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**NiH<sub>2</sub> CAPACITY FADE DURING EARLY CYCLING**

**JOHNSON CONTROLS BATTERY GROUP, INC.  
NICKEL HYDROGEN BATTERY DIVISION**

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## GENERAL CAPACITY LOSS OBSERVATIONS

### Terrestrial batteries:

- stored in warehouse for over 18 months
- no capacity loss
- electrodes contain cadmium additive
- electrodes contain no cobalt additive
- discharged to 1.0 volt/cell at C/2 rate prior to storage
- open circuit storage at room temperature

### Initial aerospace batteries:

- stored in warehouse for over 18 months
- no capacity loss
- electrodes contain cobalt/cadmium additive
- discharged to 1.0 volt/cell at C/2 rate prior to storage
- voltage above 1.0 volt/cell at end of stand
- open circuit storage at room temperature

### Recent aerospace batteries:

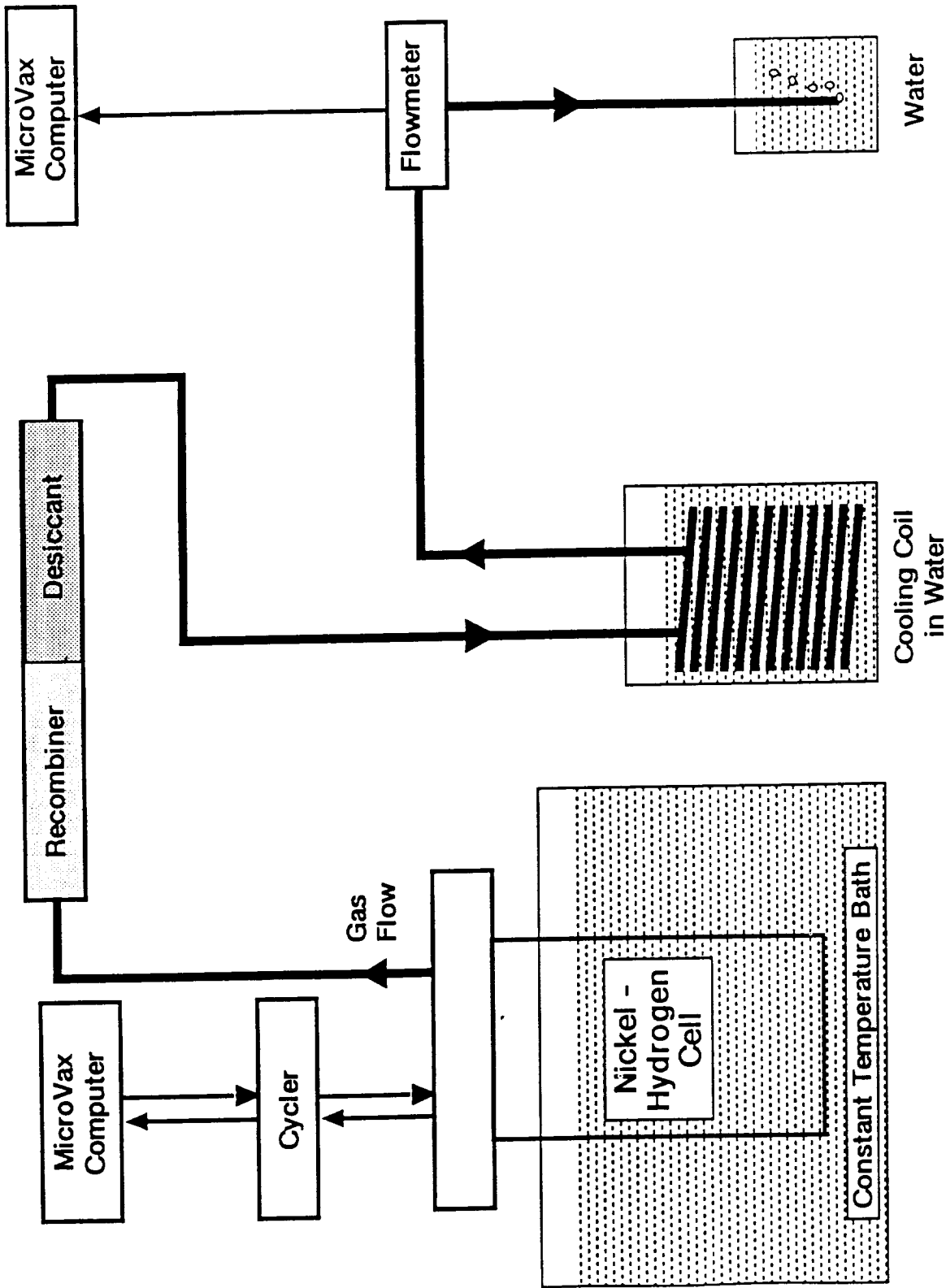
- capacity loss of over 25% seen in 3-8 week storage periods
- electrodes contain all cobalt additive
- shorted to 0 volts prior to storage
- charged stand methods not effective for recovery
- standard LEO or stepped LEO cycling was effective for recovery
- LEO cycling allowed recovery in 30-40 cycles

## **CHARGE EFFICIENCY TEST PROGRAM**

***Experiments were designed to measure the charge efficiency of the nickel electrode as a function of rate and temperature. The test matrix was varied to incorporate both cobalt, cadmium and combinations of the two nickel electrode additives. Electrolyte concentration was eliminated as a variable and was held constant at 31% KOH. Three groups of four (4) cells were tested sequentially. Lithium hydroxide was added to the electrolyte in the second set of test cells.***

## CELL ADDITIVE COMPOSITIONS

<u>Cell #</u>	<u>Bath Additive Composition</u>	<u>Electrode Additive Composition<sup>1</sup></u>
X004	0% Co/10% Cd	0.1% Co/5.6% Cd
X007	10% Co/0% Cd	10.6% Co/0.1% Cd
X010	3.3% Co/6.7% Cd	4.1% Co/3.3% Cd
X013	6.7% Co/3.3% Cd	7.1% Co/1.8% Cd



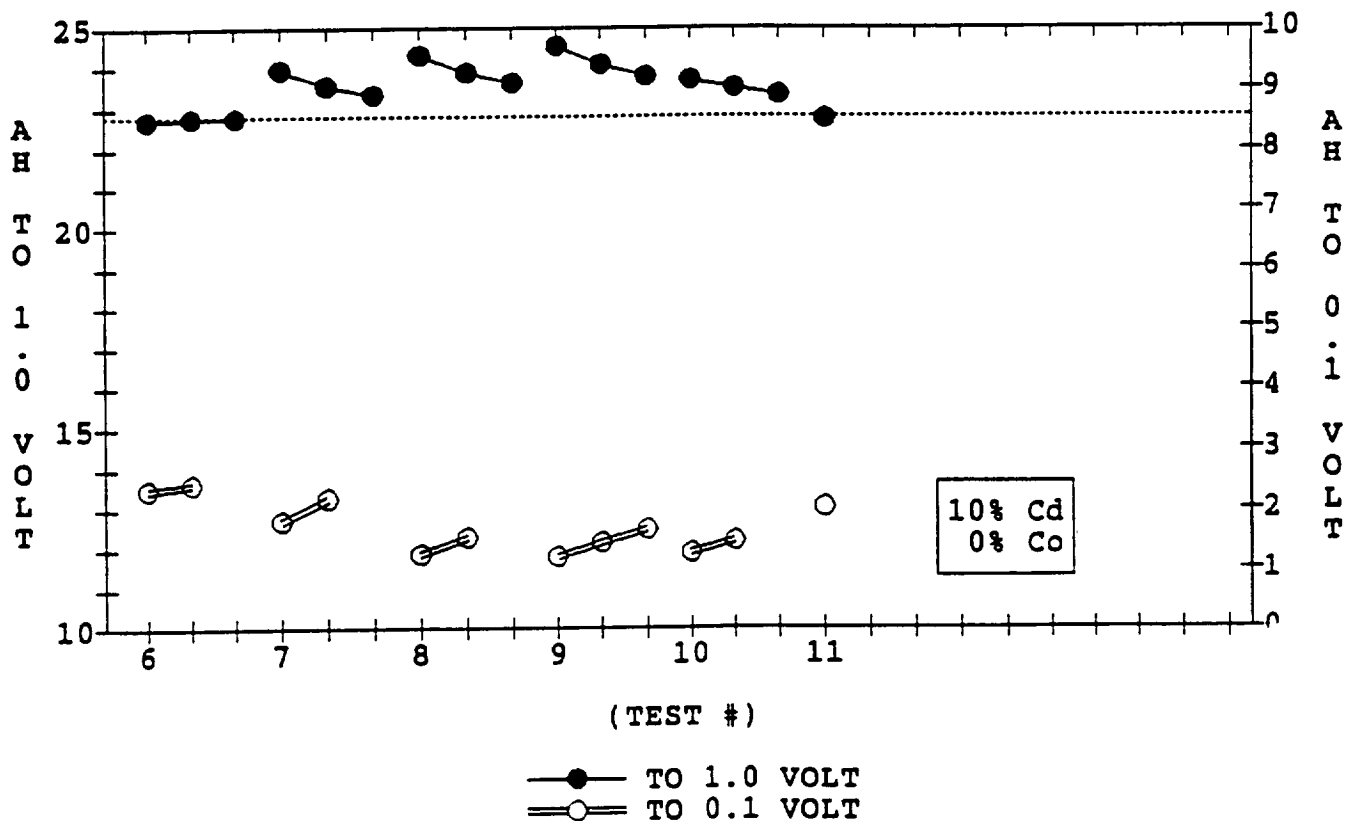
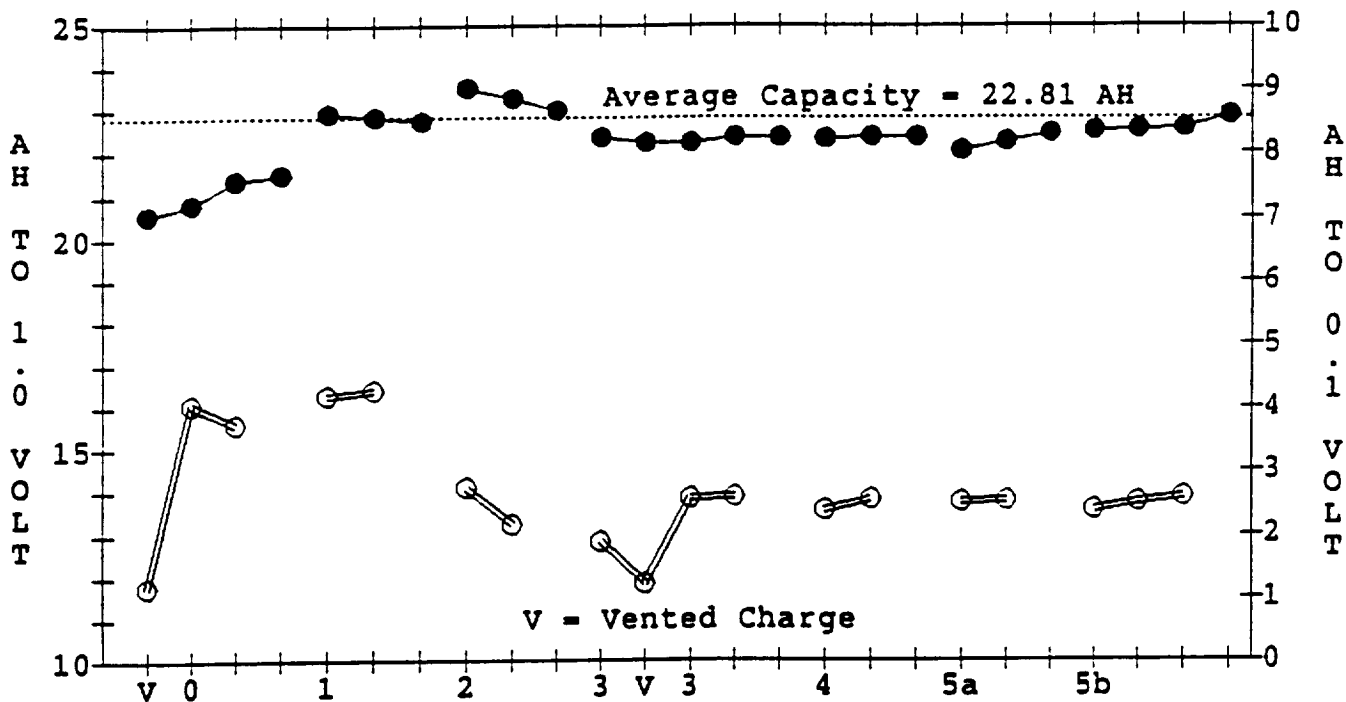
# Experimental Set-Up to Measure Charging Efficiency

## TESTING SEQUENCE

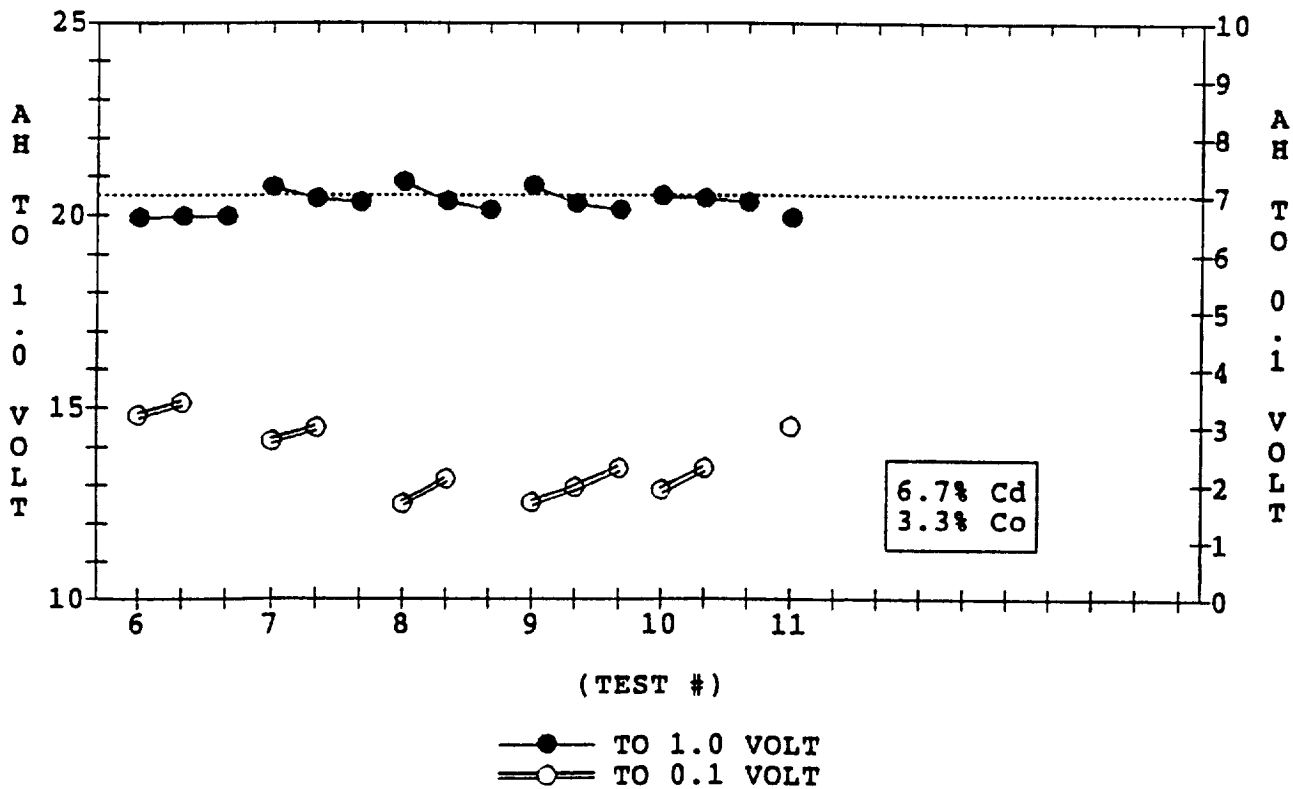
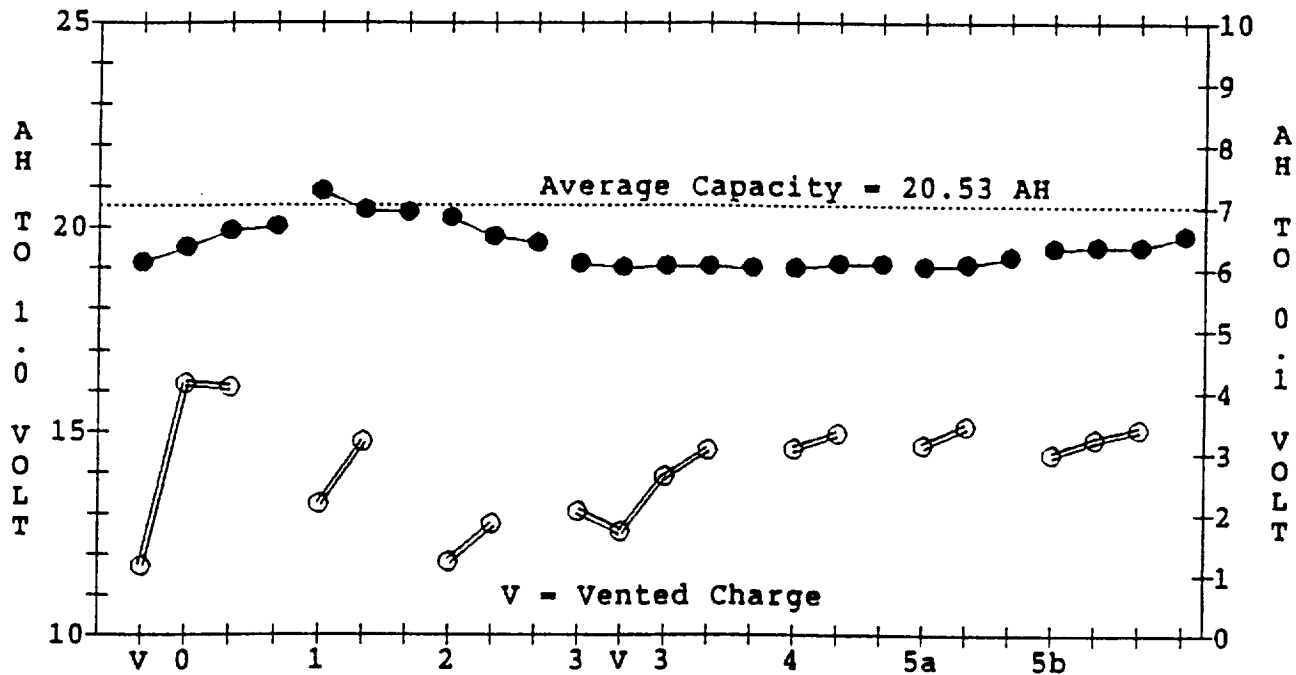
*After assembly, each cell completed a routine condition/ activation cycle regime followed by a two (2) week LEO cycle period designed to stabilize performance.*

*Prior to testing and after each efficiency test the cells were characterized by three charge/discharge cycles at 10° C to determine how the prior test had affected capacity and also to bring the cells to a reproducible state of charge before the next efficiency test. The first two cycles consisted of a C/10 charge for 16 hours followed by a 10A (~C/2) discharge to 1.0 volt and a 4.78 A discharge to 0.1 volt. On the third discharge the cells were only discharged to 1.0 volt and allowed to remain on open circuit.*

DISCHARGE CAPACITY OF TEST CELL X004 DURING CHARACTERIZATION. T = 10 DEGREES C.

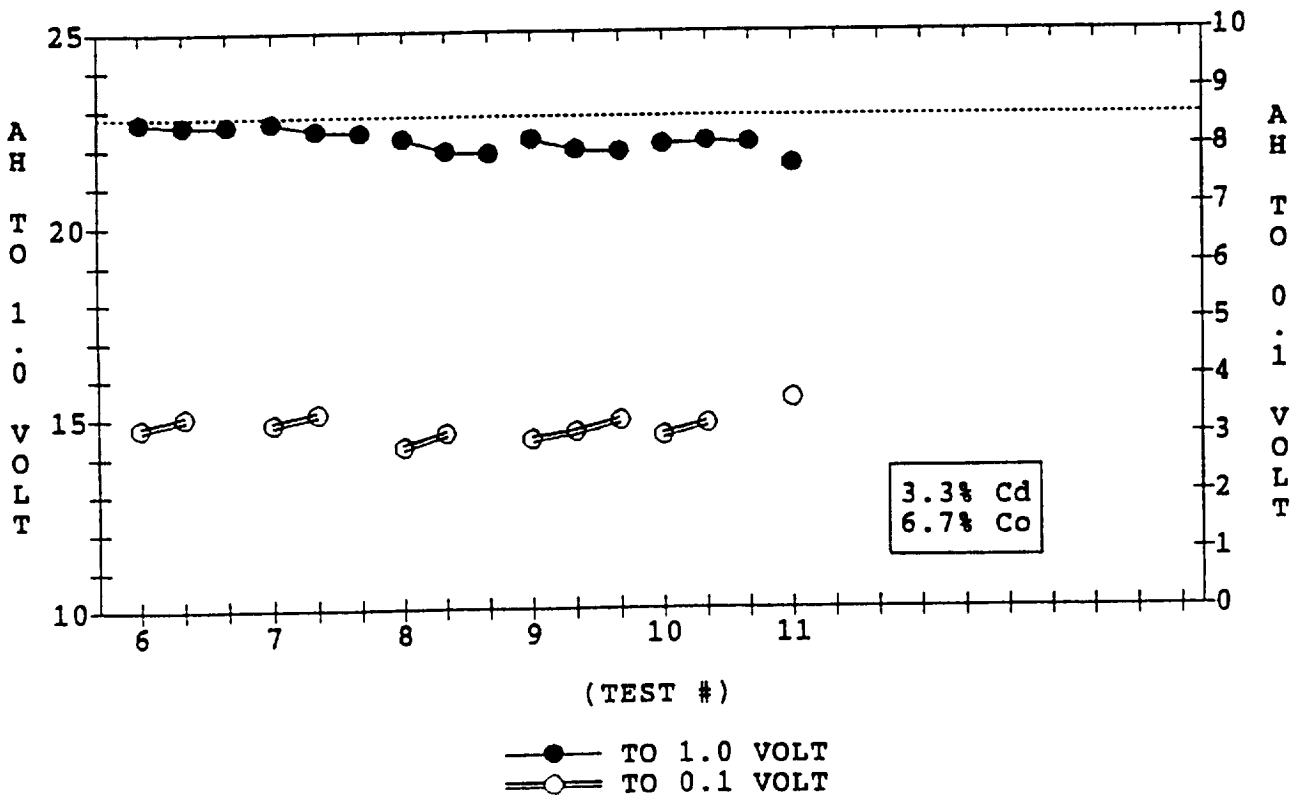
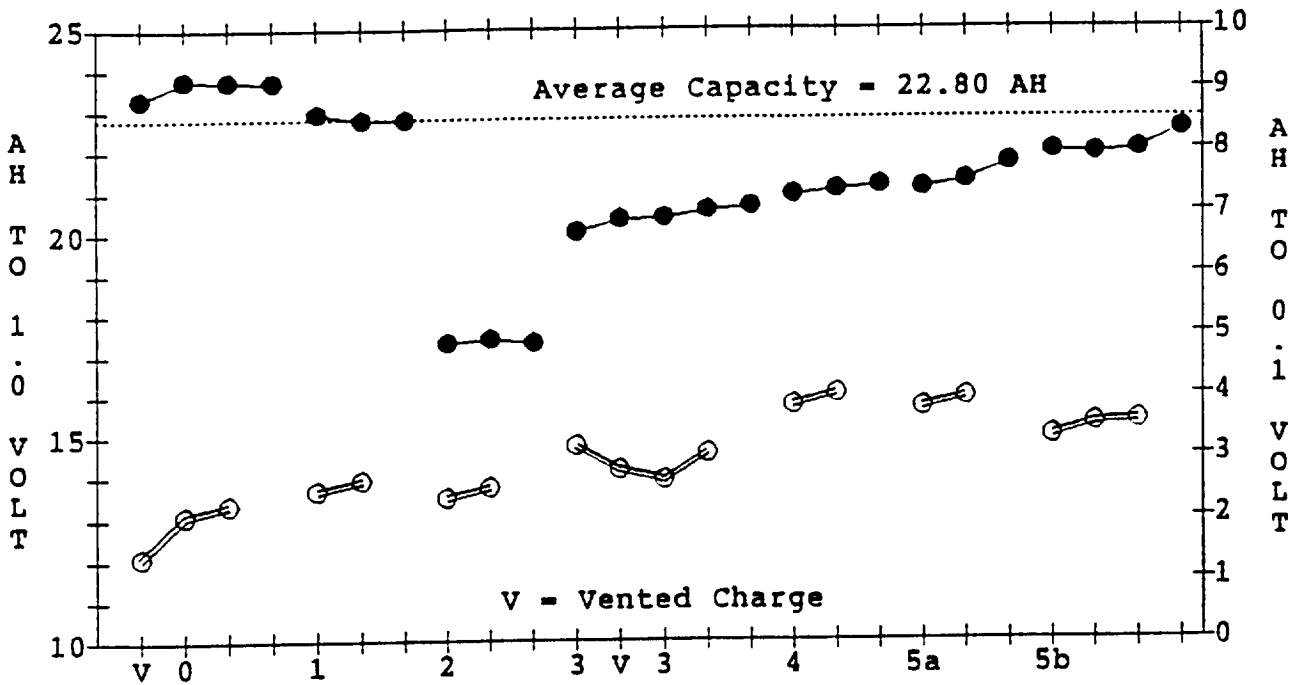


DISCHARGE CAPACITY OF TEST CELL X013 DURING CHARACTERIZATION. T = 10 DEGREES C.

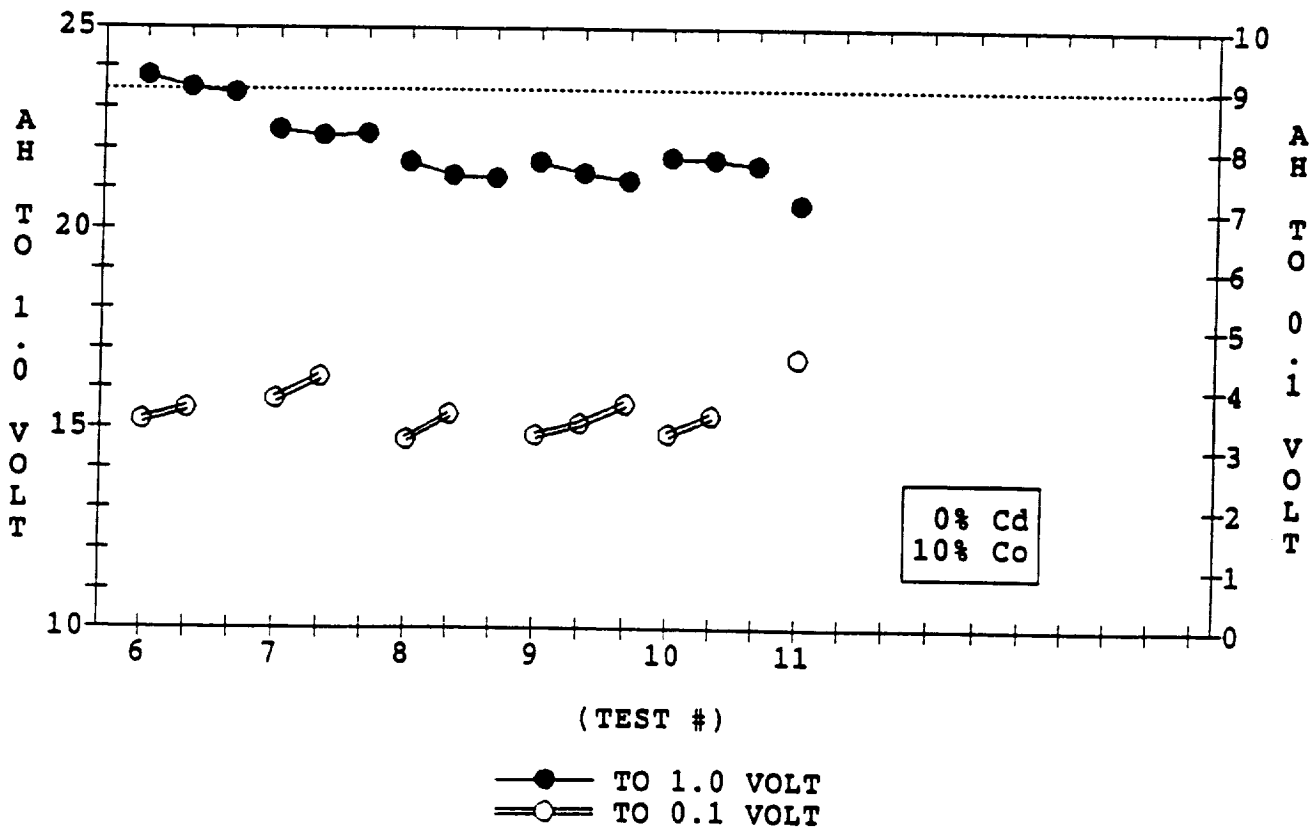
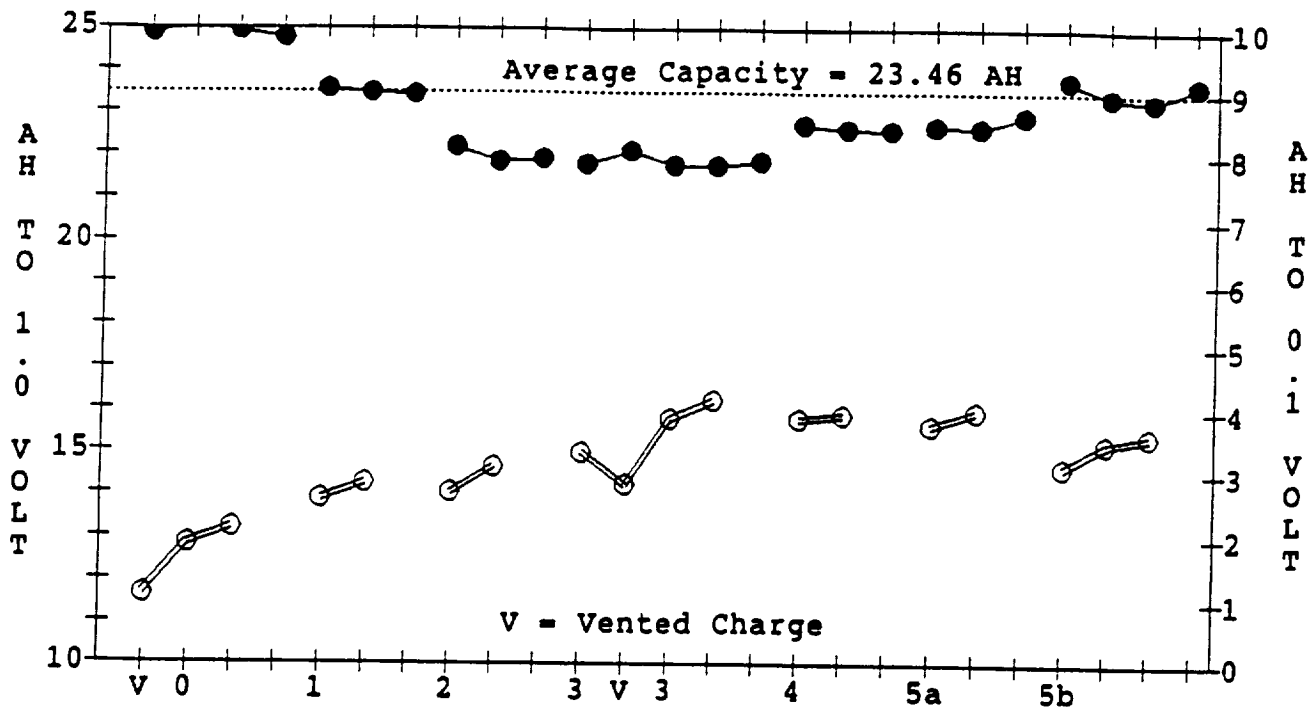




DISCHARGE CAPACITY OF TEST CELL X010 DURING CHARACTERIZATION. T = 10 DEGREES C.



DISCHARGE CAPACITY OF TEST CELL X007 DURING CHARACTERIZATION. T = 10 DEGREES C.



# DEFINITION OF CAPACITY FADE TEST

Three capacity check cycles run at 10°C and 23°C before initiating test.

Stand at room temperature, open-circuit, 50 psig hydrogen.

Prior to the first stand cells were discharged at C/2 rate to 1.0 volt/cell

First stand was 48 days duration (open circuit voltages were steady in the 1.2-1.3 volt range for all cells except X004 throughout the stand).

Cell X004 started stand at 1.3 volts but dropped suddenly to 0 volts after 27 days. Cell behaved normally in capacity cycling following the stand.

Prior to the second stand cells were discharged at C/2 rate to 0.5 volt/cell then shorted across a 1-ohm resistor for 16 hours.

Second stand was 40 days duration (all cell voltages were steady at 0 volts throughout).

Cell X007 did not recover from the second stand. Voltage behavior on subsequent charge attempts suggests that cell is shorted.

## CAPACITY FADE TEST RESULTS

	0% Co/10% Cd	10% Co/0% Cd	3.3% Co/6.7% Cd	6.7% Co/3.3% Cd
Cell:	X004	X007	X010	X013
	<u>10°C 23°C</u>	<u>10°C 23°C</u>	<u>10°C 23°C</u>	<u>10°C 23°C</u>
Theoretical Ah Capacity <sup>1</sup> :	23.9	23.8	24.0	23.9
Initial Test				
Ah capacity to 0.5 volt:	24.0 23.4	23.9 20.7	24.3 21.8	21.9 19.7
Utilization:	100% 98%	100% 87%	101% 91%	91% 82%
Following First Stand <sup>2</sup>				
Ah capacity to 0.5 volt:	25.5 25.4	26.4 22.1	27.4 23.0	25.7 22.4
Utilization:	107% 106%	111% 93%	114% 96%	108% 94%
% change from previous test:	+6% +9%	+10% +7%	+13% +6%	+17% +14%
Following Second Stand <sup>3</sup>				
Ah to 0.5 volt:	25.8 24.6	--- ---	25.5 21.3	24.5 21.1
Utilization:	108% 103%	--- ---	106% 89%	103% 88%
% change from previous test:	+1% -3%	--- ---	-7% -7%	-5% -6%
% change from initial test:	+4% +5%	--- ---	+5% -2%	+12% +7%

<sup>1</sup>Based on weight gain from total active material.  
<sup>2</sup>248-day stand following C/2 discharge to 1.0 volt cut-off.  
<sup>3</sup>340-day stand following shorting cells to 0 volts.