

## LIFE CYCLE TEST RESULTS OF A BIPOLAR NICKEL HYDROGEN BATTERY

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### ABSTRACT

This paper presents a history of low earth orbit laboratory test data on a 6.5 ampere-hour bipolar nickel hydrogen battery designed and built at the NASA Lewis Research Center. During the past several years the Storage and Thermal Branch has been deeply involved in the design, development, and optimization of nickel hydrogen devices. The bipolar concept is a means of achieving the goal of producing an acceptable battery, of higher energy density, able to withstand the demands of low-earth-orbit regimes.

### INTRODUCTION

Over the past several years the NASA's Lewis Research Center has been actively engaged in the development of a bipolar configured nickel hydrogen battery. Several studies have pointed out that battery simplicity and weight savings can be realized by employing bipolar construction techniques. The actual weight savings compared to conventional nickel hydrogen designs is in the neighborhood of 20 to 30 percent, and is largely dependent on the particular mission and its specific requirements. The aspect of modularity, where the complete system of storage and heat rejection is integrated into one package, provides the ability to accommodate the growing needs of large systems with little or no impact on the whole system.

In August of 1982, a concept verification program was initiated. A 6.5 ampere-hour 10 cell battery was placed on test. The battery was successfully cycled on a low-earth-orbit regime at 80 percent depth-of-discharge for 2000 cycles. At this point the battery was disassembled and components evaluated for early failure mechanisms.

A second battery was assembled in November, 1983 and has now accrued over 4000 low-earth-orbit cycles.

The remainder of this paper will summarize the performance characteristics of this second stack design that is currently under test.

## DESIGN FEATURES

Several special features are found in this battery that are not common to the more conventional nickel hydrogen cells made to date. These features are as follows: electrolyte reservoir plate, that aids in the function of both oxygen and water/electrolyte management; oxygen recombination sites other than the hydrogen electrode (Ref. 1). Figure 1 shows the layout of the cell components.

Some components and the method of electrolyte activation were changed from the first battery built and the one currently on test. Table I displays these modifications. These changes were made as a result of the teardown analysis performed on Build I (Ref. 2) and the battery performance during those 2000 cycles. For example, the chemically impregnated nickel electrode expanded about 50% in thickness. The bipolar plate was edge coated with teflon to eliminate shunt currents that developed within the manifolds after 1000 cycles in the first stack. The activation process was changed because the vacuum backfill method was difficult to carry out and posed problems in electrolyte clean up.

## TEST DATA

The stack was assembled in November of 1983. A series of formation tests were performed to establish an actual battery capacity. The charge ampere-hour input was increased from 8.6 Ah to 9.6 Ah over 13 cycles, charging at 3.75 A for appropriate times. The discharge current, 1.875 A remained the same for each discharge. The ampere-hours discharged to 0.5 V (lowest cell) increased from 7.82 Ah to 8.1 Ah. The nominal capacity asymptotically reached 8.1 Ah as the charge ampere-hours was increased. The capacity discharged to 1.0 V of the weakest cell was 7.8 Ah as shown in Table II, and this value was used as "C" for the characterization tests.

The characterization test matrix contained charge rates of C/4, C/2, and C and discharge rates of C/4, C/2, C and 2C, as well as one 10C discharge. The results are shown on Figure 2 and compared to similar results of Build I.

LEO cycling to 80 percent depth (based on the 1.6C rate capacity of figure 2) at the 9.6A rate was started following the characterization tests. Twenty cycles were performed with decreasing end-of-discharge (EOD) voltages. A decision was made to pull a vacuum on the vessel. A hard vacuum was pulled on the vessel because we had not done this prior to pressuring the vessel with hydrogen. During Build I we found electrolyte in the vessel and thought that evacuating the air from the vessel prior to the hydrogen fill expelled

electrolyte from the stack. The battery EOD voltage increased by 1.0 volts as shown in Figure 2. The vacuum was thought to have relocated some electrolyte into the smaller pores and into the hydrogen electrode. The battery degraded about 0.5 volts in fifty cycles and then stabilized. The stack was removed from the vessel and vacuum back filled with electrolyte. This procedure had a longer lasting effect on EOD performance; however, voltages were still degrading.

The performance of Build II was not as good as Build I. Some design changes had been made as indicated in Table I. At this point it was decided to rebuild cells 1, 2 and 3 to try to determine the effects of the changes that had been made.

Cell 1 received all new components. The hydrogen and nickel electrode were vacuum filled prior to assembly and 21 mils of separator was used. Cell 2 only received a vacuum filled hydrogen electrode and 14 mils of separator. Cell 3 got a change of separator from 14 mils to 21 mils. These modifications were made in an attempt to isolate the design changes that were not improvements. However, the following cycle data did not provide a basis for any judgements, other than a vacuum filling of the hydrogen electrodes is necessary. A performance increase was noted in the other 7 cells that were undisturbed.

A performance increase was observed by doing several LEO rate discharges to 0.5 volts of the lowest cell. The deep discharge reconditioning made a significant increase in battery voltage for 20-30 cycles and also decreased the rate of degradation of EOD voltages.

Several times during cycling the stack was deep discharged and electrically shorted out over night. This procedure also provided marked improvements in EOD voltages. Several self-discharge open circuit stands were performed. No shunt currents were observed and a 30 percent loss in the C/4 capacity was recorded in a 3-day period with the hydrogen pressure a constant 400 psi. This proved the teflon edge coating of the bipolar plate provides a means of prohibiting shunt currents from forming.

After 2800 cycles were run, a 4 mil nickel shim was added to each cell. The shim was added to increase the stack component compression. Compression tests on various materials and separator thicknesses indicated that our stack pre-load was not sufficient to compress the separator and provide good contact with the bipolar plate. Table II shows the individual cell voltages for over 300 cycles prior to and after the installation of the shims. It is of interest to note that all the cells had declined in EOD voltage prior to the shim installation; however, six cells increased and four cells decreased in voltage afterward. Again, the results are not clear about the merit of increased compression.

The nickel electrode was removed from cell 10 during the shim installation and replaced with a new electrode. The cycled electrode expanded 3-4 mils or 10 percent of the original thickness, which further increases the compression. It is possible the cells with reduced voltage have been over compressed, which may have forced electrolyte from the active areas.

Table II displays the C/4 capacities measured to 1.0 volts throughout battery cycling. A loss in capacity is noted in all cells. Cell 6 has experienced the greatest decline, 35 percent, while the other cells have degraded about 30 percent. The nickel electrode removed from cell 10 at 2800 cycles measured a loss of about 15 percent in capacity at C/4 rates and 25 percent at the 2 C rate in flooded capacity tests while the electrodes under cell conditions at 3350 cycles showed a 20 percent decrease. In the span of cycles 3100 to 3860 the depth of discharge was adjusted to 70% corresponding to their original capacity as noted in Figure 3. Following the last C/4 capacity discharges at cycle 3906, the depth of discharge was resumed to the 80 percent level. The ampere-hours discharged is almost 90 percent of the actual electrode capacity.

#### CONCLUDING REMARKS

Over 4100 LEO cycles have been established on a ten cell battery. It seems that any perturbation on normal cycling affects the cells performance. Explanations and theories of the battery's behavior are varied and widespread among those closely associated with it. Deep discharging does provide a reconditioning effect and further experimentation is planned in this area.

The battery watt-hour efficiency is about 75 percent and the time averaged, discharge voltage is about 1.26 volts for all cells at both the C/4 and LEO rate.

Since a significant portion of the electrode capacity has degraded, the LEO cycle discharges are approaching depths of 90-100 percent of the high rate capacity. Therefore, the low end-of-discharge voltages occur precipitously after the knee of the discharge curve and is more an indication of electrode capacity and is a lesser indicator of overall cell performance.

## REFERENCES

1. Cataldo, R. L.: Test Results for a Ten Cell Bipolar Nickel-Hydrogen Battery, 18th IECEC Proceedings, NASA TM 83384.
2. Manzo, M. A., Gonzalez-Sanabria, O. D., Herzau, J. S. and Scaglione, L. J.: Teardown Analysis of a Ten Cell Bipolar Nickel-Hydrogen Battery, 19th IECEC Proceedings, NASA TM 83618.

	Build I	Build II	Remarks
Nickel Electrode	Chemically Loaded 2.1g/cc	Electrochemically Loaded 1.6g/cc	Electrode expanded 50%
Hydrogen Electrode	Fuel Cell Type Non-backed	Fuel Cell Type Non-backed	Need to vacuum fill
Separator	Asbestos 21 mils 5% Binder	Asbestos 14 mils 5% Binder	
Electrolyte Reservoir	Nickel Foam	Nickel Foam	
Recombination Sites	H <sub>2</sub> Electrode Open Gortex	H <sub>2</sub> Electrode Sealed Gortex	
Bipolar Plate	Gold Plated Nickel	Gold Removed, Teflon Coated Edges	Shunt currents developed
Activation Process	Vacuum Backfill with KOH Drain	Vacuum Fill Nickel Electrodes; Metered Amount Added to Each Cell	Simplify process

Table I.

CYCLE #	CELL NUMBER									
	1	2	3	4	5	6	7	8	9	10
16 <sup>e</sup>	7.8 <sup>a</sup>	8.0 <sup>b</sup>	8.0 <sup>b</sup>	8.0 <sup>b</sup>	8.0 <sup>b</sup>	8.0 <sup>b</sup>	8.0 <sup>b</sup>	8.0 <sup>b</sup>	8.0 <sup>b</sup>	8.0 <sup>b</sup>
2363 <sup>c</sup>	5.76	5.76	5.73	5.82	5.9	5.7	5.7	5.9	5.6 <sup>a</sup>	5.7
2364 <sup>c</sup>	6.7	6.7	6.3 <sup>a</sup>	6.45	6.74	6.74	7.0	6.9	7.0	7.0
3350 <sup>d</sup>	6.5 <sup>b</sup>	6.34	6.34	6.5 <sup>a</sup>	6.5 <sup>b</sup>	5.93	5.85	6.47	6.5 <sup>b</sup>	6.5 <sup>b</sup>
3862 <sup>d</sup>	5.9 <sup>b</sup>	5.8	5.7 <sup>a</sup>	5.8	5.9 <sup>b</sup>	5.2	5.6	5.7	5.9 <sup>b</sup>	5.9 <sup>b</sup>
390 <sup>b</sup> <sup>d</sup>	5.6 <sup>b</sup>	5.55	5.4 <sup>a</sup>	5.5	5.6 <sup>b</sup>	5.0	5.23	5.3	5.6 <sup>b</sup>	5.6 <sup>b</sup>

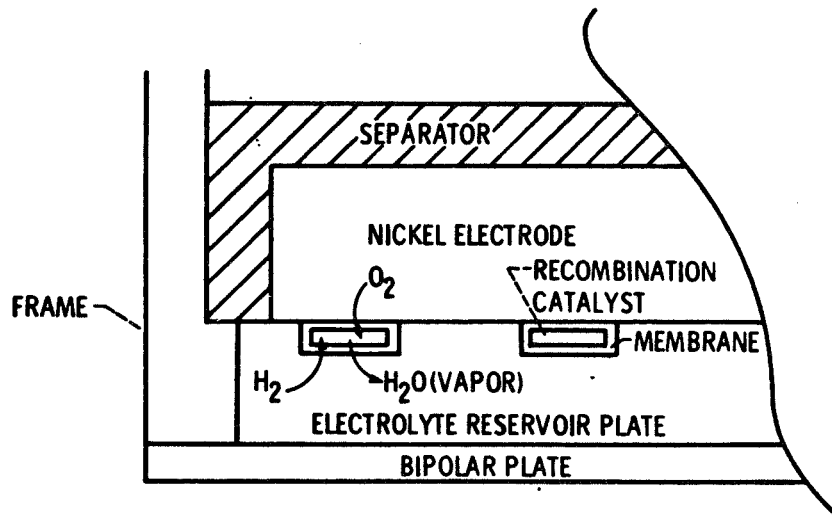
Table II. DISCHARGE CAPACITIES TO 1.0 V AT THE C/4 RATE OF 1.9 A .

- a = first cell to reach 0.5 Volts
- b = cells not reaching 1.0 Volts before event a
- c = charge; 8 A-H; 4 A for 2 Hrs.
- d = charge; normal LEO cycle interruption
- e = charge; 9.1 Ah

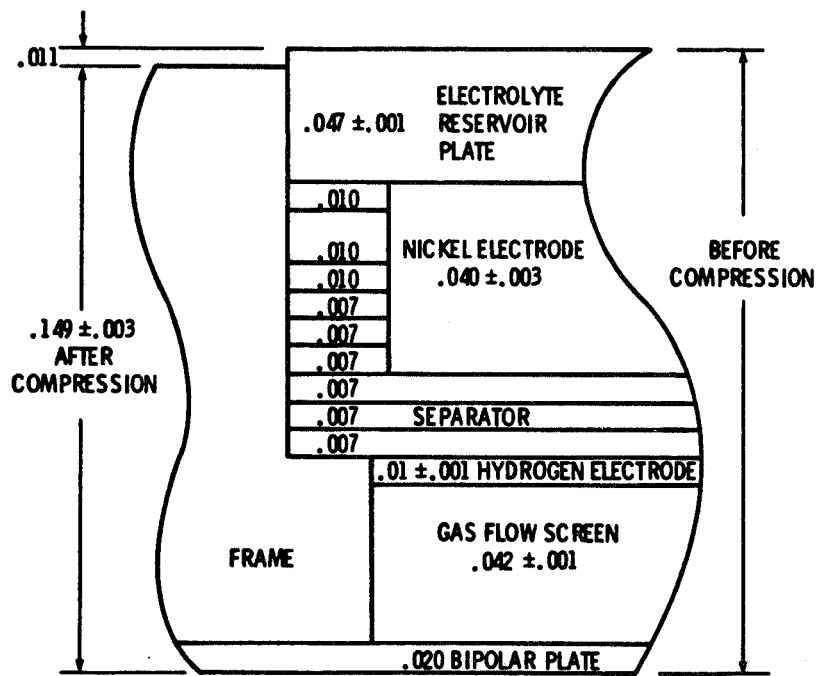


CELL NO	CYCLE NO.					
	2410	2800	ADDED SHIM	2807	3167	
1	1.173	1.129	-.044	1.123	1.162	+.039
2	1.164	1.125	-.039	1.122	1.117	-.005
3	1.156	1.095	-.061	1.096	1.031	-.065
4	1.192	1.145	-.047	1.138	1.158	-.020
5	1.209	1.173	-.036	1.166	1.187	-.021
6	1.175	1.112	-.063	1.102	1.109	-.007
7	1.192	1.139	-.053	1.133	1.026	-.107
8	1.139	1.097	-.042	1.092	1.074	-.018
9	1.186	1.127	-.059	1.125	1.154	-.029
10	1.168	1.121	-.047	1.112	1.178	+.066
NET			-.491			-.013

Table III. CELL VOLTAGES BEFORE AND AFTER ADDING SHIM TO EACH CELL



Graphic representation of oxygen - hydrogen recombination.



Cell cross section with dimensions of components, in.

Figure 1. Cell Component Layout

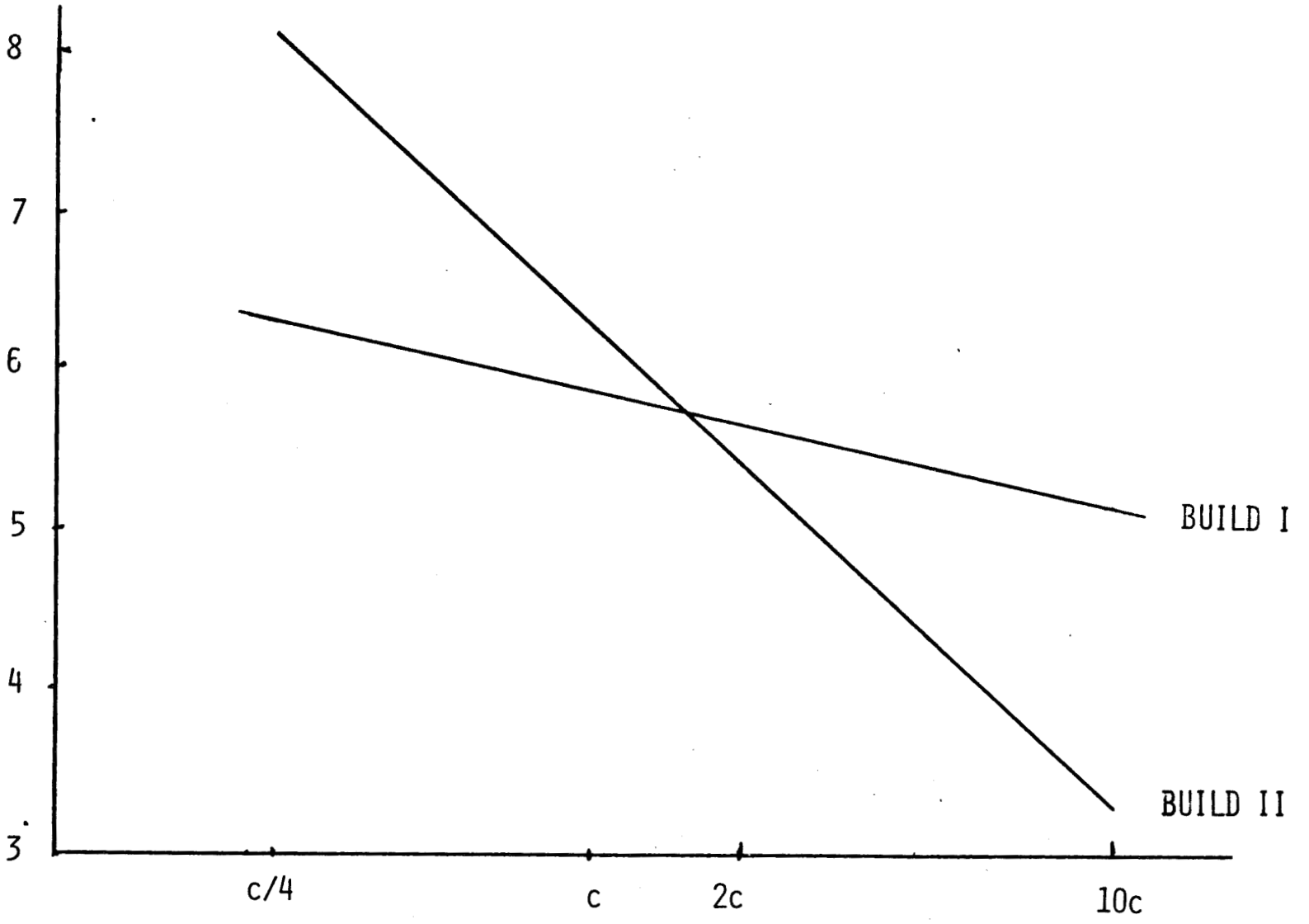


Figure 2. Discharge Capacity vs. Current Rate

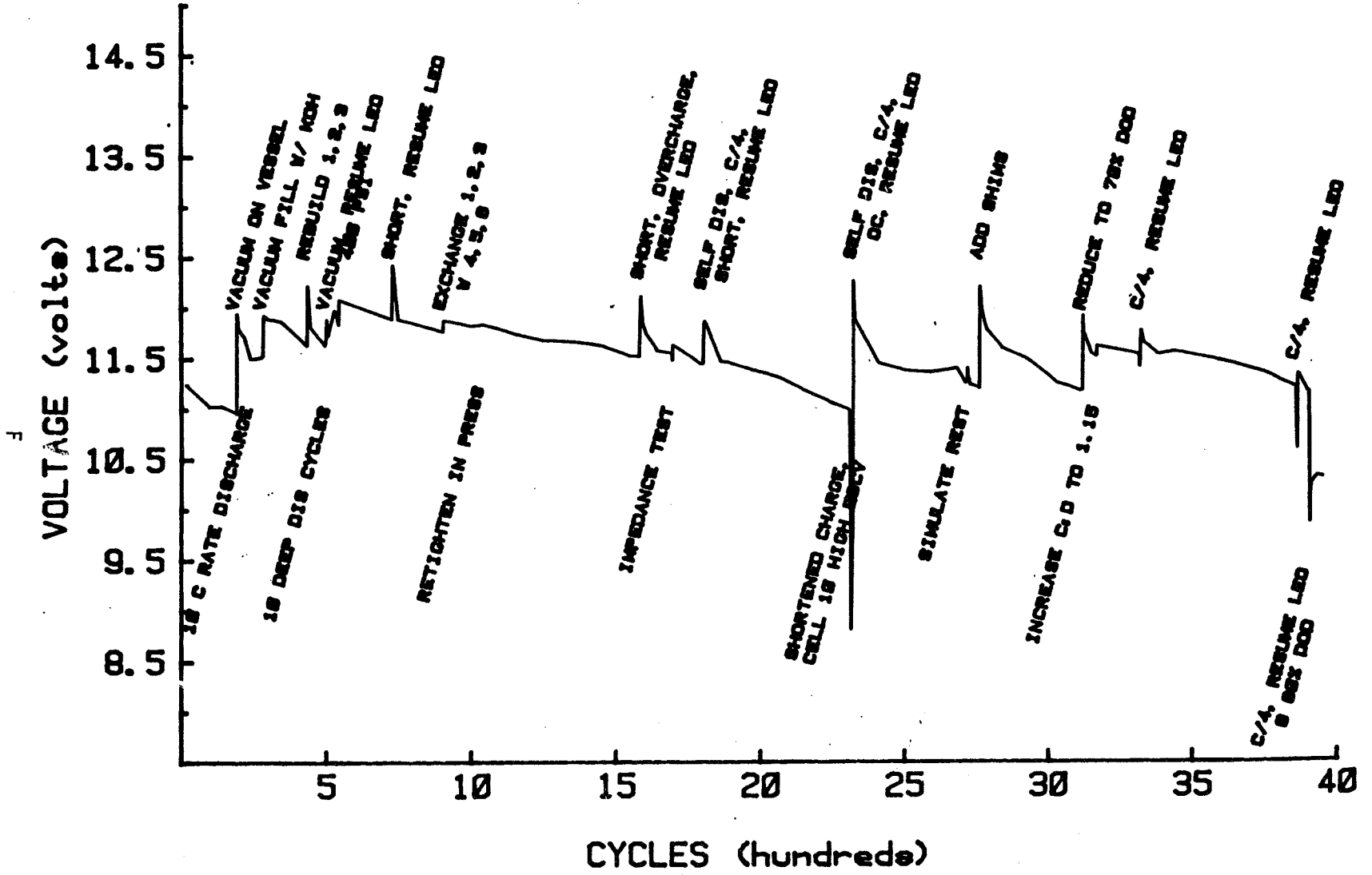


Figure 3. End of Discharge Voltage vs. Cycles for Build II