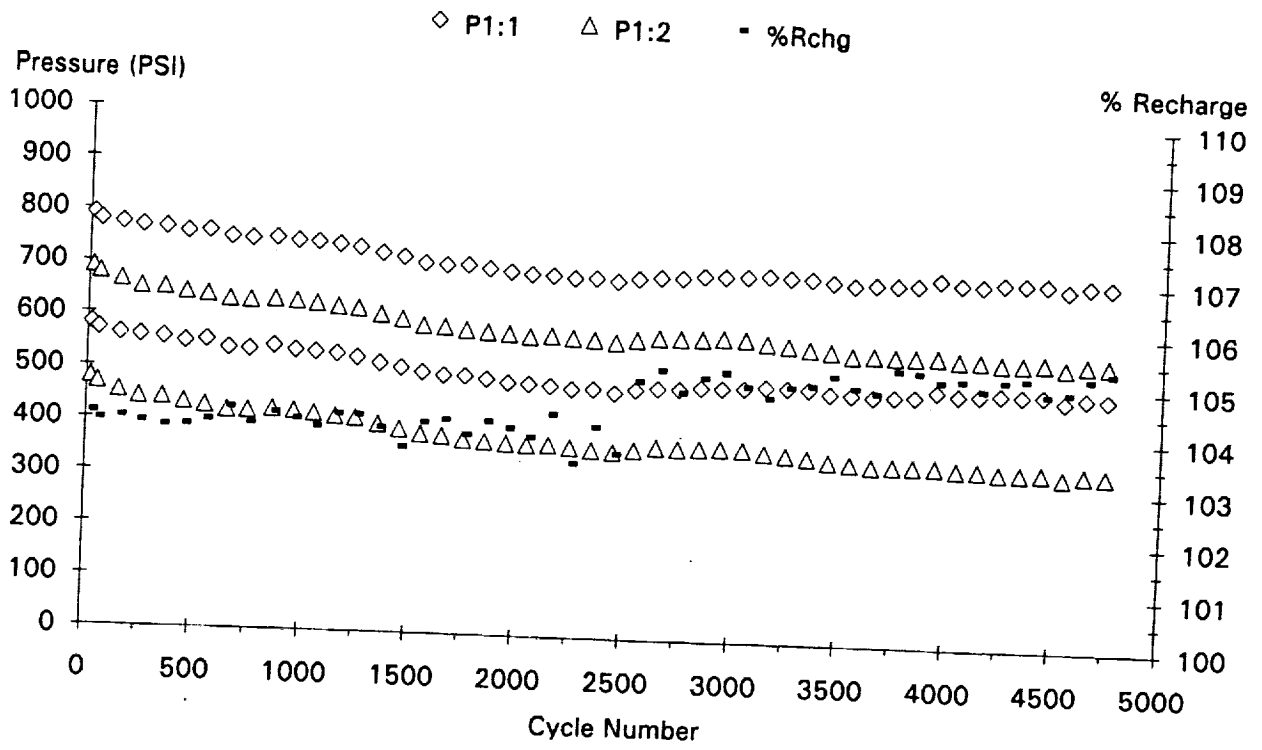
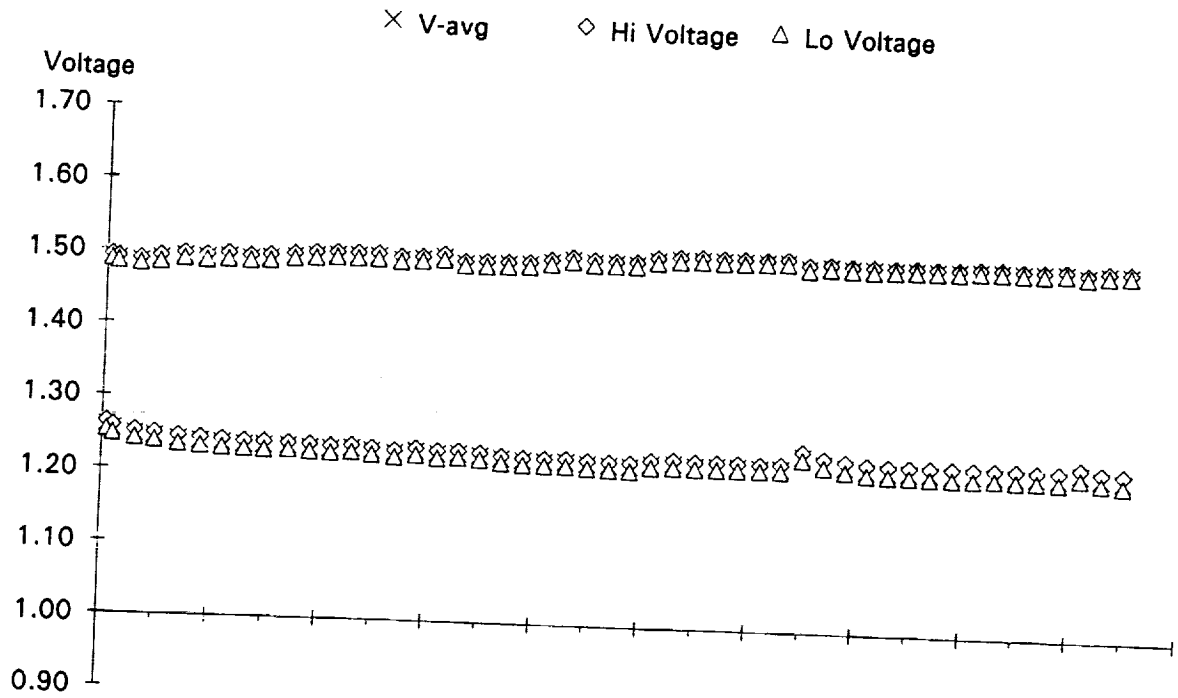
Cycle 2250. Raised Rchg from 104.0% to 105.0%.

-81.0A for .6Hr ; 69.25A for .667Hr ; 20.86A for .233Hr ; Rchg = 105.0%

Cycle 5091. Cells #4 and #6 (SN36 and SN39) hit 1.0V at EOD. Pack average voltage was 1.036V.

Cycle 6188. Average pack EOD voltage fell below 1.0V. Five of the four cells have voltages of less than 1.0V.

NSWC Crane **Pack ID 3600G** **4 cells**
 Voltage/Pressure/Recharge EOC/EOD Trend Plot 11/21/92 - 09/27/93
 Gates 65 AmpHr 35% DOD 10 Deg C Taper Chg



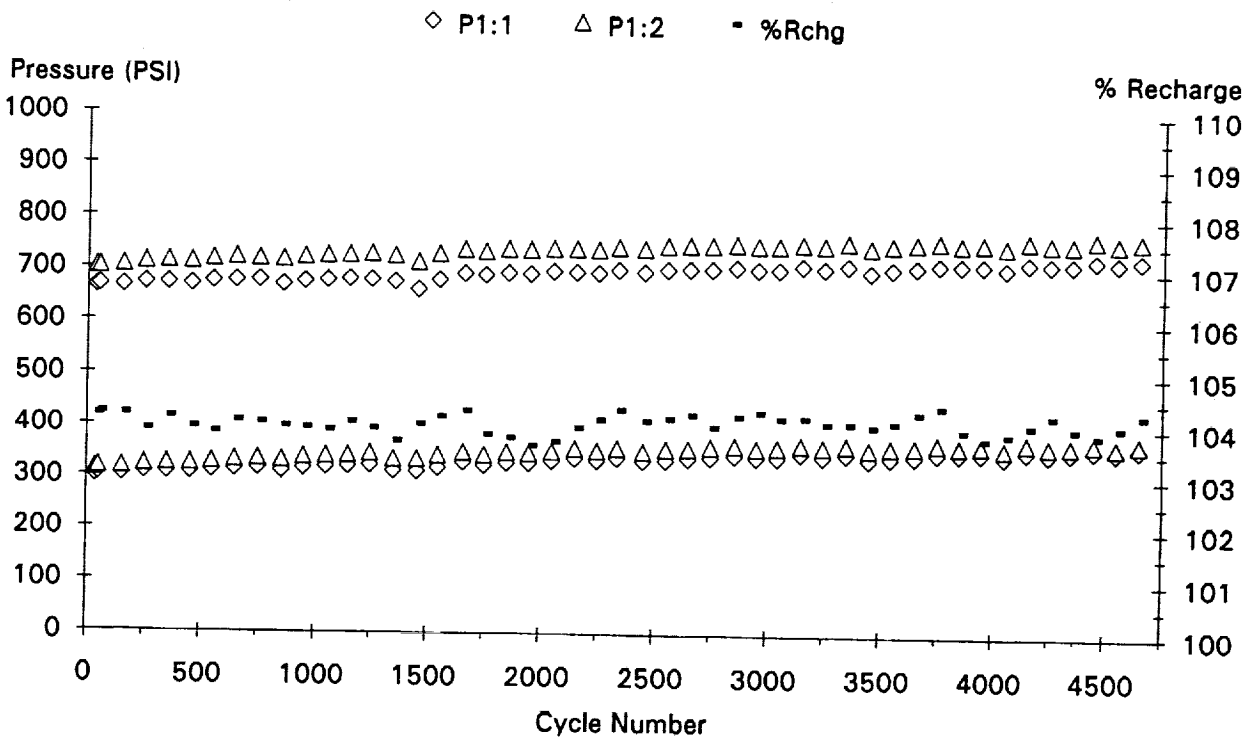
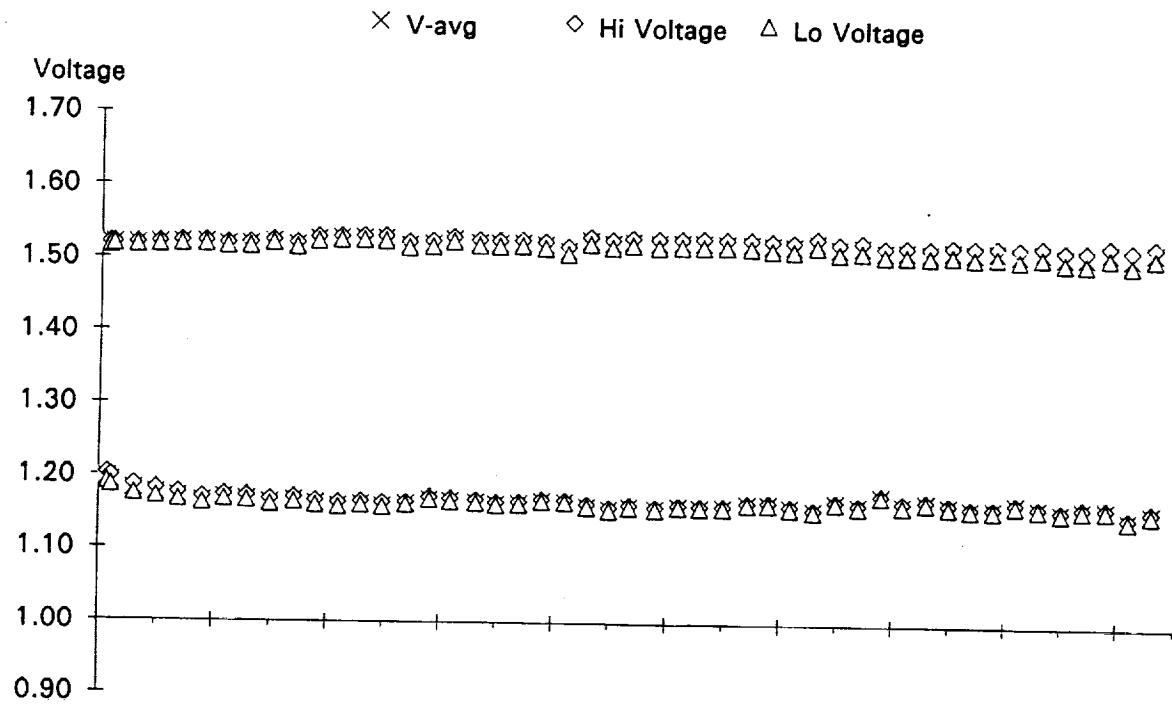
Cycle 1. Started Life Cycle Test.

-37.92A for .6Hr ; 26.76A for .633Hr ; 29.03 to 7.045A Taper for .266Hr ;
Rchg = 104.0%

Cycle 2468. Raised Rchg from 104.0% to 105.0%.

-37.92A for .6Hr ; 26.76A for .633Hr ; 29.084 to 8.698A Taper for .266Hr

NSWC Crane **Pack ID 3601G** **4 cells**
 Voltage/Pressure/Recharge EOC/EOD Trend Plot 11/25/92 - 09/29/93
 Gates 65 AmpHr 60% DOD 10 Deg C Taper Chg



Cycle 1. Started Life Cycle Test.

-65.0A for .6Hr ; 50.14A for .7Hr ; 48.237 to 6.363A Taper for .2Hr ; Rchg = 104.0%

NSWC Crane

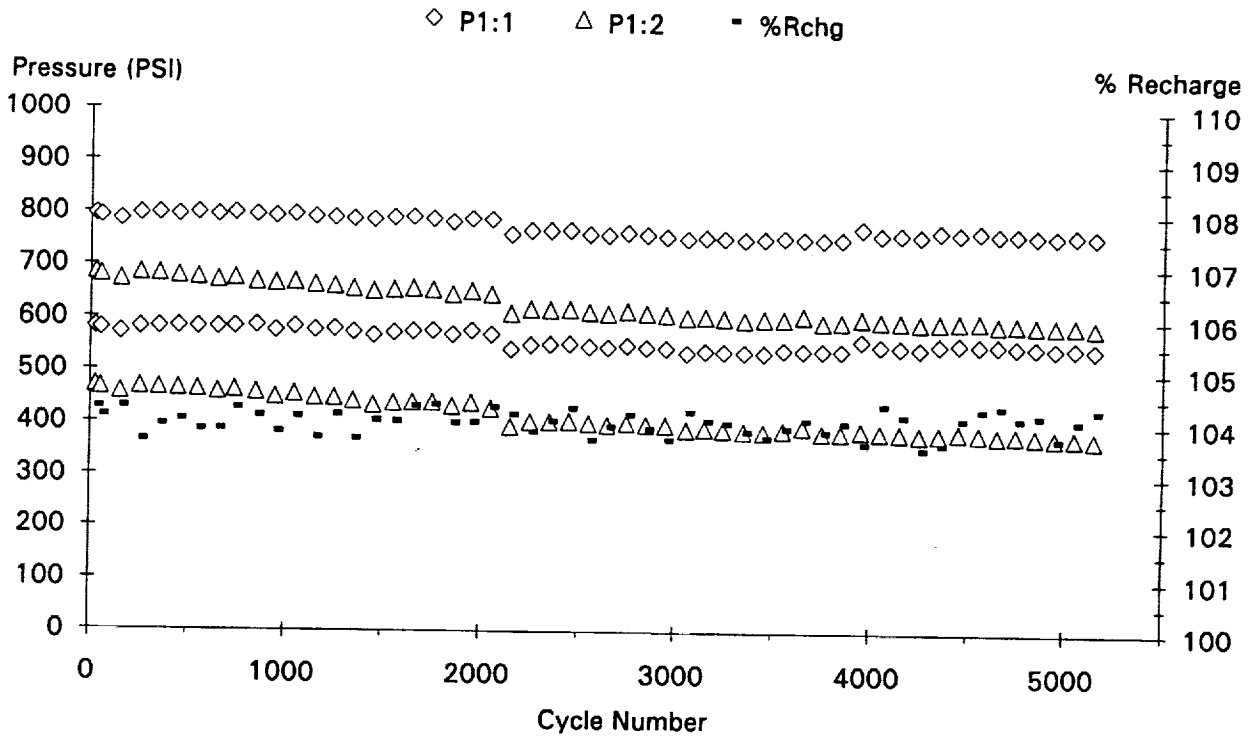
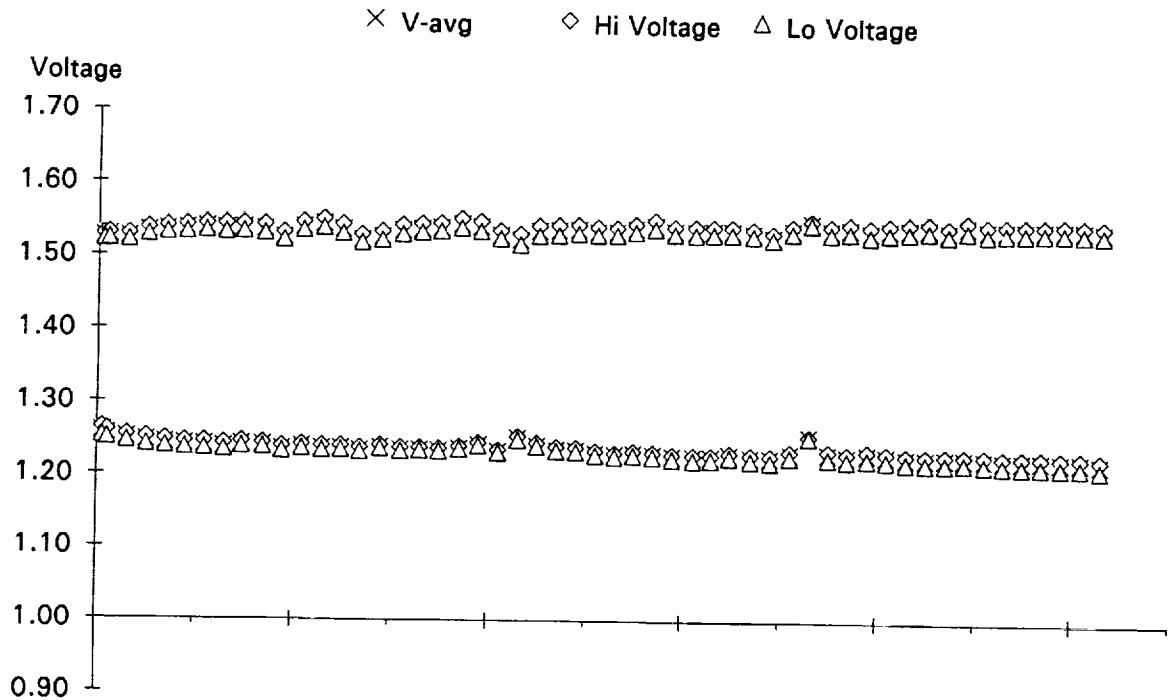
Pack ID 3602G

4 cells

Voltage/Pressure/Recharge EOC/EOD Trend Plot

10/28/92 - 09/28/93

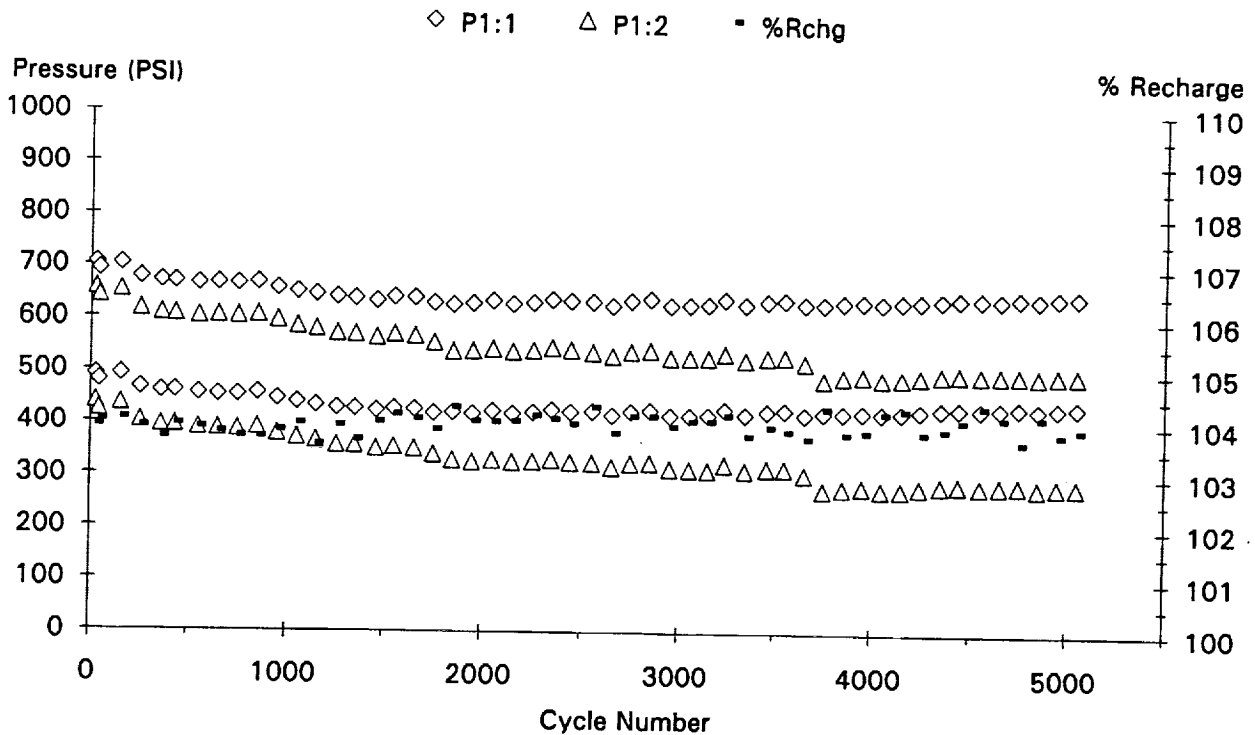
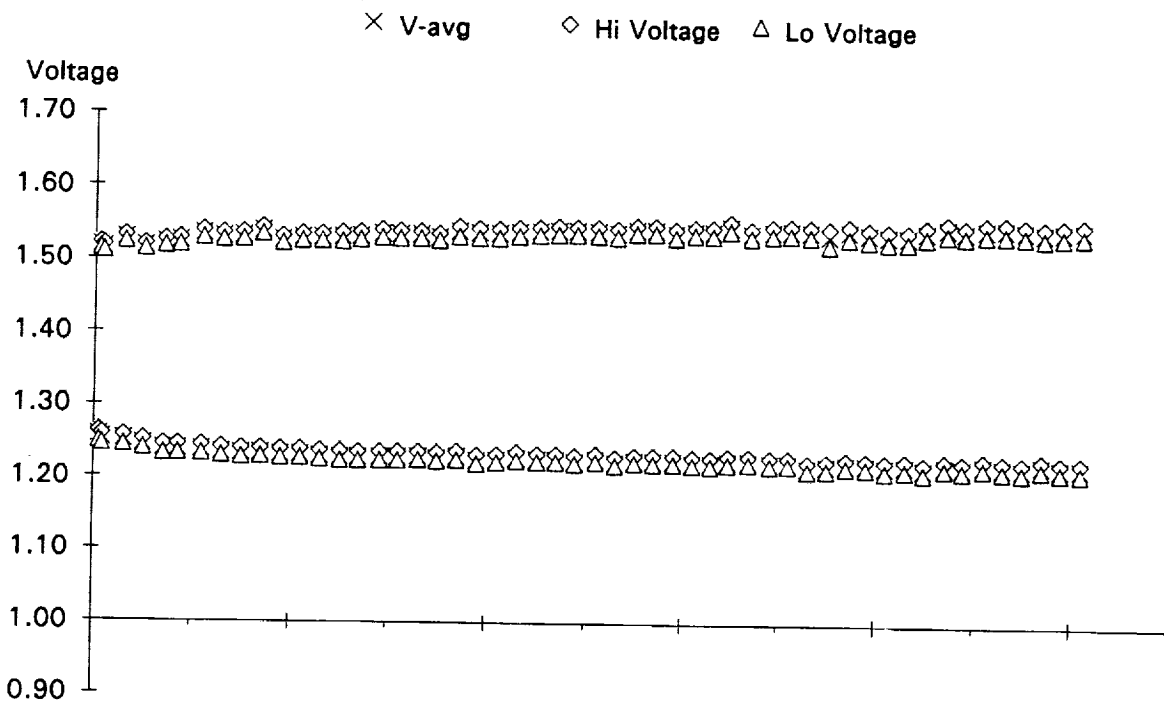
Gates 65 AmpHr 35% DOD 10 Deg C



Cycle 1. Started Life Cycle Test.

-37.92A for .6Hr ; 26.29A for .9Hr ; Rchg = 104.0%

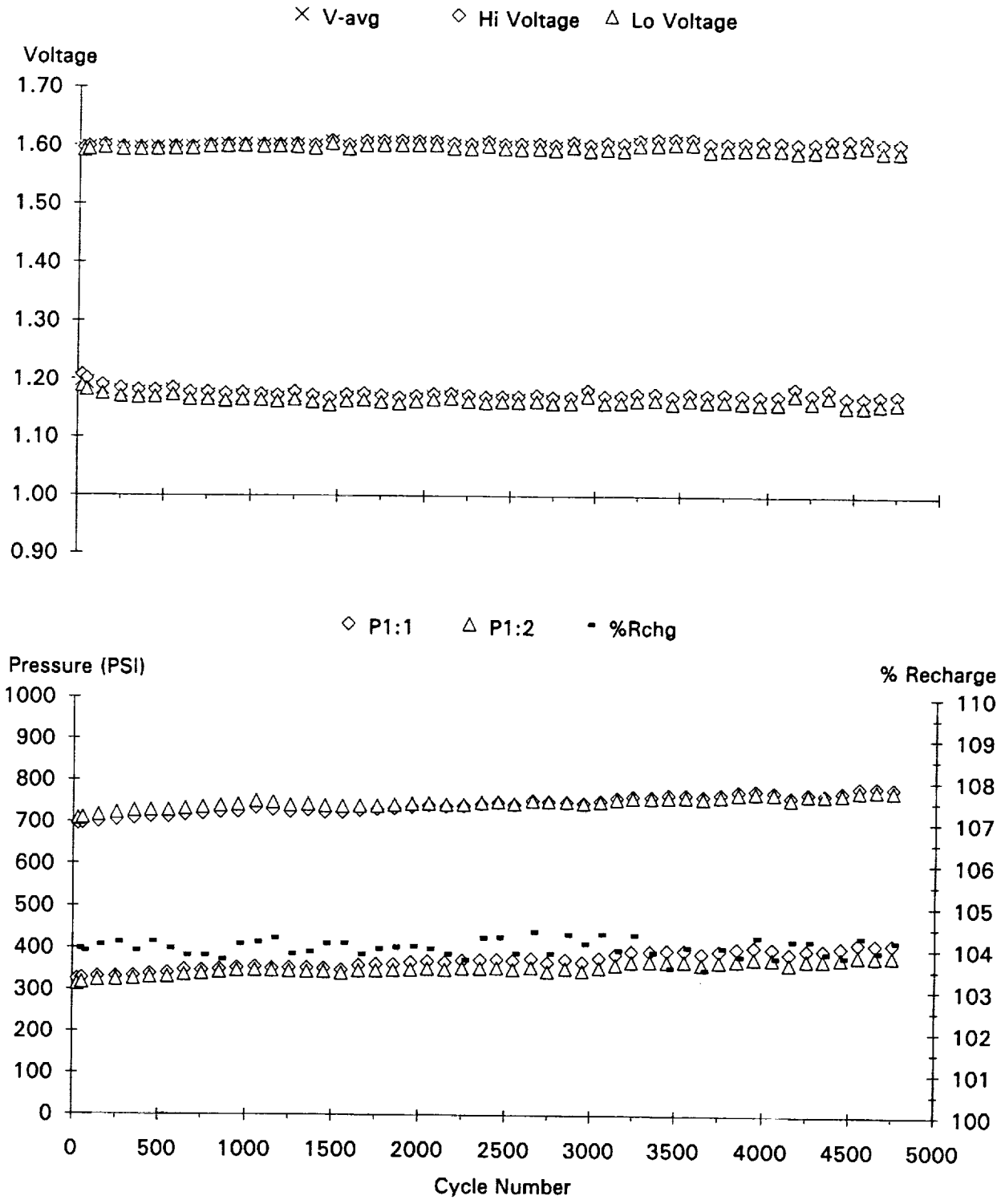
NSWC Crane **Pack ID 3603G** **4 cells**
 Voltage/Pressure/Recharge EOC/EOD Trend Plot 10/28/92 - 09/28/93
 Gates 65 AmpHr 35% DOD 10 Deg C 94% SOC



Cycle 1. Started Life Cycle Test.

-37.92A for .6Hr ; 26.29A for .9Hr ; Rchg = 104%

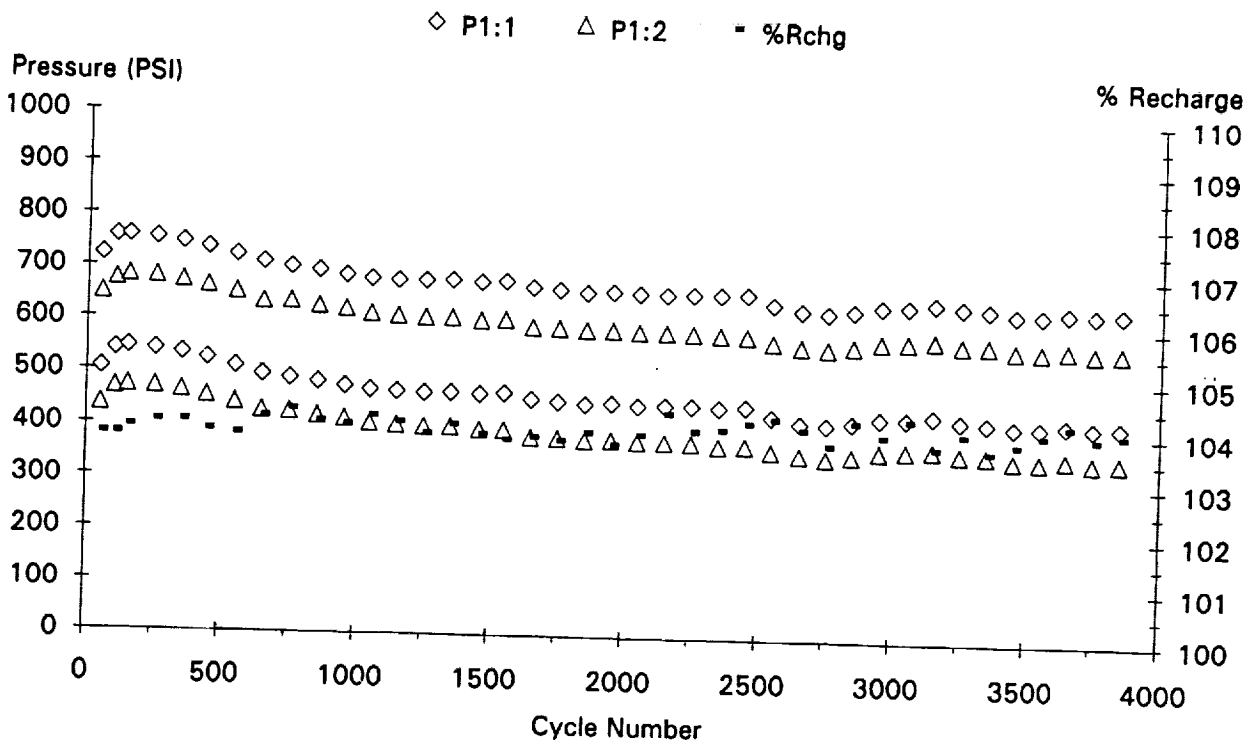
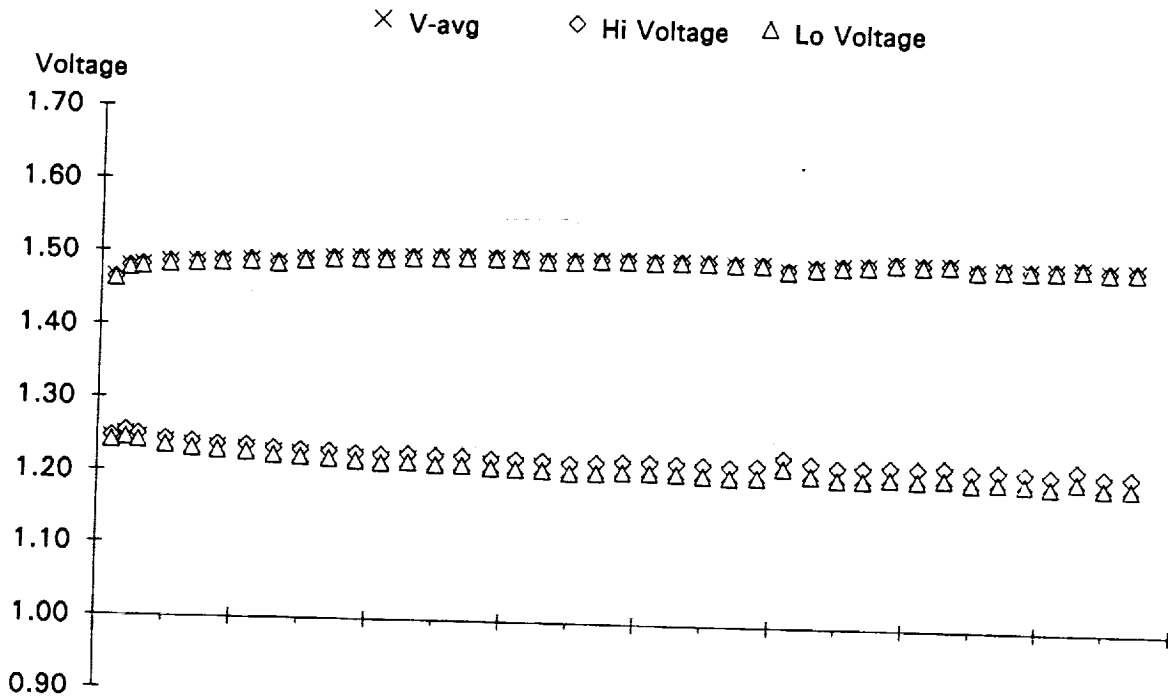
NSWC Crane **Pack ID 3604G** **4 cells**
 Voltage/Pressure/Recharge EOC/EOD Trend Plot 11/21/92 - 09/28/93
 Gates 65 AmpHr 60% DOD 10 Deg C 94% SOC



Cycle 1. Started Life Cycle Test.

-65.0A for .6Hr ; 45.07A for .9Hr ; Rchg = 104.0%

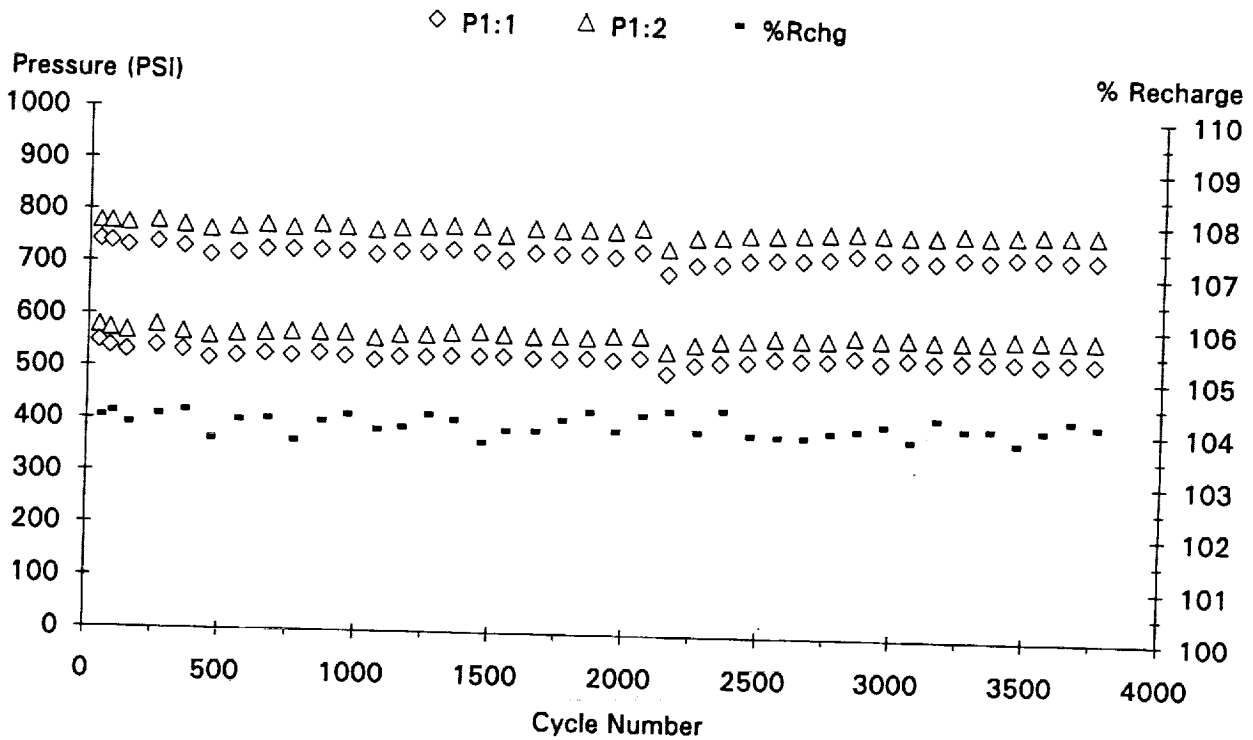
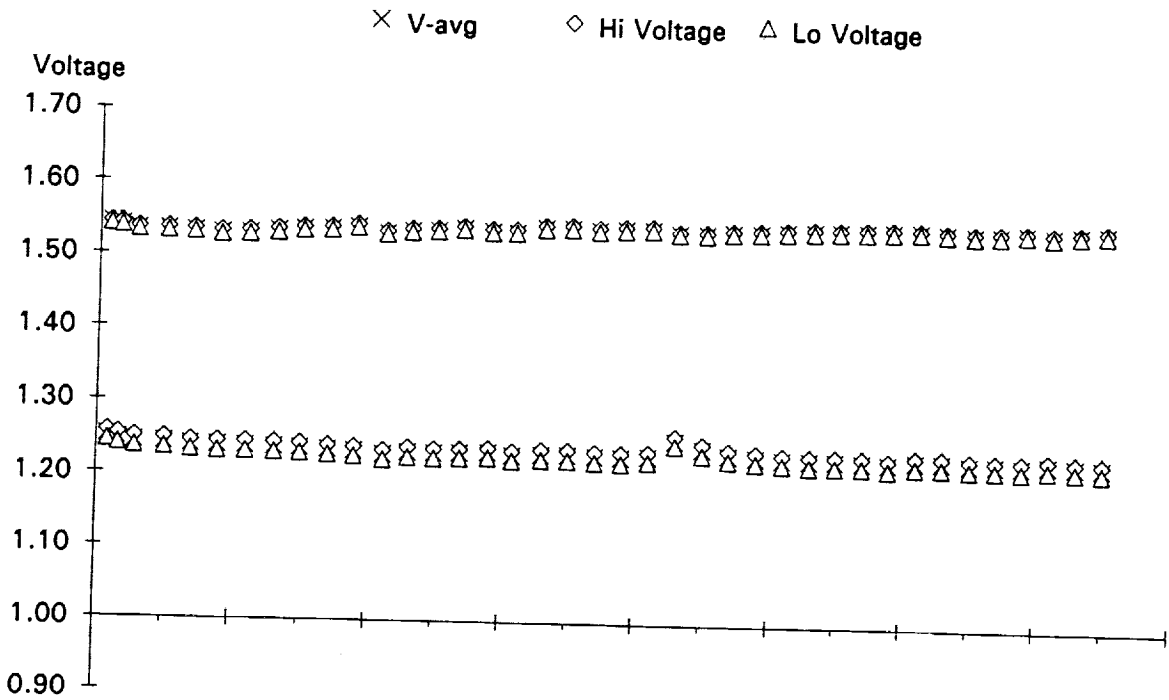
NSWC Crane **Pack ID 3631G** **10 cells**
 Voltage/Pressure/Recharge EOC/EOD Trend Plot 01/18/93 - 09/26/93
 Gates 65 AmpHr 35% DOD 10 Deg C



Cycle 10. Started Life Cycle Test.

-37.92A for .6Hr ; 36.02A for .6Hr ; 6.883A for .3Hr ; Rchg = 104.0%

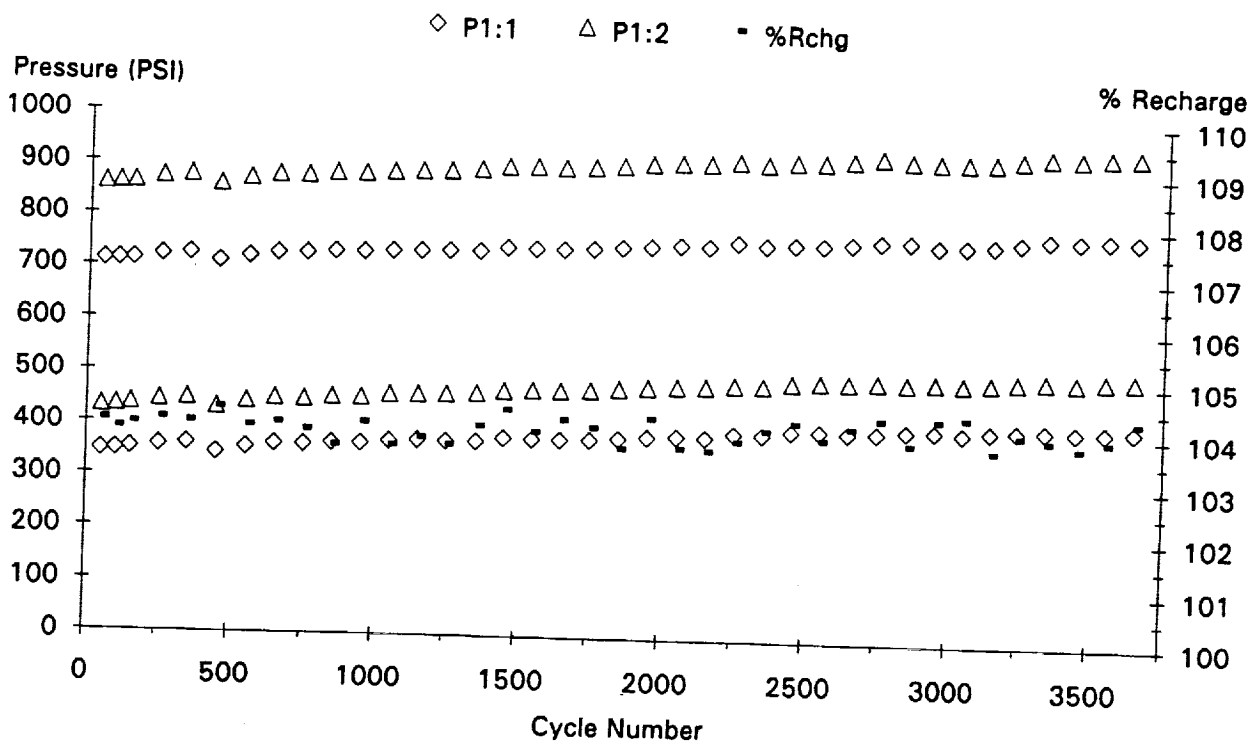
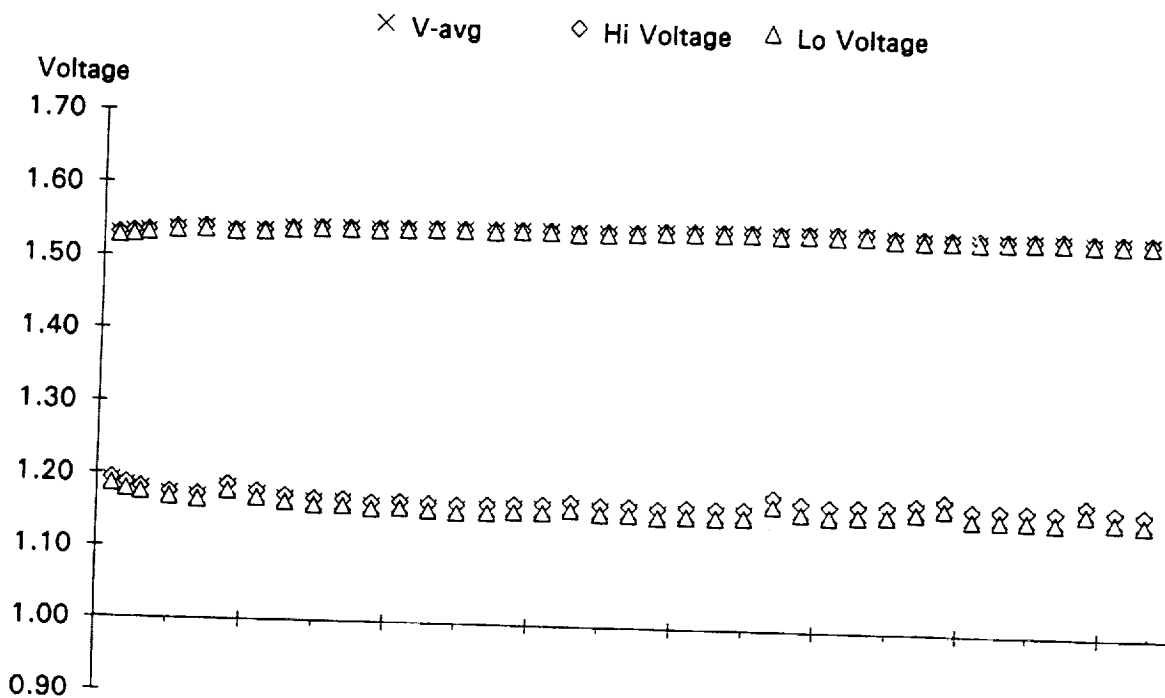
NSWC Crane **Pack ID 3635G** **10 cells**
 Voltage/Pressure/Recharge EOC/EOD Trend Plot 01/30/93 - 10/01/93
 Gates 65 AmpHr 35% DOD -5 Deg C



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Cycle 11. Started Life Cycle Test.

-37.92A for .6Hr ; 36.02A for .6Hr ; 6.883A for .3Hr ; Rchg = 104.0%

NSWC Crane Pack ID 3661G 10 cells
 Voltage/Pressure/Recharge EOC/EOD Trend Plot 01/30/93 - 09/25/93
 Gates 65 AmpHr 60% DOD 10 Deg C

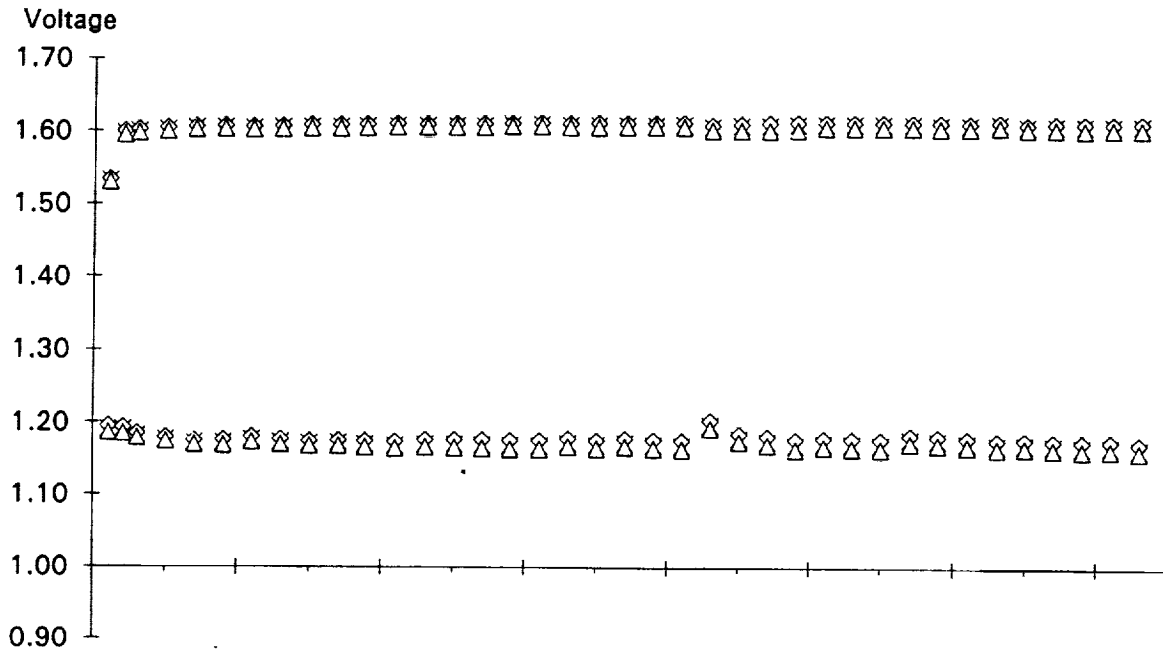


Cycle 13. Started Life Cycle Test.

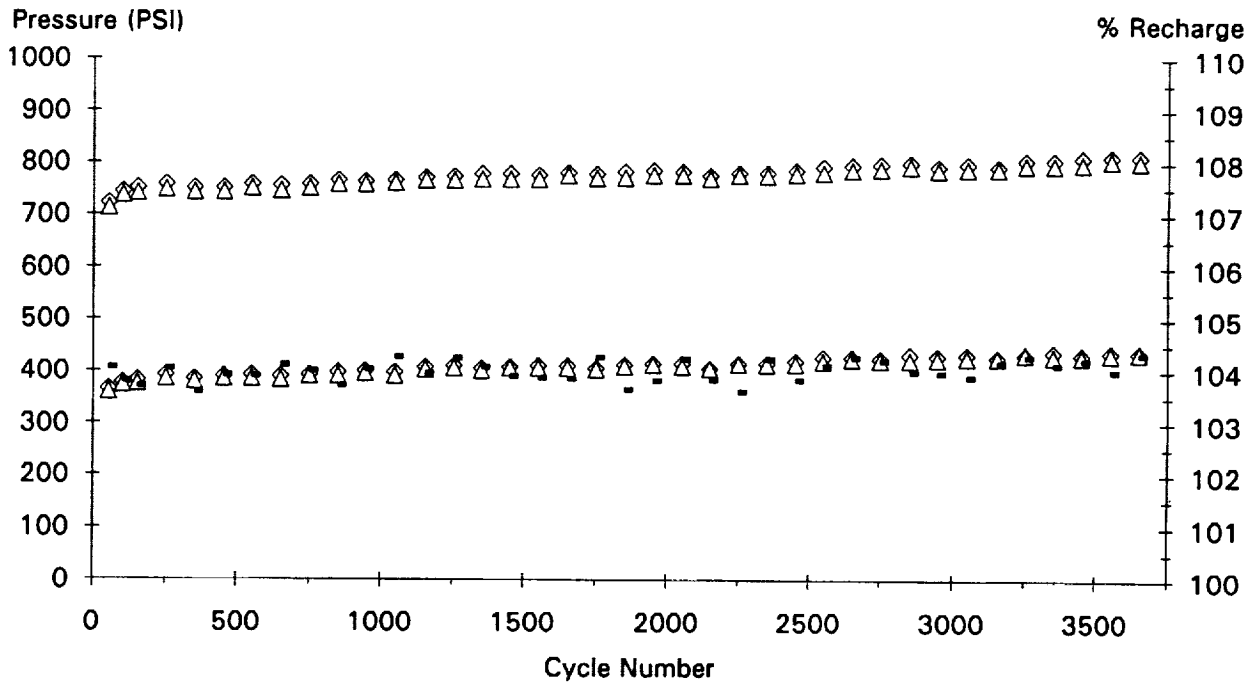
-65.0A for .6Hr ; 55.57A for .67Hr ; 15.06A for .23Hr ; Rchg = 104.0%

NSWC Crane Pack ID 3665G 10 cells
Voltage/Pressure/Recharge EOC/EOD Trend Plot 01/31/93 - 09/26/93
Gates 65 AmpHr 60% DOD 10 Deg C

× V-avg ◇ Hi Voltage △ Lo Voltage



◇ P1:1 △ P1:2 - %Rchg



Cycle 14. Started Life Cycle Test.

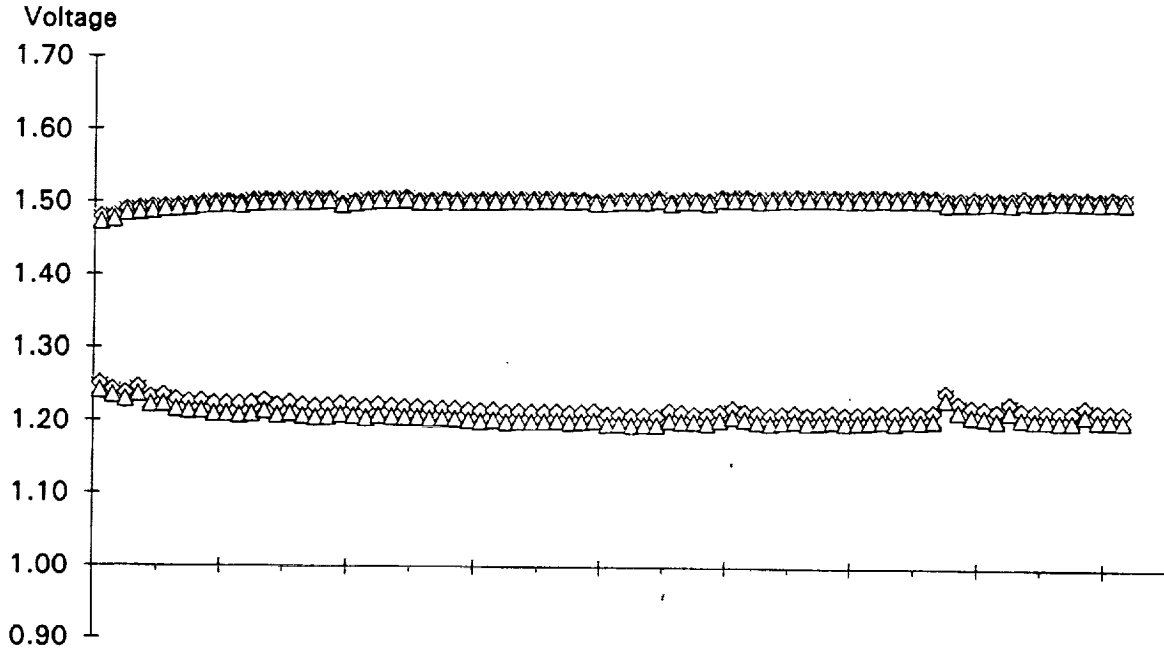
-65.0A for .6Hr ; 55.57A for .67Hr ; 15.06 A for .23Hr ; Rchg = 104.0%

Cycle 78. Restarted L.C. with a different regime.

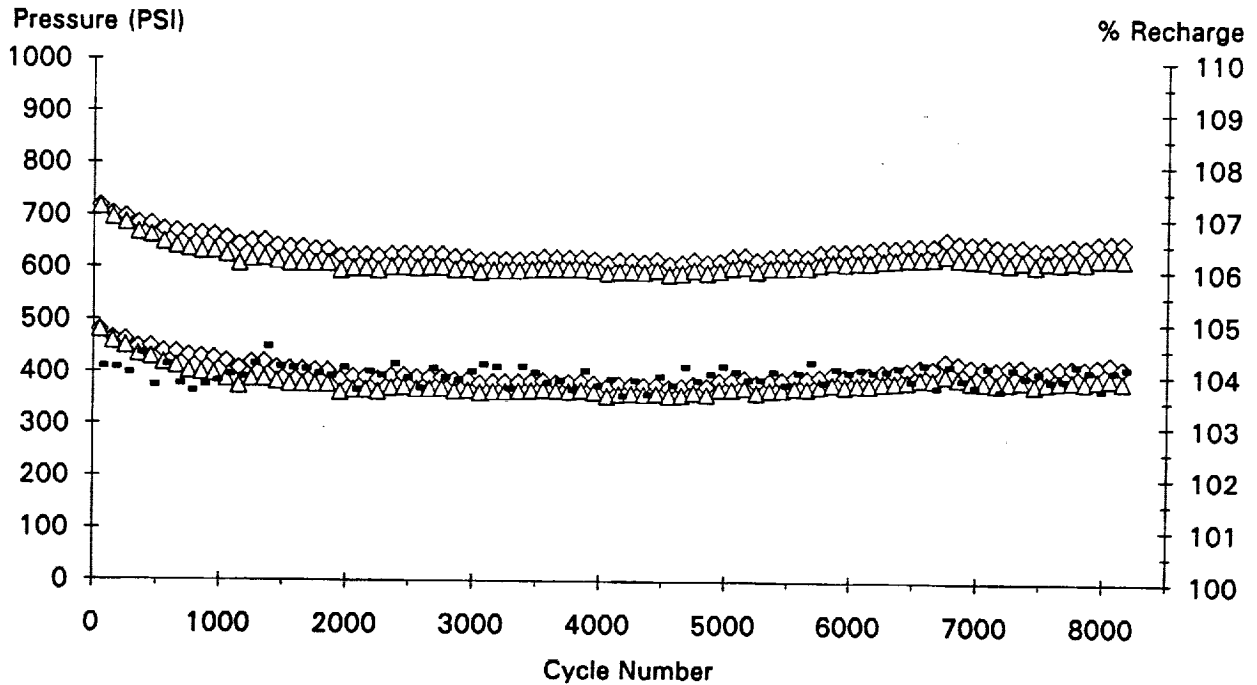
-65.0A for .6Hr ; 45.07A for .9Hr ; Rchg = 104.0%

NSWC Crane **Pack ID 3831G** **10 cells**
 Voltage/Pressure/Recharge EOC/EOD Trend Plot 04/19/92 - 10/01/93
 Gates 81 AmpHr 35% DOD 10 Deg C

× V-avg ◇ Hi Voltage △ Lo Voltage



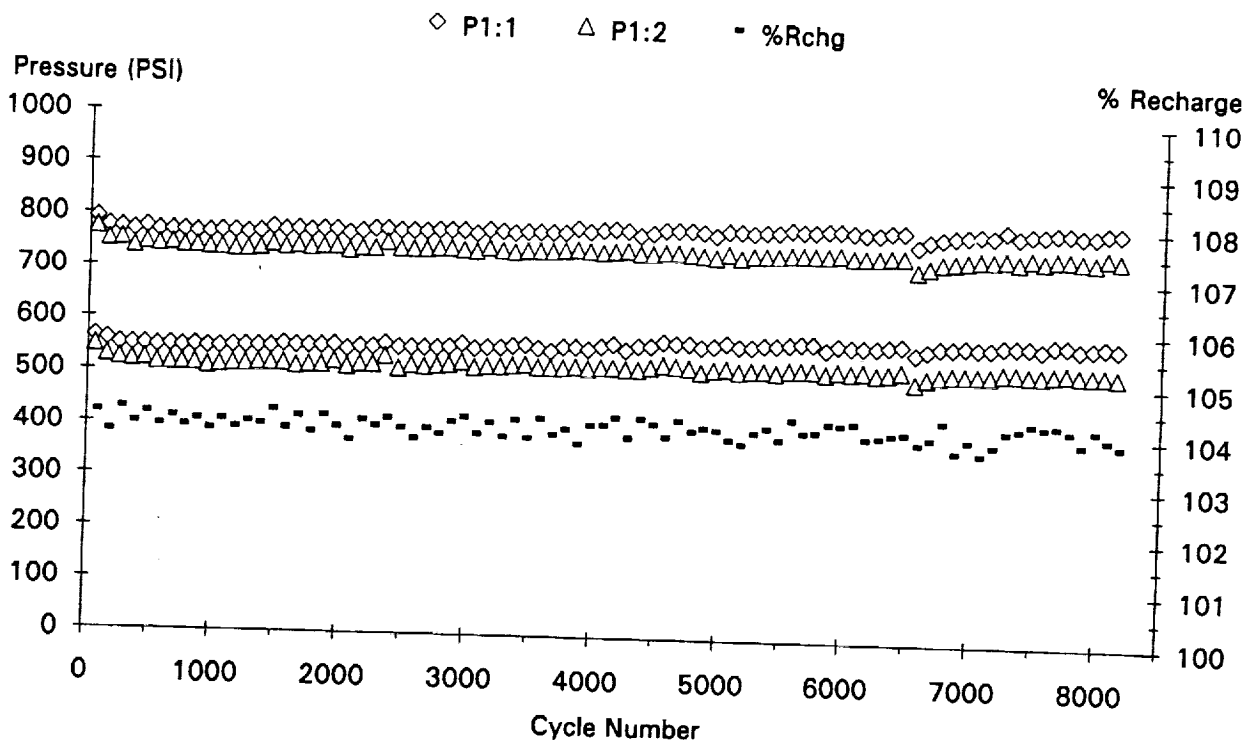
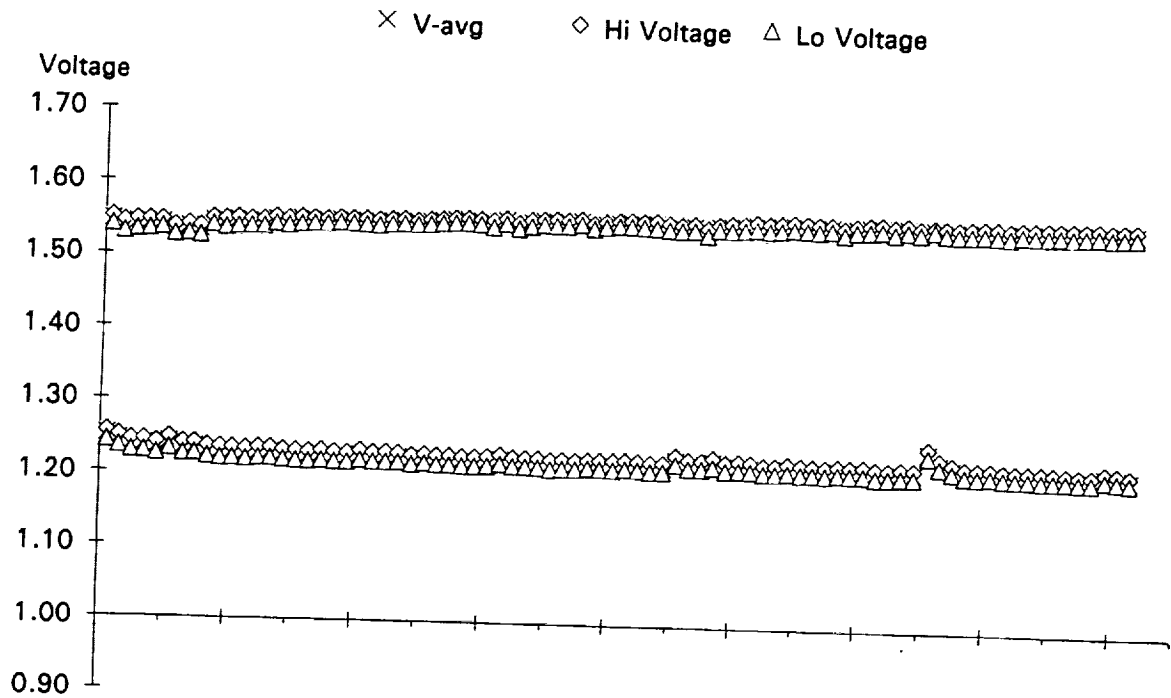
◇ P1:1 △ P1:2 - %Rchg



Cycle 1. Started Life Cycle Test.

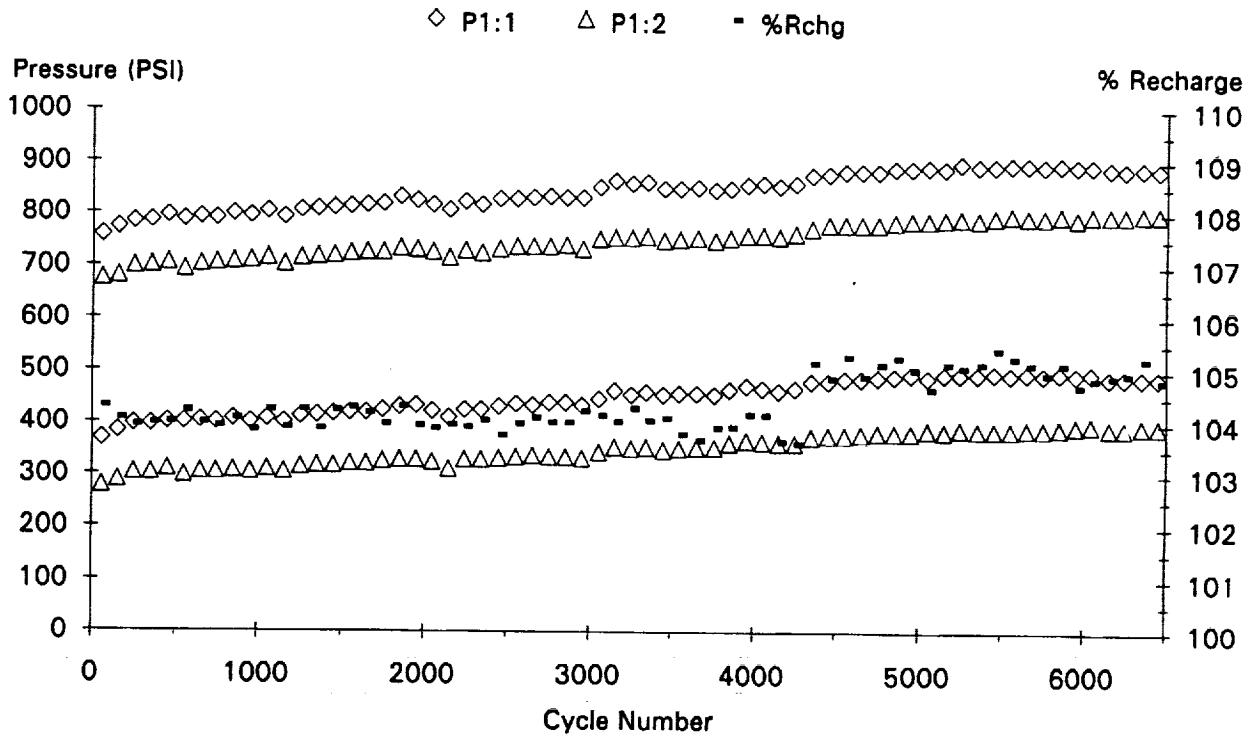
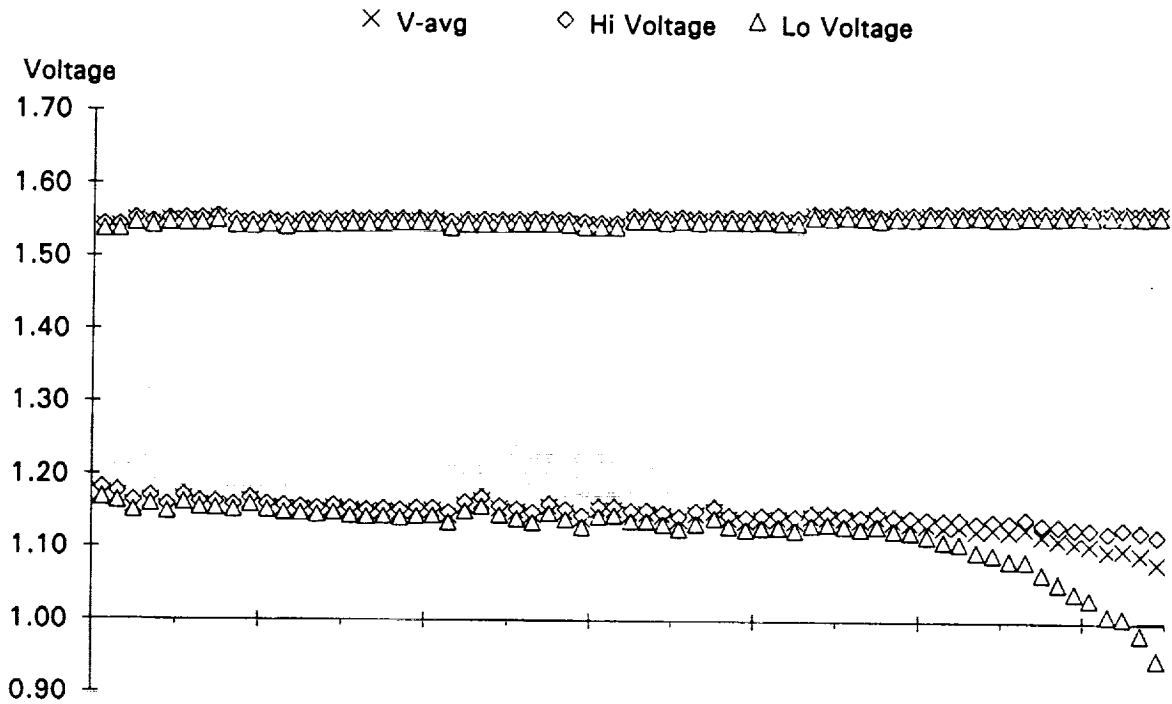
-47.25A for .6Hr ; 44.88A for .6Hr ; 8.5A for .3Hr ; Rchg = 104.0%

NSWC Crane **Pack ID 3835G** **10 cells**
 Voltage/Pressure/Recharge EOC/EOD Trend Plot 04/19/92 - 10/01/93
 Gates 81 AmpHr 35% DOD -5 Deg C



Cycle 1. Started Life Cycle Test.

-47.25A for .6Hr ; 44.88A for .6Hr ; 8.5A for .3Hr ; Rchg = 104.0%



Cycle 1. Started Life Cycle Test.

-81.0A for .6Hr ; 69.25A for .667Hr ; 18.77A for .233Hr ; Rchg = 104.0%

Cycle 4276. Raised Rchg fro 104.0% to 105.0%.

-81.0A for .6Hr ; 69.25A for .667Hr ; 20.86A for .233Hr

NSWC Crane

Pack ID 3865G

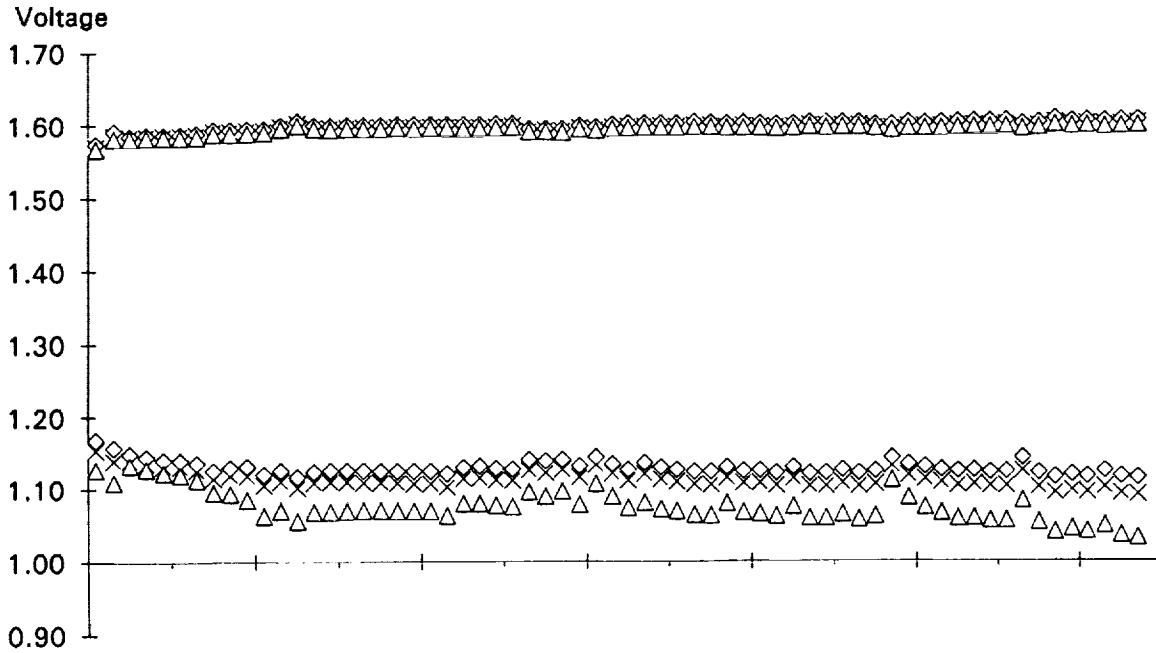
10 cells

Voltage/Pressure/Recharge EOC/EOD Trend Plot

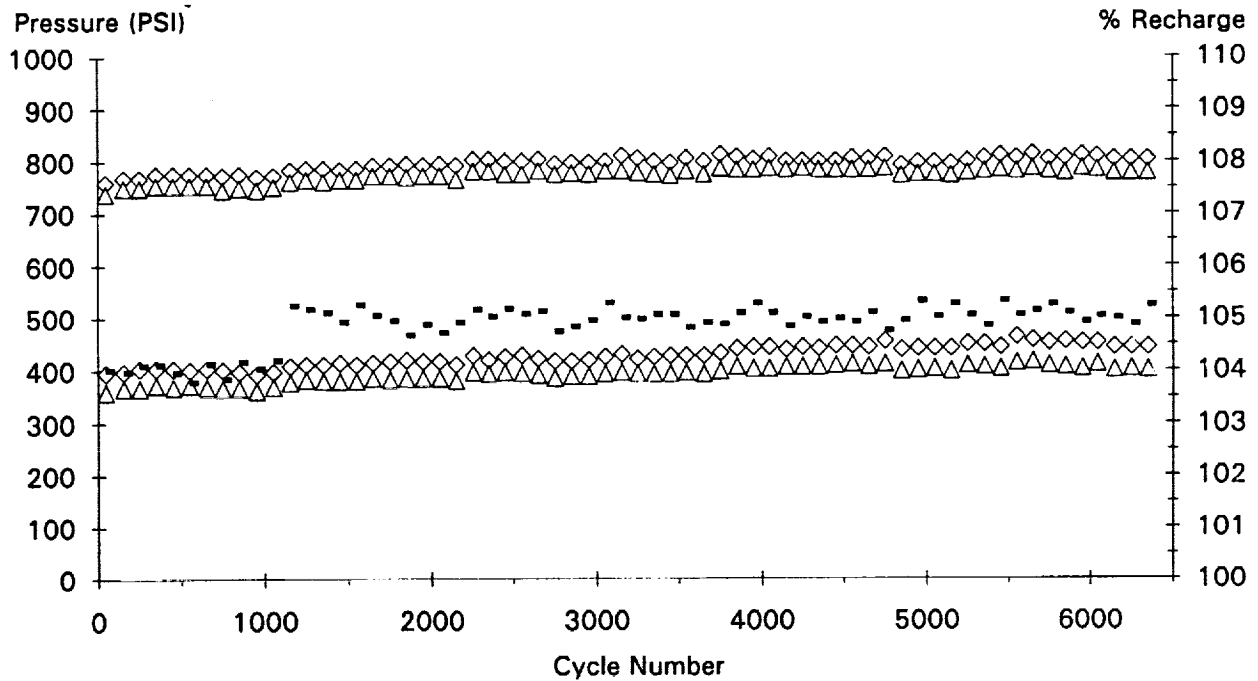
08/05/92 - 09/30/93

Gates 81 AmpHr 60% DOD -5 Deg C

× V-avg ◇ Hi Voltage △ Lo Voltage



◇ P1:1 △ P1:2 ■ %Rchg



Cycle 1. Started Life Cycle Test.

-81.0A for .6Hr ; 69.25A for .667Hr ; 18.77A for .233Hr ; Rchg = 104.0%

Cycle 1096. Raised Rchg from 104.0% to 105.0%.

-81.0A for .6Hr ; 69.25A for .667Hr ; 20.86A for .233Hr

NSWC Crane

Pack ID 3831Y

10 cells

Voltage/Pressure/Recharge EOC/EOD Trend Plot

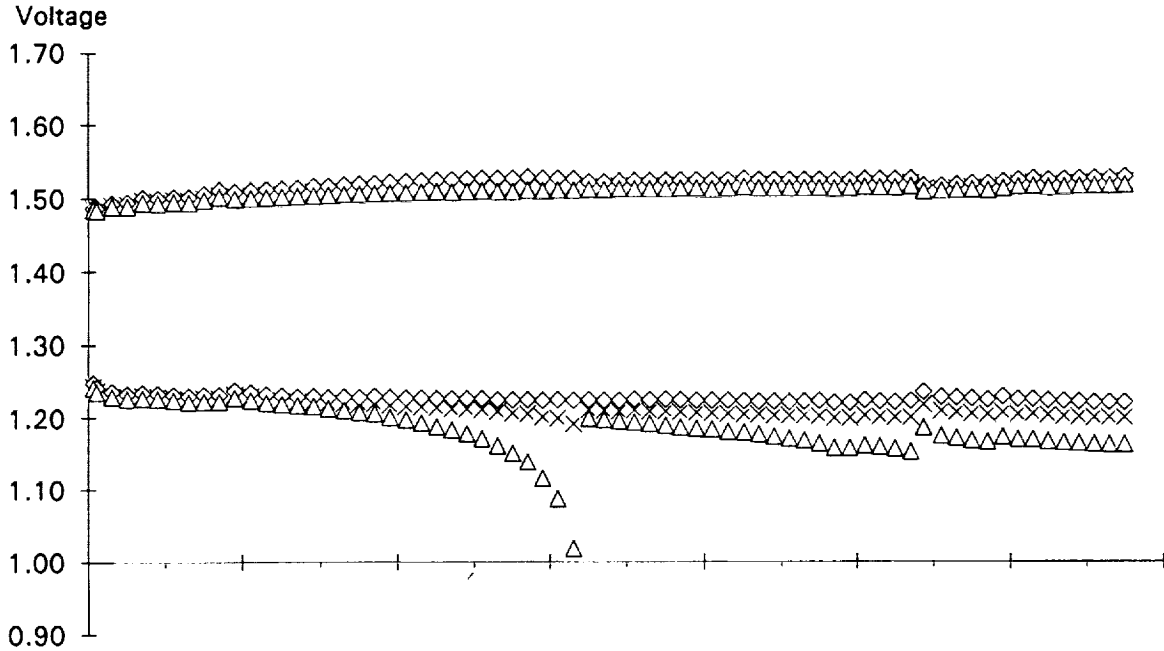
07/16/92 - 09/28/93

Yardney 81 AmpHr

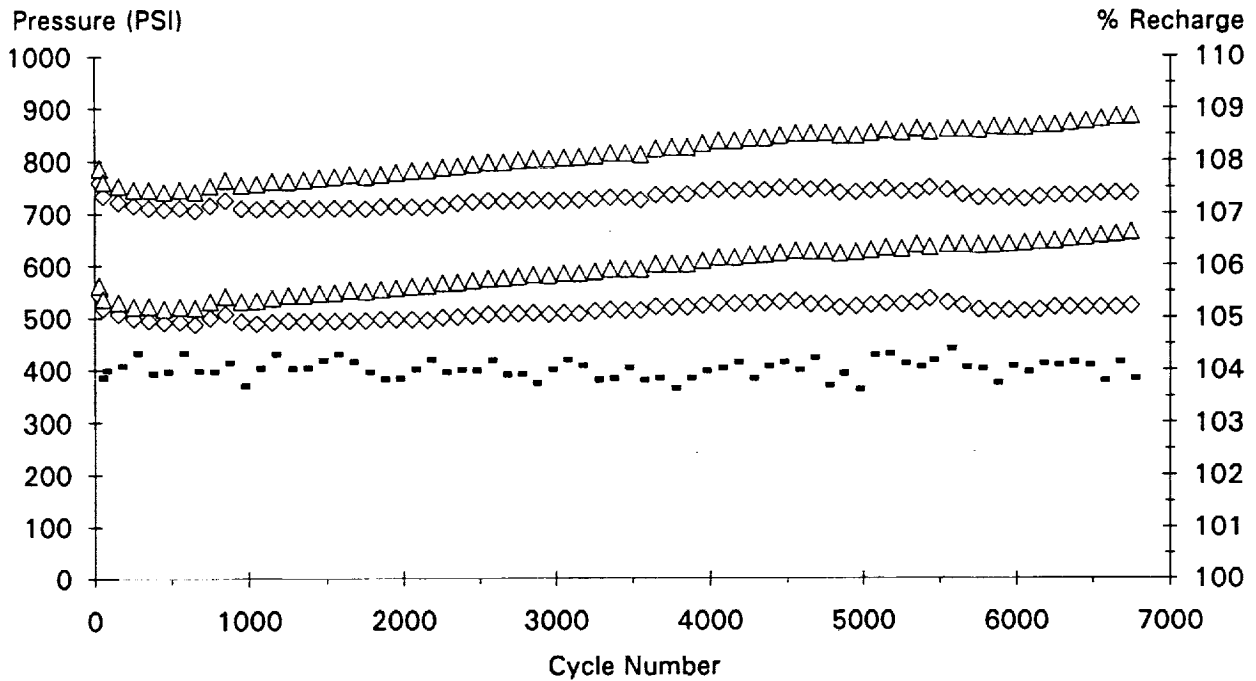
35% DOD

10 Deg C

× V-avg ◇ Hi Voltage △ Lo Voltage



◇ P1:1 △ P1:2 ▪ %Rchg



Cycle 20. Started Life Cycle Test.

-47.25A for .6Hr ; 44.88A for .6Hr ; 8.50A for .3Hr ; Rchg = 104.0%

Cycle 3199. Removed cell #2 (SN08) from pack because of low EOD voltage.

NSWC Crane

Pack ID 3835Y

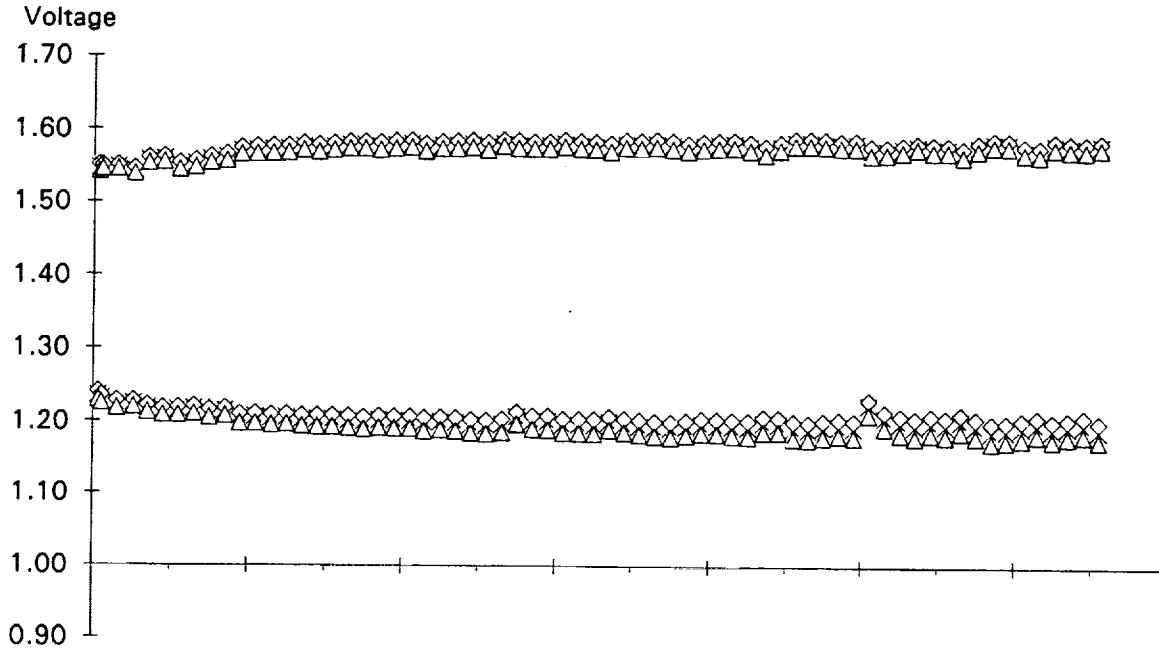
10 cells

Voltage/Pressure/Recharge EOC/EOD Trend Plot

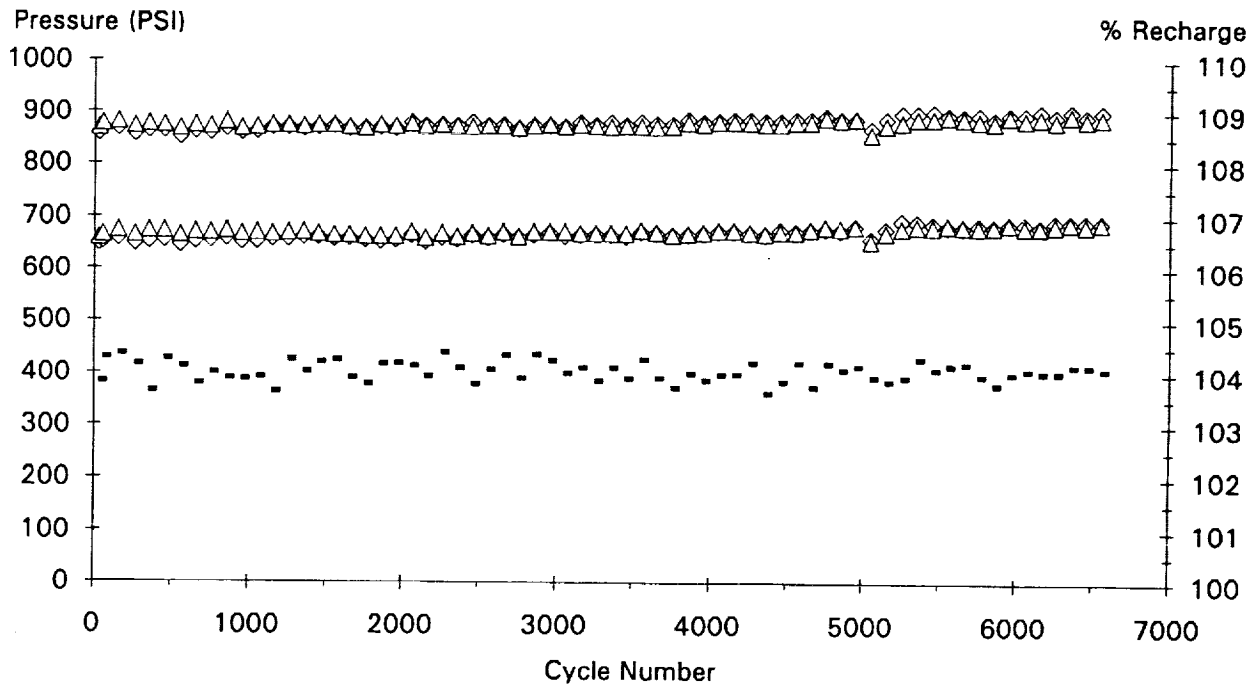
07/17/92 - 09/28/93

Yardney 81 AmpHr 35% DOD -5 Deg C

× V-avg ◇ Hi Voltage △ Lo Voltage

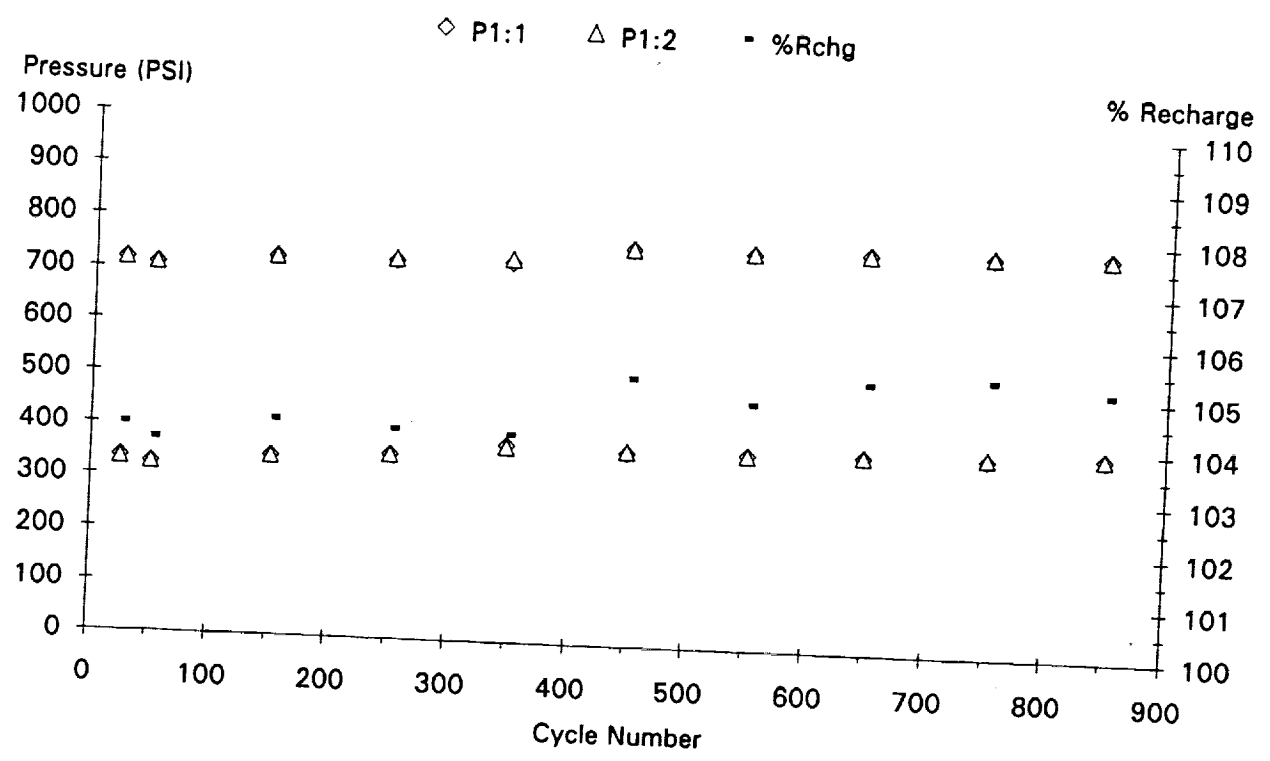
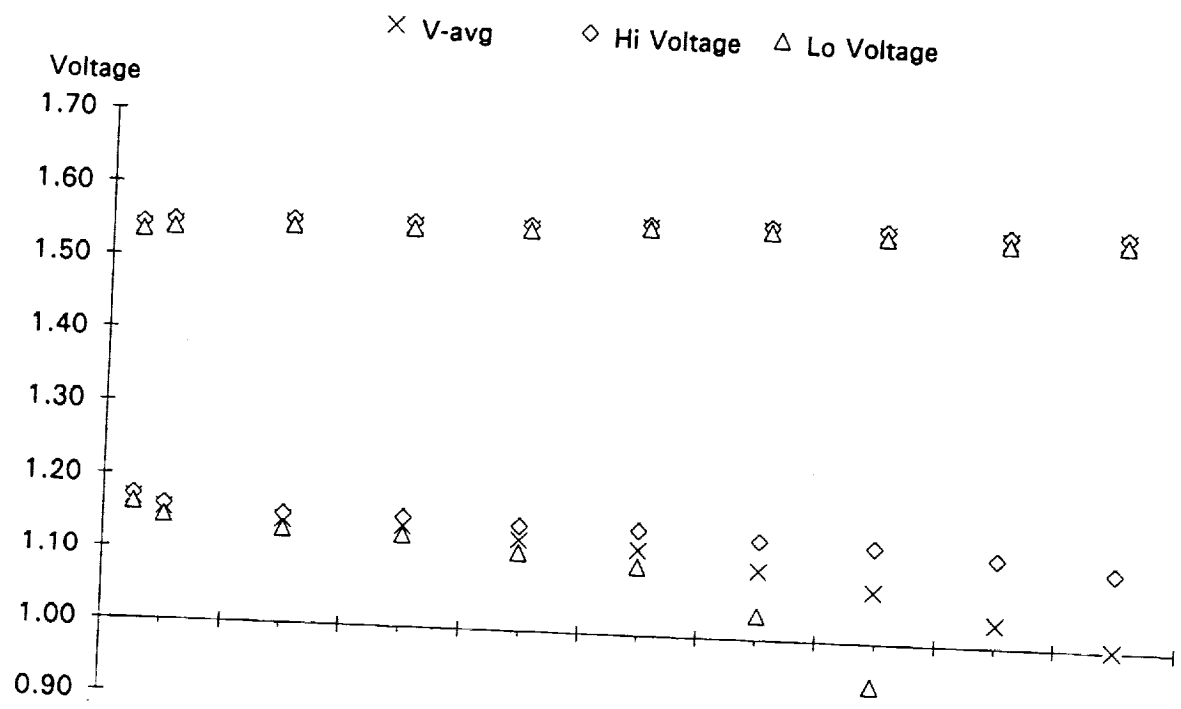


◇ P1:1 △ P1:2 - %Rchg



Cycle 23. Started Life Cycle Test.

-47.25A for .6Hr ; 44.88A for .6Hr ; 8.50A for .3Hr ; Rchg = 104.0%



Cycle 19. Started Life Cycle Test.

-81.0A for .6Hr ; 69.25A for .667Hr ; 18.77A for .233Hr ; Rchg = 104.0%

Cycle 429. Raised Rchg from 104.0% to 105.0%.

-81.0A for .6Hr ; 69.25A for .667Hr ; 20.86A for .233Hr

Cycle 504. Restarted L.C. Test regime modified as follows;

-81.0A for .6Hr ; 56.7A for .9Hr Tchg = 105.0%

Cycle 583. Cell #6 (SN09) fell below 1.0V EOD. Pack Average was 1.085V EOD.

Cycles 713 - 717. Halted life cycle test for capacity cycles.

Cycle 858. Pack average EOD voltage fell below 1.0V. Low cell was #6 at .766V.

Cycle 881. 4/8/93. Life Cycle test halted. Low cell at EOD was #6 at .757V. Pack average voltage at EOD was .986.

NSWC Crane

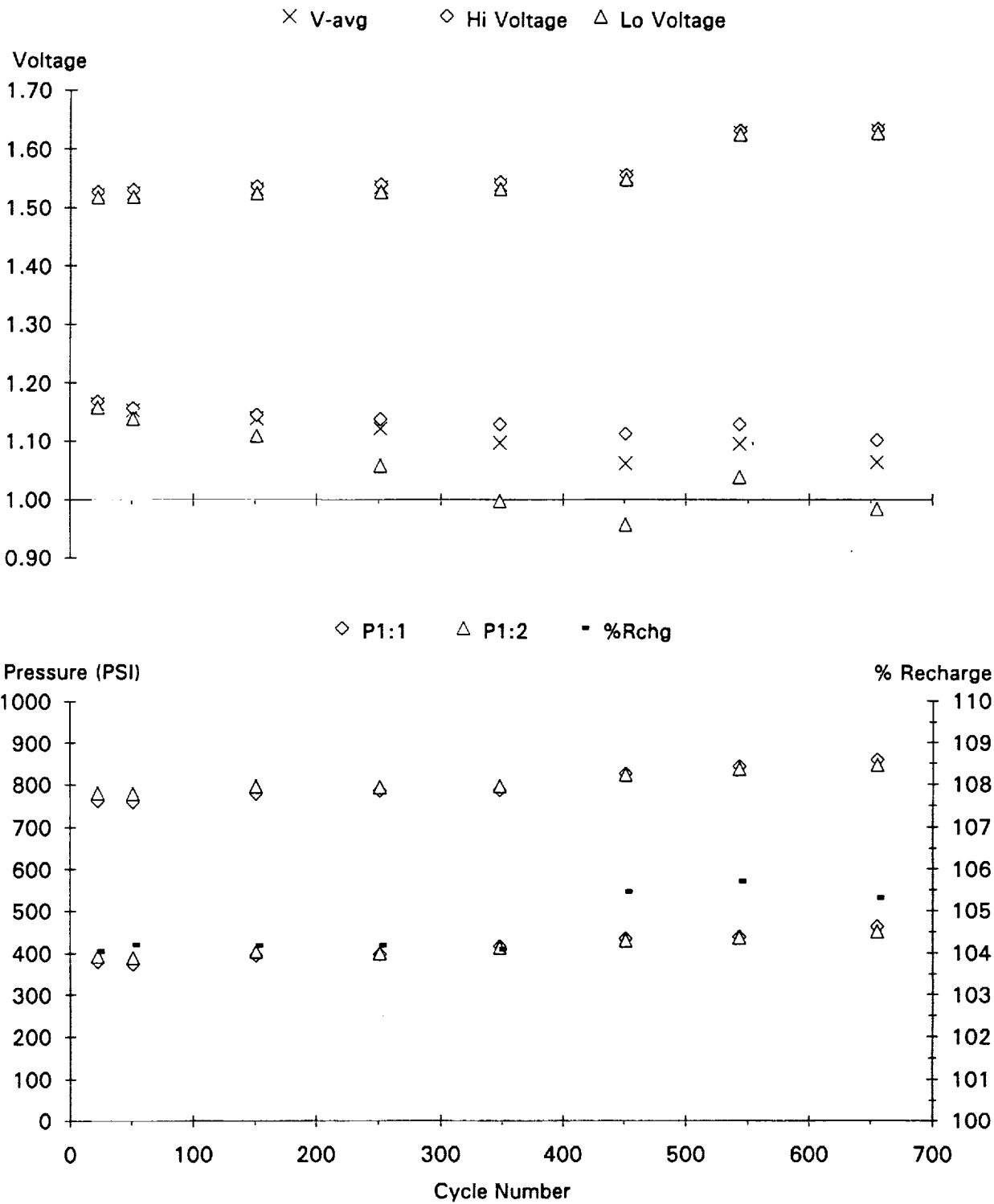
Pack ID 3865Y

10 cells

Voltage/Pressure/Recharge EOC/EOD Trend Plot

02/05/93 - 03/26/93

Yardney 81 AmpHr 60% DOD -5 Deg C



Cycle 15. Started Life Cycle Test.

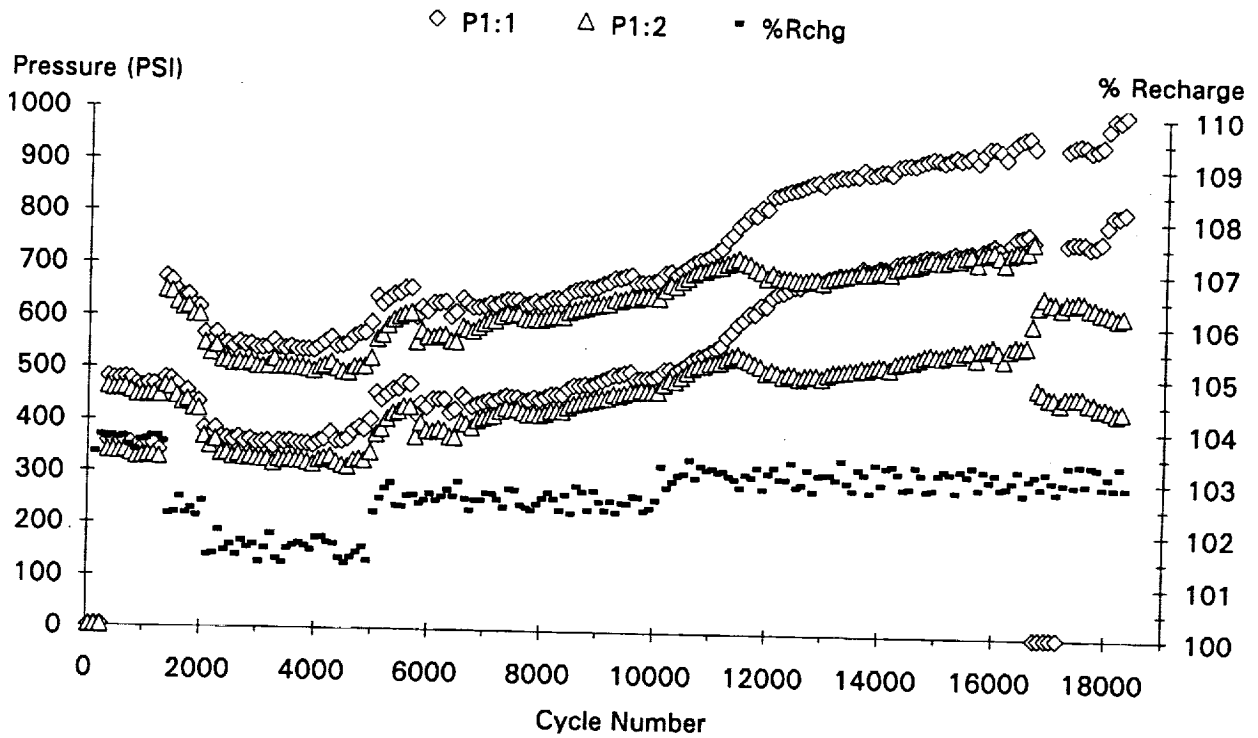
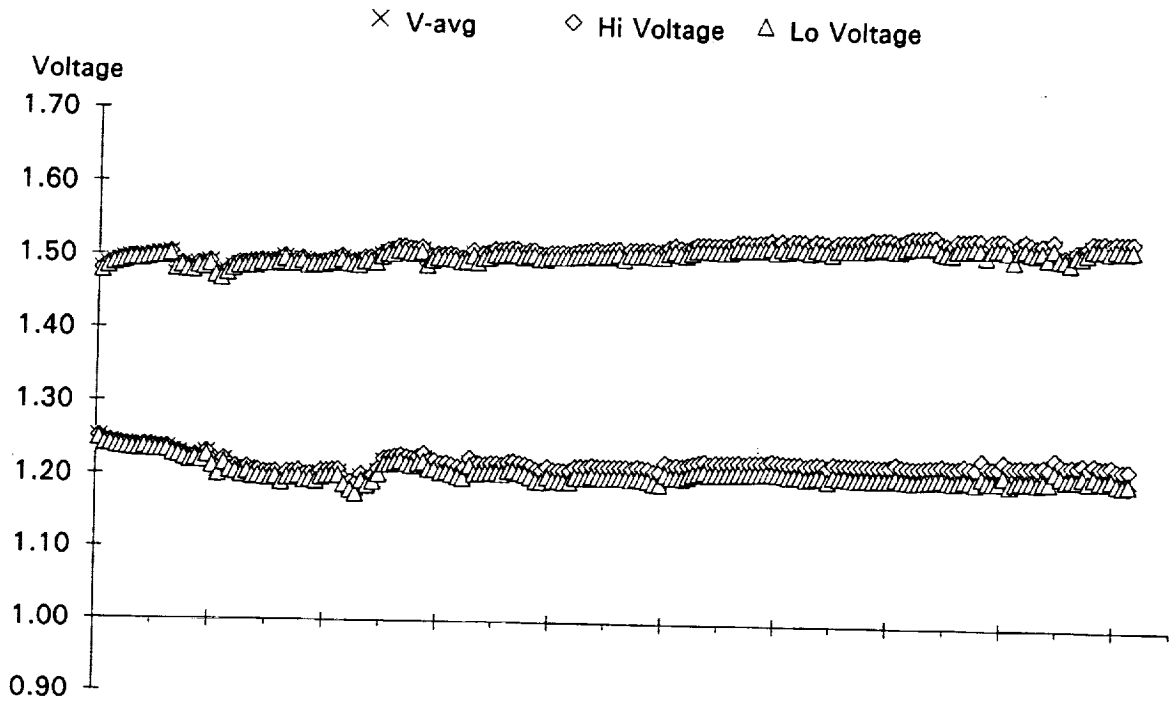
-81.0A for .6Hr ; 62.49A for .7Hr ; 60.118-7.923A Taper for .2Hr ; Rchg = 104.0%
Cycle 323. Cell #1 (SN10) fell below EOD voltage of 1.0V. Pack average EOD voltage was 1.079V.

Cycle 406. Raised Rchg from 104.0% to 105.0%.

-81.0A for .6Hr ; 62.49A for .7Hr ; 60.320-12.580A Taper for .2Hr
Cycles 502 - 503. Halted life cycle test for capacity cycles.

Cycle 709. 3/29/93. Life Cycle test halted. Low cell at EOD was #2 SN15) at .902V. Pack average voltage at EOD was 1.041.

NSWC Crane **Pack ID 5631W** **10 cells**
 Voltage/Pressure/Recharge EOC/EOD Trend Plot 07/01/90 - 09/26/93
 Yardney 65 AmpHr 35% DOD 10 Deg C



Cycle 1. Started Life Cycle Test.

-37.9A for .6Hr ; 36.0A for .6Hr ; 6.49A for .3Hr ; Rchg = 103.5%

Cycle 1368. Lowered Rchg from 103.5% to 101.5%.

-37.9A for .6Hr ; 36.0A for .6Hr ; 4.97A for .3Hr

Cycle 4864. Raised Rchg from 101.5% to 102.5%.

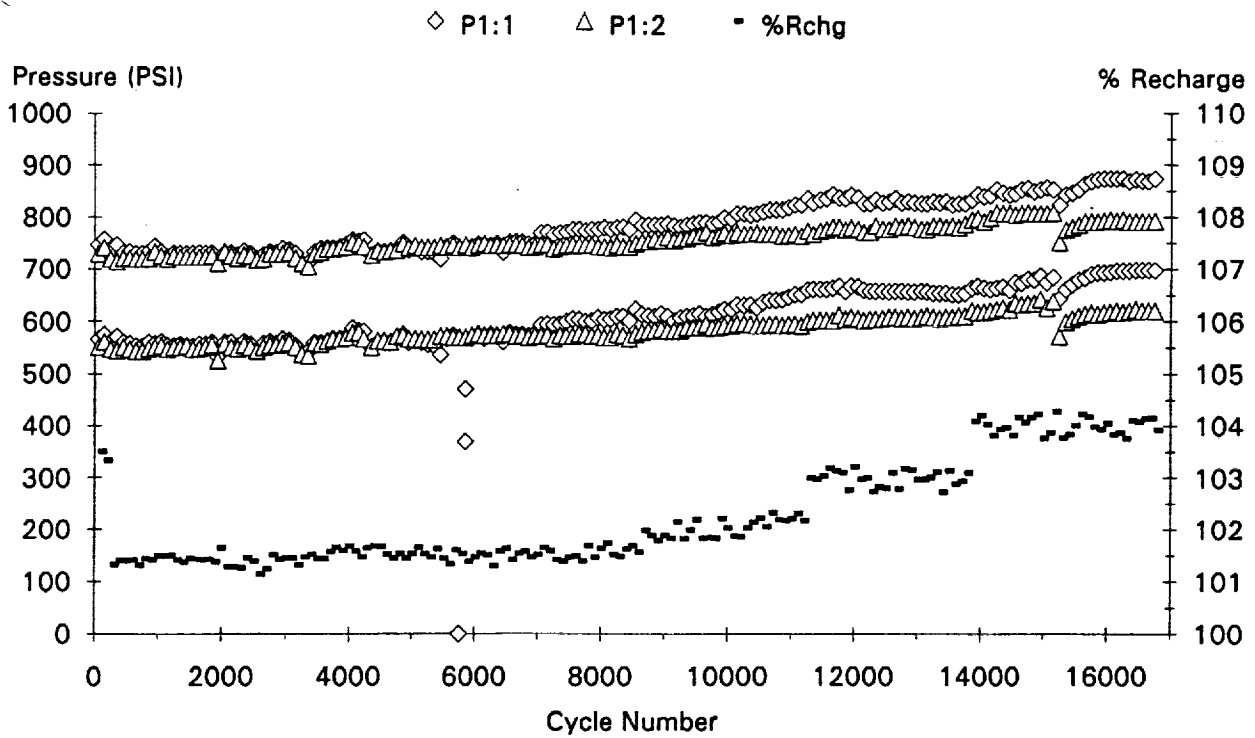
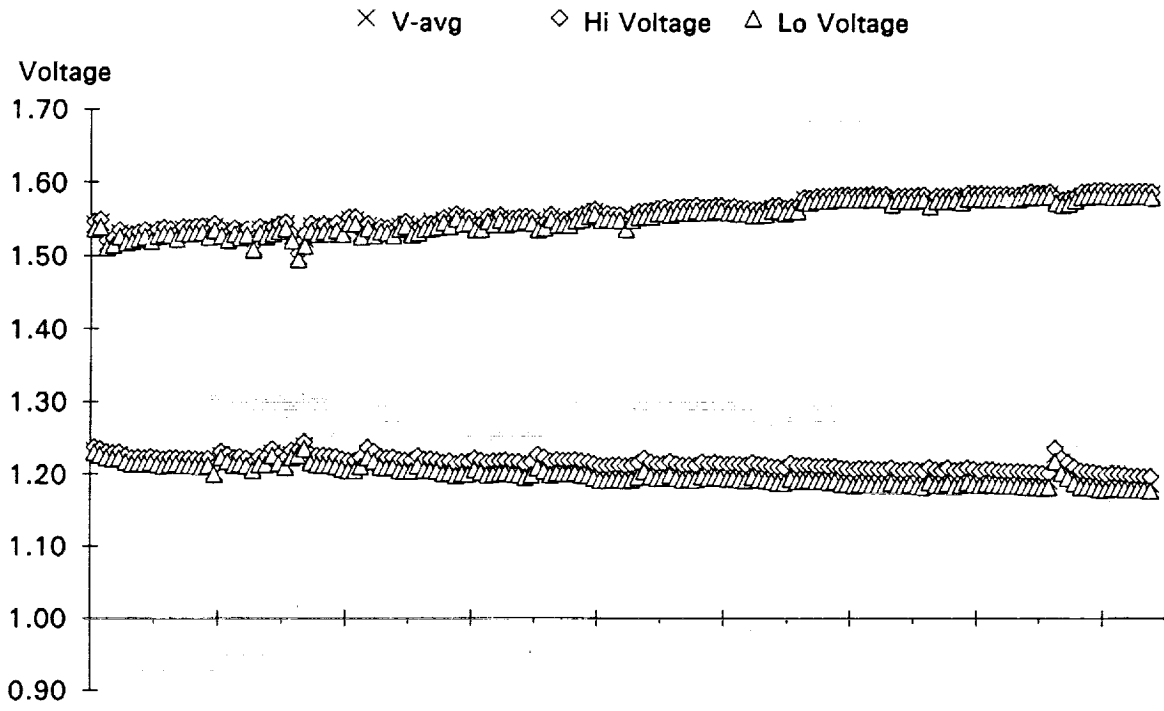
-37.9A for .6Hr ; 36.0A for .6Hr ; 5.73A for .3Hr

Cycle 10144. Raised Rchg from 102.5% to 103.0%.

-37.9A for .6Hr ; 36.0A for .6Hr ; 6.11A for .3Hr

Cycle 16707 - 17180. P1:1 pressure indication not working.

NSWC Crane Pack ID 5635W 10 cells
 Voltage/Pressure/Recharge EOC/EOD Trend Plot 09/22/90 - 09/28/93
 Yardney 65 AmpHr 35% DOD -5 Deg C



Cycle 1. Started Life Cycle Test.

-37.9A for .6Hr ; 36.0A for .6Hr ; 4.97A for .3Hr ; Rchg = 101.5%

Cycle 5654. Strain Gauge on Pressre P1:1 failed. Changed to monitor a different cell on cycle 5885.

Cycle 8630. Raised Rchg from 101.5% to 102.0%.

-37.9A for .6Hr ; 36.0A for .6Hr ; 5.35A for .3Hr

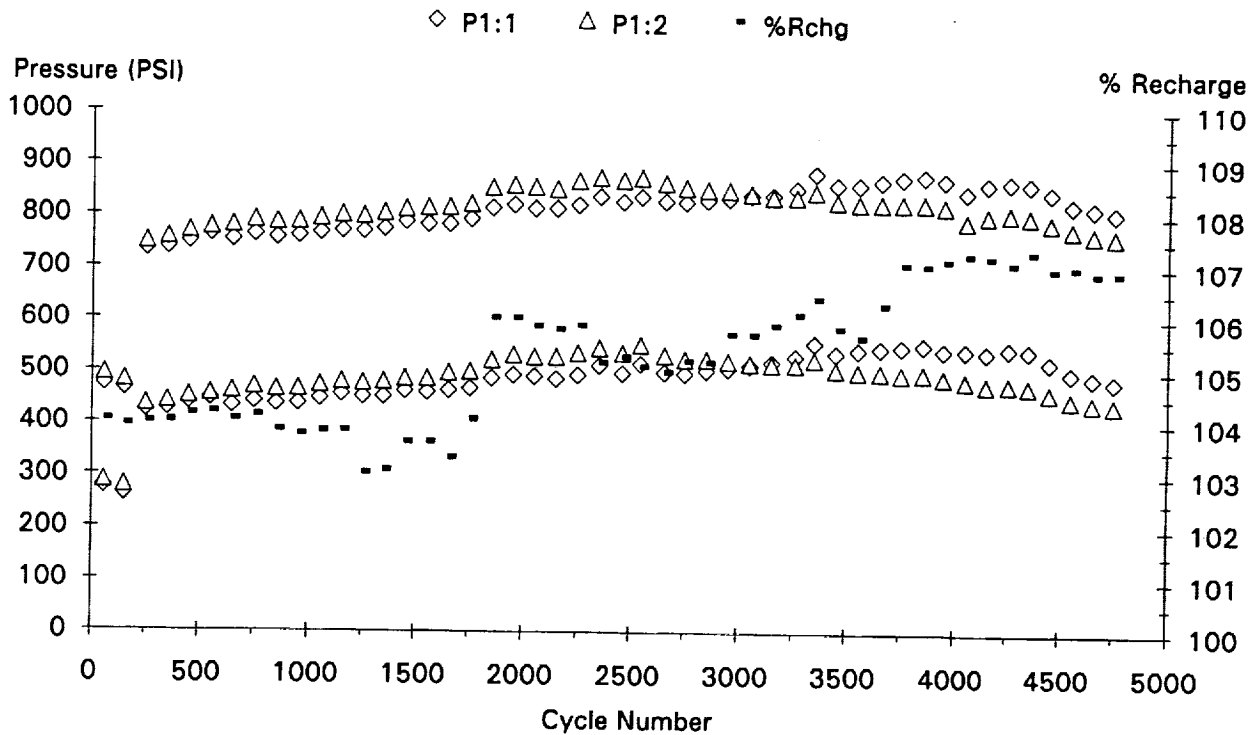
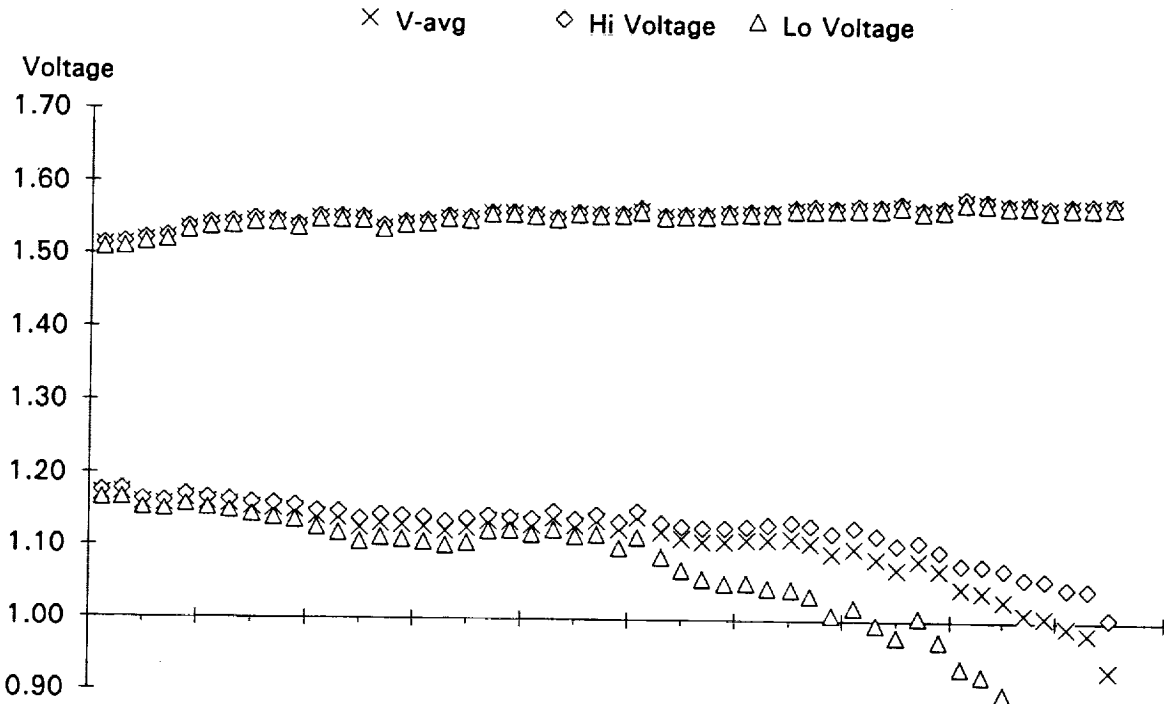
Cycle 11243. Raised Rchg from 102.0% to 103.0%.

-37.9A for .6Hr ; 36.0A for .6Hr ; 6.11A for .3Hr

Cycle 13748. Raised Rchg from 103.0% to 104.0%.

-37.9A for .6Hr ; 36.0A for .6Hr ; 6.87A for .3Hr

NSWC Crane **Pack ID 5661W** **10 cells**
 Voltage/Pressure/Recharge EOC/EOD Trend Plot 09/10/90 - 07/22/91
 Yardney 65 AmpHr 60% DOD 10 Deg C Test Ended at Cycle 4751



Cycle 1. Started Life Cycle Test.

-65.0A for .6Hr ; 61.75A for .6Hr ; 11.7A for .3Hr ; Rchg = 104.0%

Cycle 1828. Raised Rchg from 104.0% to 106.0%.

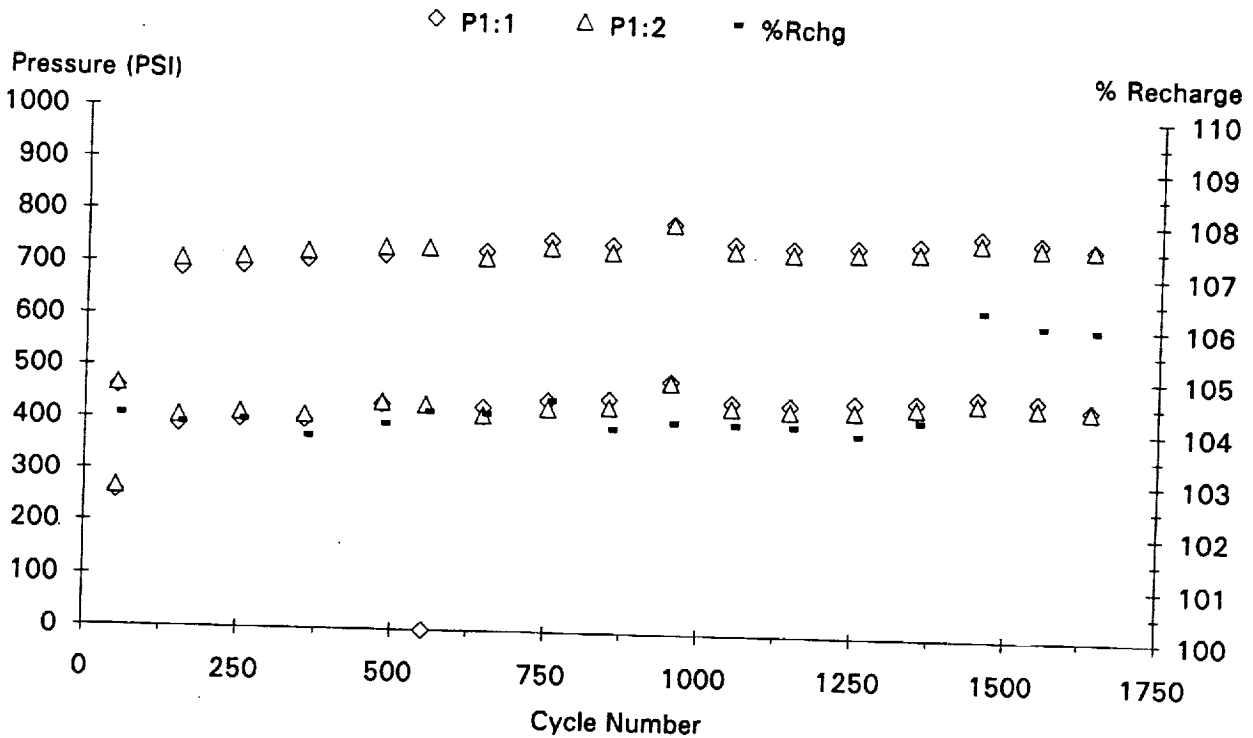
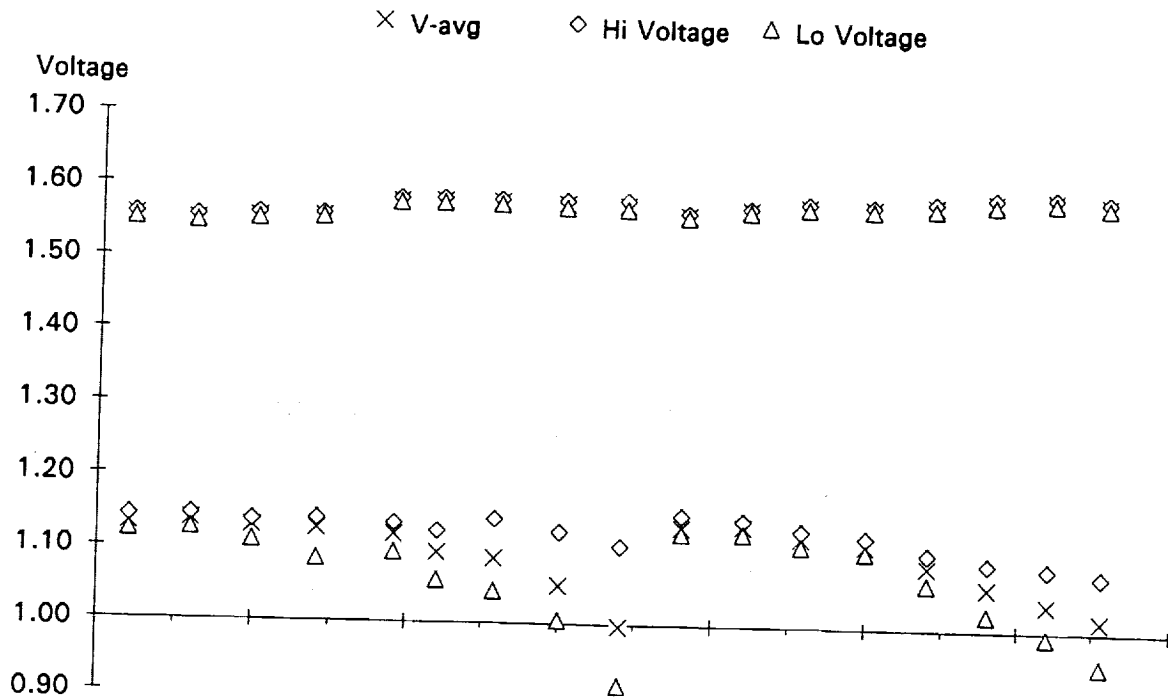
-65.0A for .6Hr ; 61.75A for .6Hr ; 14.3A for .3Hr

Cycle 3716. Raised Rchg from 106.0% to 107.0%.

-65.0A for .6Hr ; 61.75A for .6Hr ; 15.6A for .3Hr

Cycle 4751. Pack failed. EOD Pack Average Voltage below 1.0V.

NSWC Crane **Pack ID 5665W** **10 cells**
 Voltage/Pressure/Recharge EOC/EOD Trend Plot 09/14/90 - 01/25/91
 Yardney 65 AmpHr 60% DOD -5 Deg C Test Ended at Cycle 1720



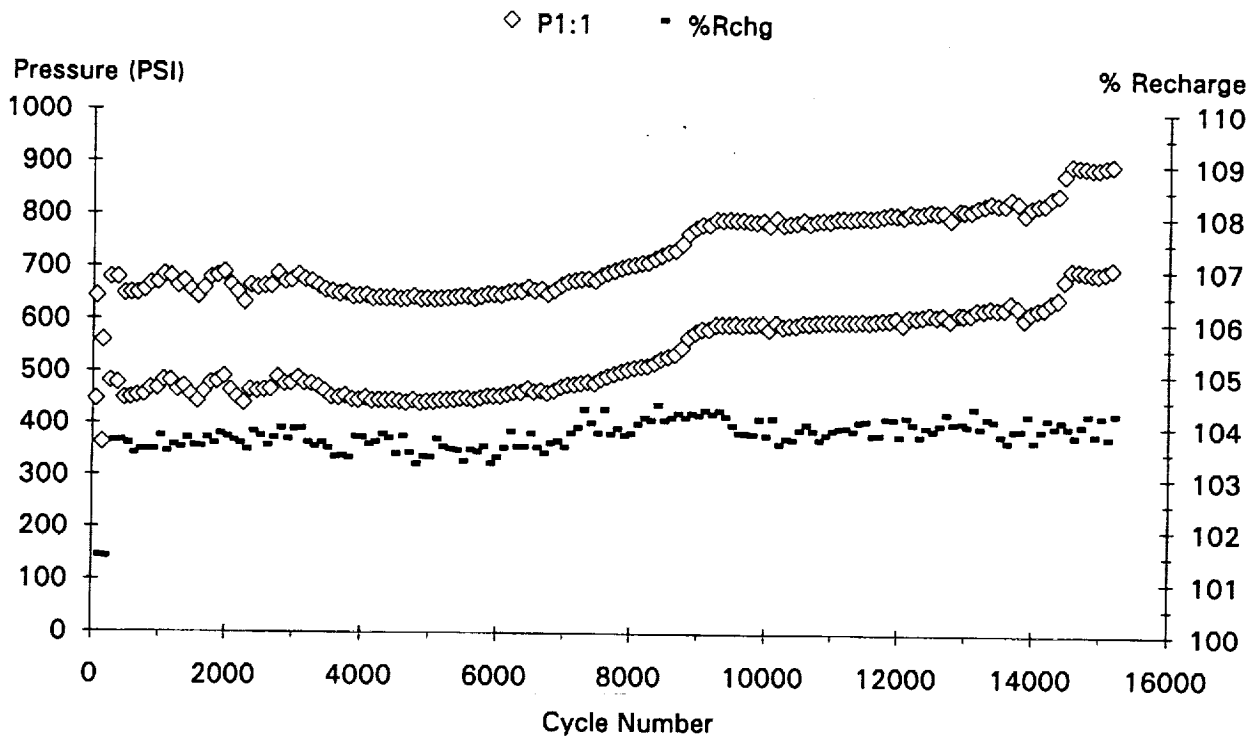
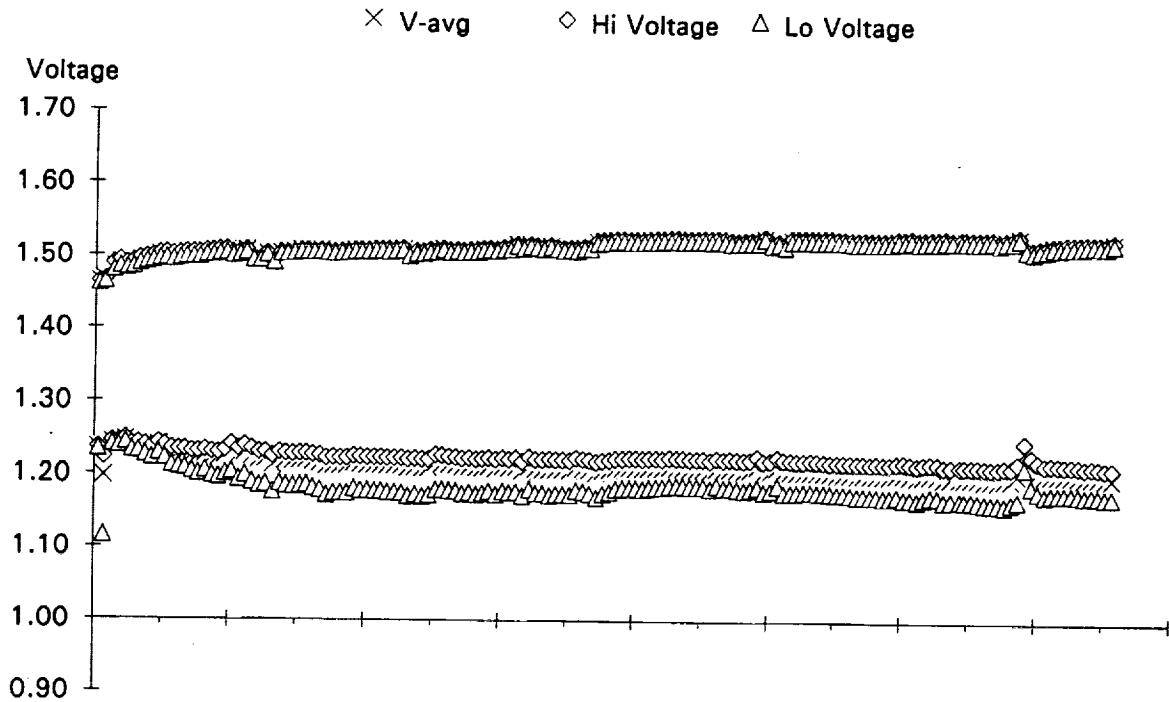
Cycle 1. Started Life Cycle Test.

-65.0A for .6Hr ; 61.75A for .6Hr ; 11.7A for .3Hr ; Rchg = 104.0%

Cycle 1400. Raised Rchg from 104.0% to 106.0%.

-65.0A for .6Hr ; 61.75A for .6Hr ; 14.3A for .3Hr

NSWC Crane Pack ID 5731W 5 cells
 Voltage/Pressure/Recharge EOC/EOD Trend Plot 12/14/90 - 09/22/93
 Yardney 65 AmpHr 35% DOD 10 Deg C



Cycle 1. Started Life Cycle Test.

-37.9A for .6Hr ; 36.0A for .6Hr ; 6.49A for .3Hr ; Rchg = 103.5%

Cycle 7065. Raised Rchg from 103.5% to 104.0%.

-37.9A for .6Hr ; 36.0A for .6Hr ; 6.87A for .3Hr

NSWC Crane

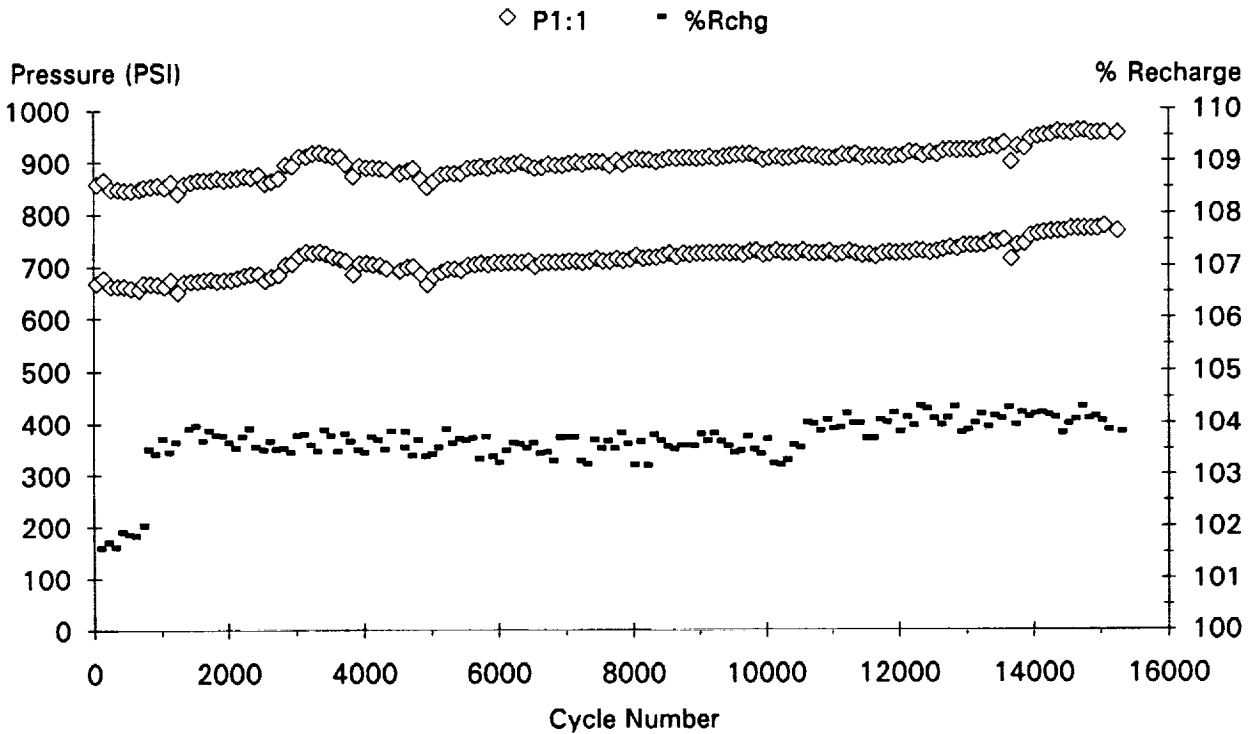
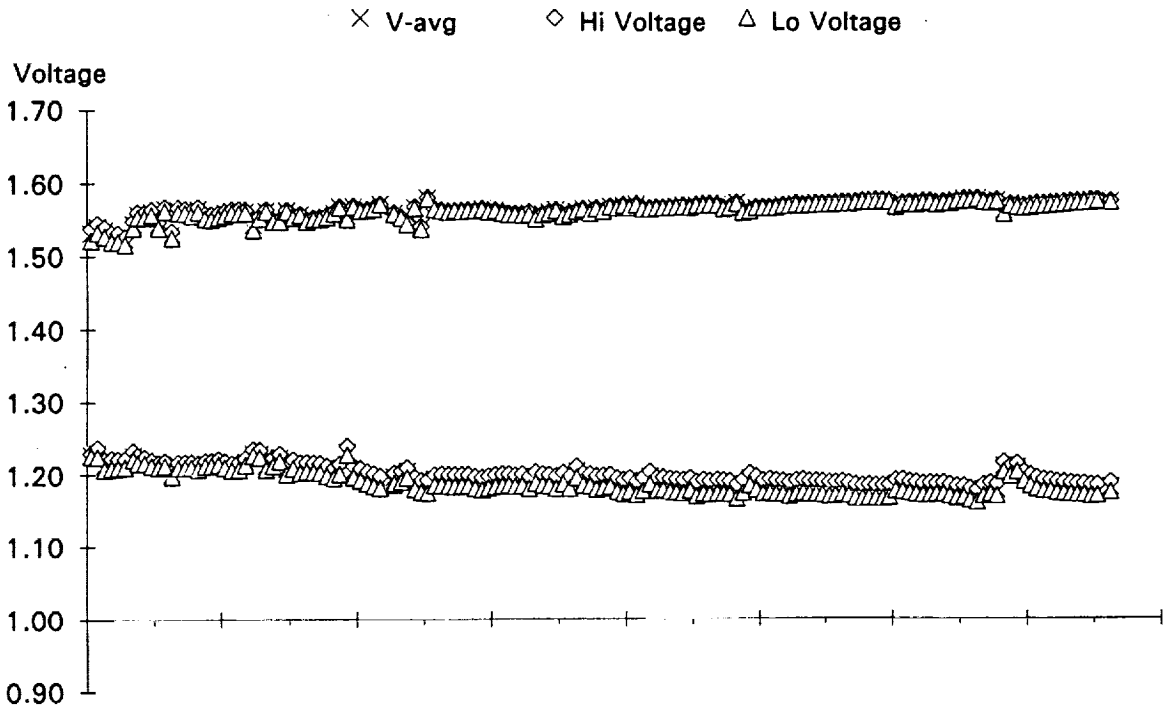
Pack ID 5735W

5 cells

Voltage/Pressure/Recharge EOC/EOD Trend Plot

12/14/90 - 10/03/93

Yardney 65 AmpHr 35% DOD -5 Deg C



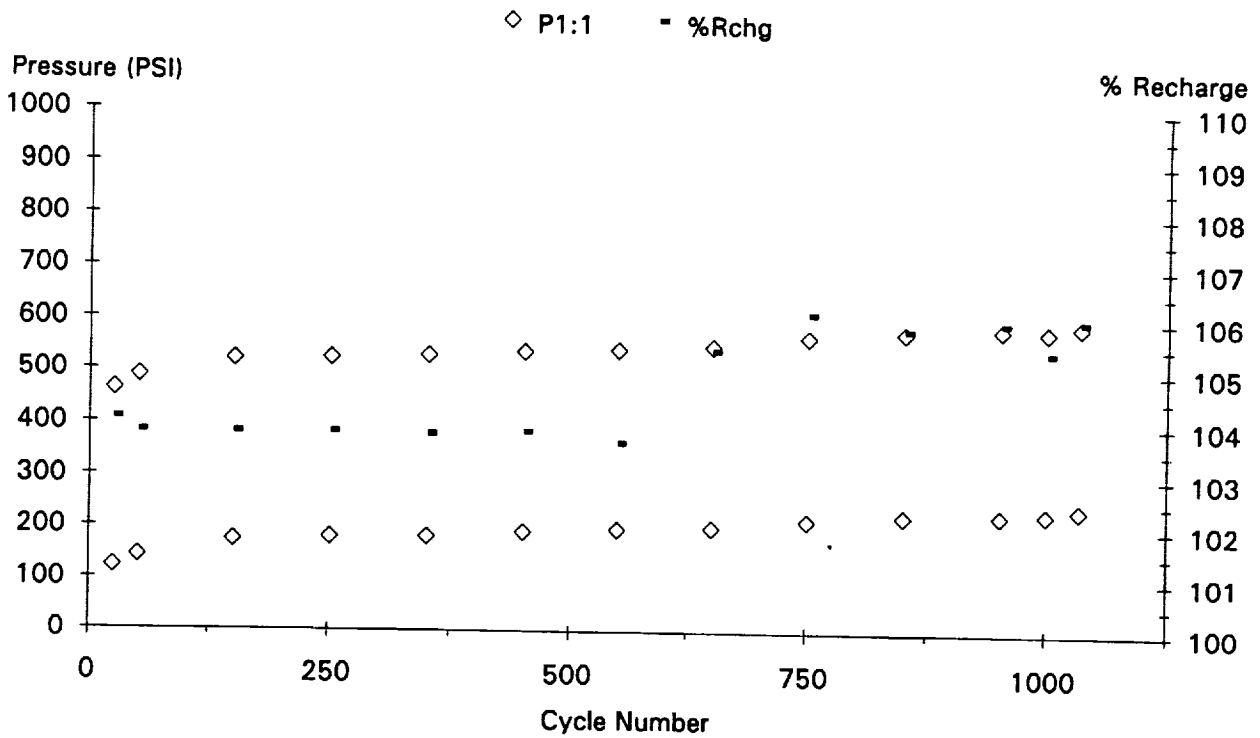
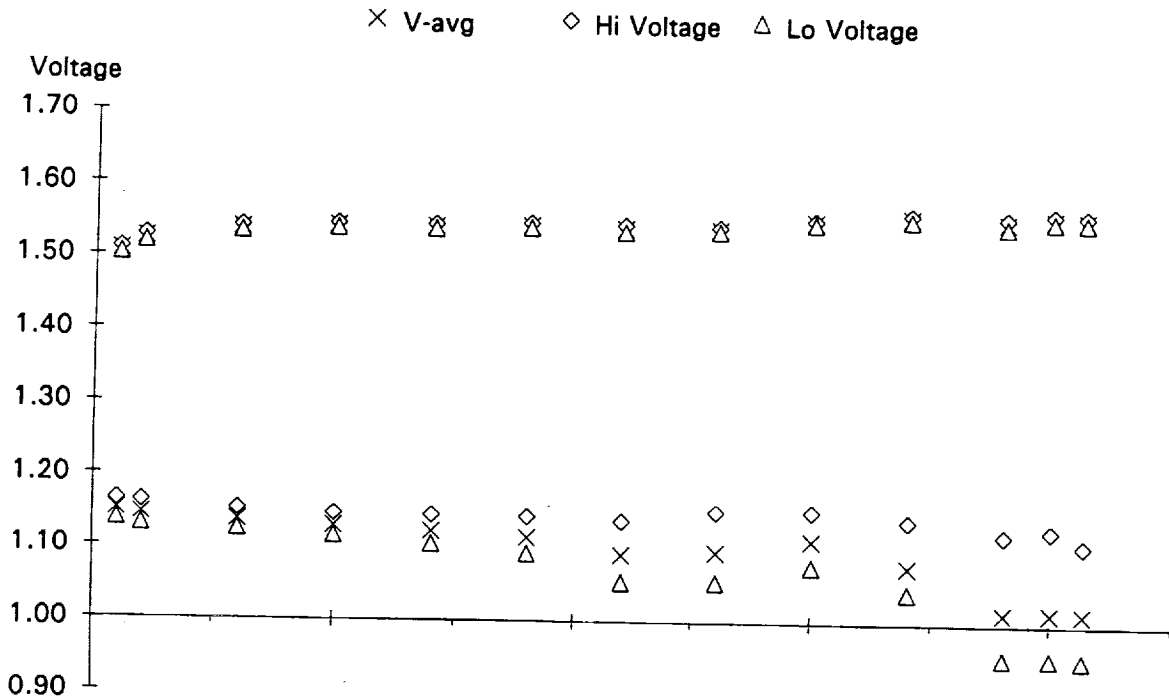
Cycle 1. Started Life Cycle Test.

-37.9A for .6Hr ; 36.0A for .6Hr ; 6.49A for .3Hr ; Rchg = 103.5%

Cycle 10492. Raised Rchg from 103.5% to 104.0%.

-37.9A for .6Hr ; 36.0A for .6Hr ; 6.87 A for .3 Hr

NSWC Crane **Pack ID 5761W** **5 cells**
 Voltage/Pressure/Recharge EOC/EOD Trend Plot 12/13/90 - 03/06/91
 Yardney 65 AmpHr 60% DOD 10 Deg C Test Ended at Cycle 1067



Cycle 1. Started Life Cycle Test.

-65.0A for .6Hr ; 61.75A for .6Hr ; 11.7A for .3Hr ; Rchg = 104.0%

Cycle 650. Raised Rchg from 1.04.0% to 1.06%.

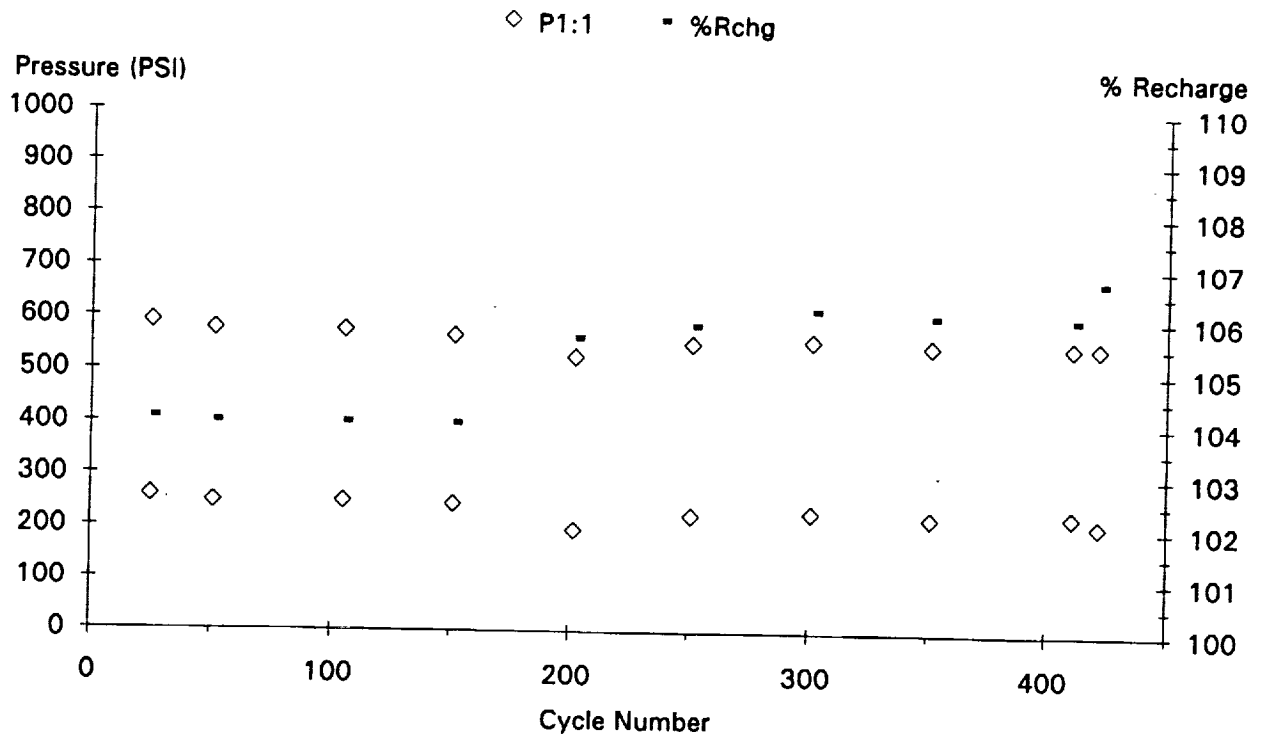
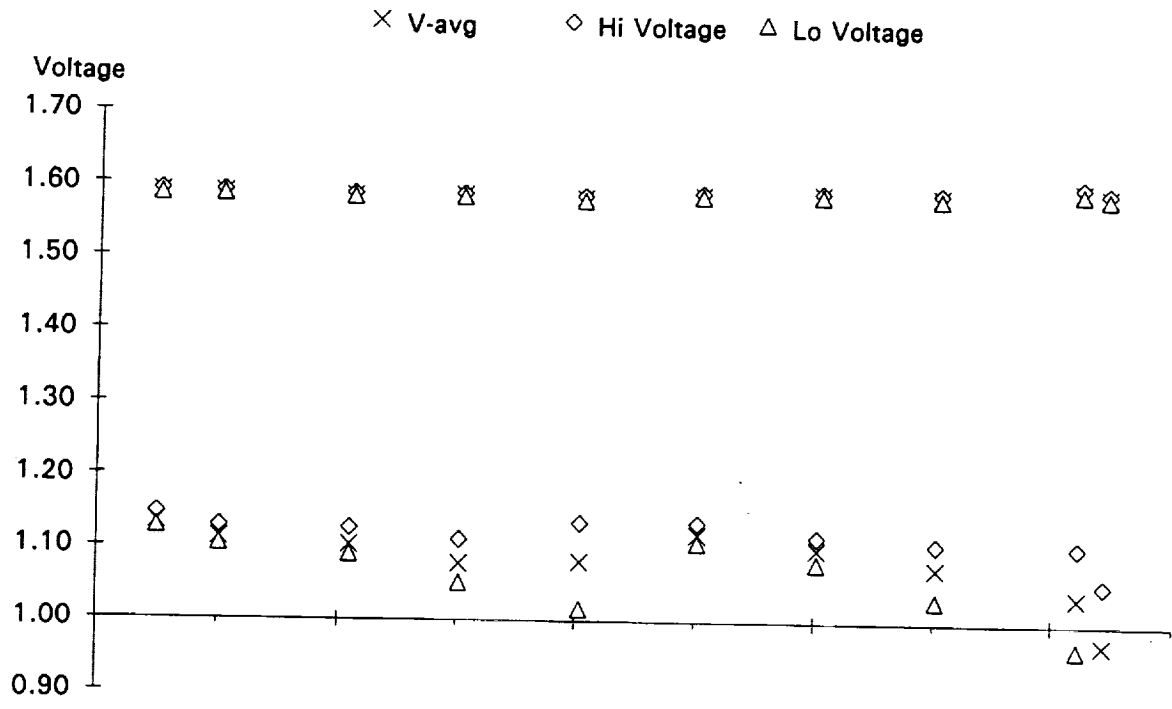
-65.0A for .6Hr ; 61.75A for .6Hr ; 14.3A for .3Hr

Cycle 1004. Pack failed. EOD Pack Average Voltage below 1.0V.

Cycle 1046. Last LEO Cycle.

Cycle 1047-1067. Special testing run on pack to determine post LEO characteristics.

NSWC Crane **Pack ID 5765W** **5 cells**
 Voltage/Pressure/Recharge EOC/EOD Trend Plot 12/14/90 - 02/02/91
 Yardney 65 AmpHr 60% DOD -5 Deg C Test Ended at Cycle 427



Cycle 1. Started Life Cycle Test.

-65.0A for .6Hr ; 61.75A for .6Hr ; 11.7A for .3Hr ; Rchg = 104.0%

Cycle 194. Raised Rchg from 1.04.0% to 1.06%.

-65.0A for .6Hr ; 61.75A for .6Hr ; 14.3A for .3Hr

Cycle 427. Pack failed. EOD Pack Average Voltage below 1.0V. Last

LEO Cycle,

Cycle 428-448. Special testing run on pack to determine post LEO characteristics.

