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ELECTRONICS DIVISION
Joplin, MO

ADVANCED SYSTEMS OPERATION

CPV Designs Developed and Tested

Technology Update

Nickel-Hydrogen Common Pressure Vessel (CPV) 2.5V Twin Stack Cell Designs

Tim Harvey and Lee Miller
EAGLE-PICHER INDUSTRIES, INC.
Joplin, Missouri

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Common Pressure Vessel (CPV) 2.5 Volt (2 Stack) Technology

** Dual cell CPV batteries represent a 30% reduction in volume, approximately a 7% reduction in mass, and approximately a 50% reduction in mounting footprint when compared with an equivalent battery of IPV cells of like capacity (higher gravimetric and volumetric energy density results).

** Reduced conductor "IR" loss due to shorter internal series connections than if cells were IPV with external connections (at battery level only half the number of intercell connections required).

** Low voltages associated with two (2) electrode stack design (2.5 volts) minimizes potential for electrolyte "bridging" or communication.

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Common Pressure Vessel (CPV) 2.5 Volt (2 Stack) Technology (cont.)

** Very low risk approach to CPV technology, components are flight tested through the IPV heritage.

** Improvements suggested for IPV designs, such as reduced platinum catalyst electrodes and alternative separators can be equally applied to CPV cells.

**The factor of possible cost savings represented by the CPV design in conjunction with Eagle-Picher's range of lower cost 5-20 A-hr. cells makes this design particularly attractive for "small-sat" and commercial applications.

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CPV (2.5 V) vs. IPV: "Same Energy" Analysis (Cell Level)

1. Example: 80 Ah (IPV) vs. 40 Ah (CPV)
2. Discharge:

	Rate C/2	Ah	Energy
IPV	40 A	80.0 Ah	102.4 Wh
CPV	0 A	40.0 Ah	102.4 Wh

3. Reduced rate results in reduction in current conductor mass required.
4. Cell Mass Comparison:
   80 Ah (IPV) = 1960 grams
   40 Ah (CPV) = 1840 grams
   **Difference due to reduction in current conductor mass.
5. Energy Density (gravimetric) Comparison:
   80 Ah (IPV) = 52.2 Wh/kg
   40 Ah (CPV) = 55.6 Wh/kg

CPV (2.5 V) vs. IPV: "Same Energy" Analysis (Battery Level)

1. Example: 28 cell/80 Ah (IPV) vs. 28 cell/40 Ah (CPV)
2. Wiring Configuration:

   IPV = **One** 28 cell series string = 80 Ah and 2.9 kWh
   CPV = **Two** 14 cell series strings connected in parallel = 80 Ah and 2.9 kWh
3. Assume a two (2) battery spacecraft in which an open string failure occurs:

   IPV = 50% Capacity Loss
   CPV = 25% Capacity Loss

CPV (2.5 V) vs. IPV: "Same Energy" Analysis (Battery Level) (cont.)

4. Given this difference in reliability equip the IPV battery with diodes:

	Mass		Energy Density (gravimetric)
IPV	66.3	kg (w/diodes) per batt.	43.7 Wh/kg
CPV	60.6	kg (no diodes) per batt.	47.8 Wh/kg

5.7 kg difference of which 1.68 kg is due to diodes. The remaining wt. savings is due to conductor mass reduction.

6. The mass savings achieved per two (2) battery spacecraft without significant mechanical design or cost impact: **11.4 kg**

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CPV Design Comparison

	RNHC-6-1	RNHC-12-1	RNHC-35-9	RNHC-40-3 (Proto.)
Design:	Two 6 Ahr Stacks In Series	Two 12 Ahr Stacks In Series	Two 35 Ahr Stacks In Series	Two 40 Ahr Stacks In Series
Rated Cap. (C):	6 Ah	12 Ah	35 Ah	40 Ah
Positive Electrodes:		Same Standard Technology		
# of Pos. Elect. Per Stack:	10 (2.4" dia.)	10 (3.4" dia.)	26 (3.4" dia.)	32 (3.4" dia.)
Plate Config.:	Mantech	Intelsat	Mantech	Intelsat

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CPV Design Comparison (cont.)

	RNHC-6-1	RNHC-12-1	RNHC-35-9	RNHC-40-3 (Proto.)
Separator:	Zircar	Asbestos	Zircar	Asbestos
Negative Elect.:	------Platinum/Teflon Catalyst Over Patented Nickel Grid ------ w/Reduced Pt			
Electrolyte Management:	Non-Recirc. No Weld Ring	Non-Recirc.	Recirc.	Non-Recirc.
		------Open Spoke Weld Ring------		
Design MEOP:	500 psig	480 psig	950 psig	950 psig

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CPV Designs Developed and Tested

CPV Design Comparison (cont.)

	RNHC-6-1	RNHC-12-1	RNHC-35-9	RNHC-40-3 (Proto.)
Capacity (C/2 Discharge to 2.0 volts, 10 deg. C):	7.6 Ah	15.0 Ah	38.9 Ah	45.4 Ah
Max. Length:	6.75"	9.0"	11.6"	10.0"
Max. Diameter:	2.55"	3.51"	3.51"	3.51"
Cell Mass: (S.G. = Strain Gage)	663 g	1022 g w/S.G.	2000 g w/S.G.	1850 g w/S.G.
Energy Density: (Gravimetric)	28.7 Wh/kg	36.7 Wh/kg	48.6 Wh/kg	61.4 Wh/kg

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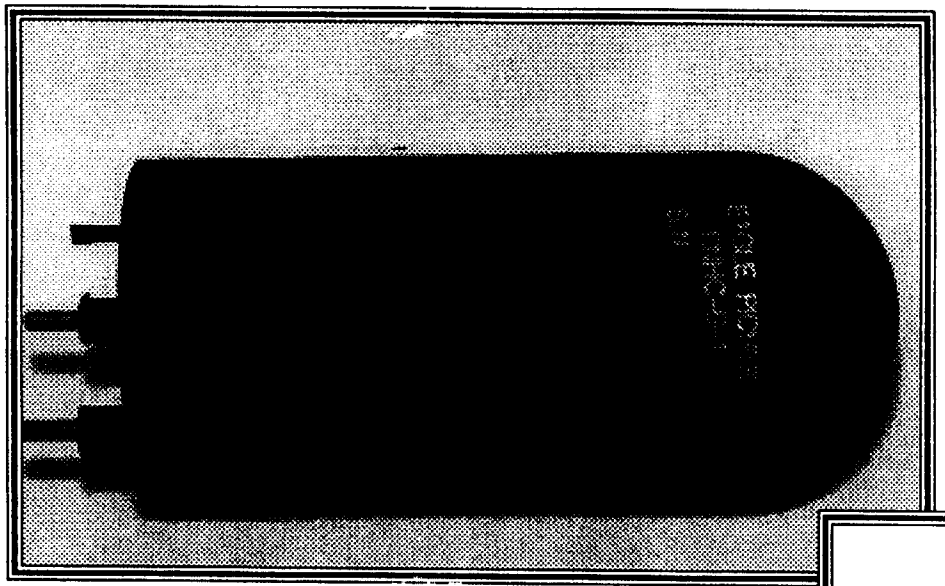
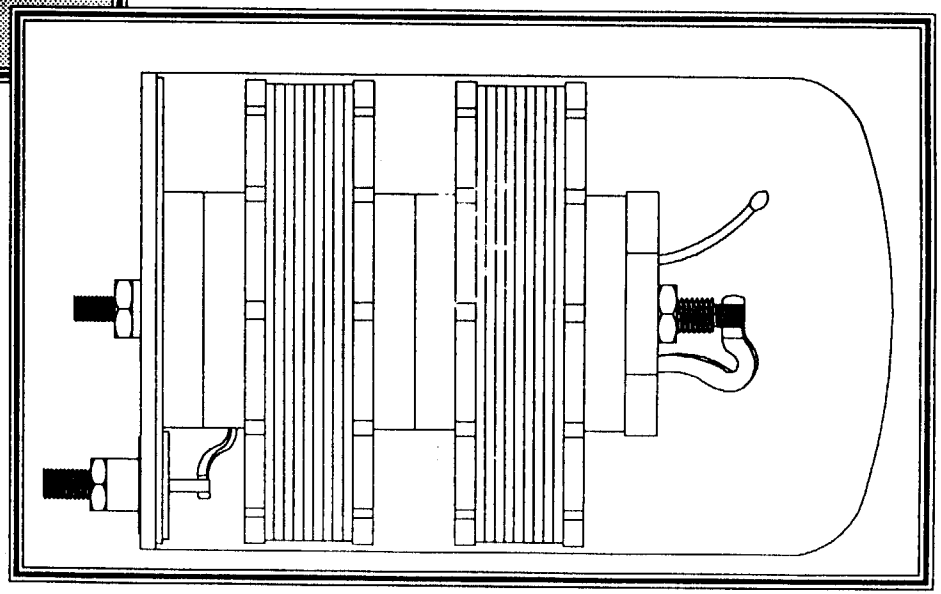


RNHC-6-1
&
RNHC-10-1



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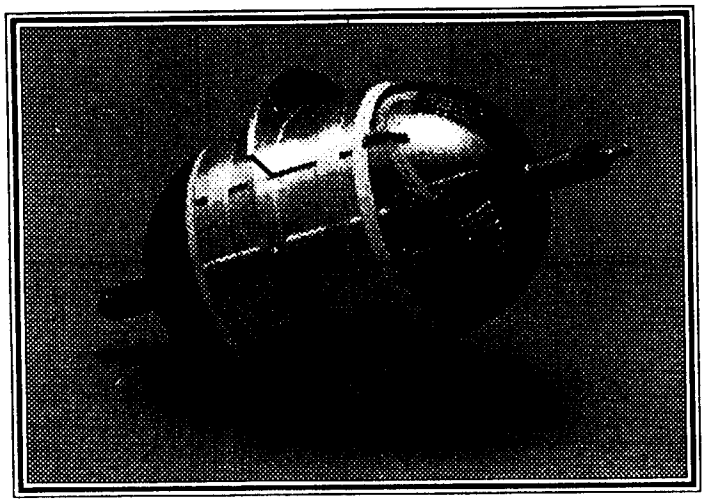
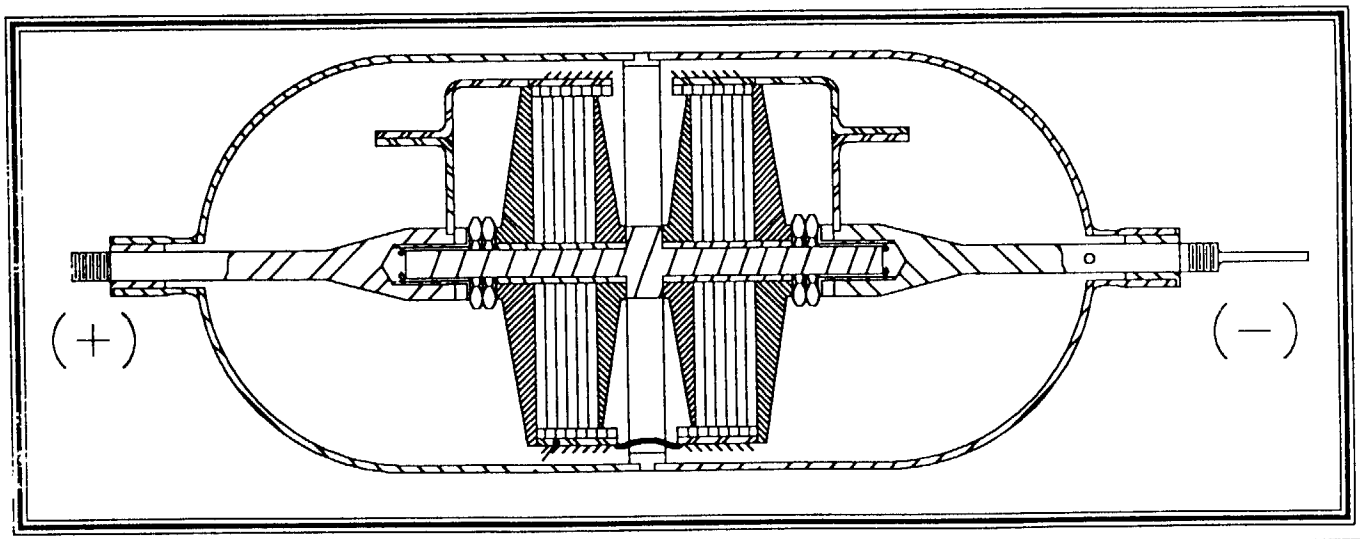


RNHC-12-1



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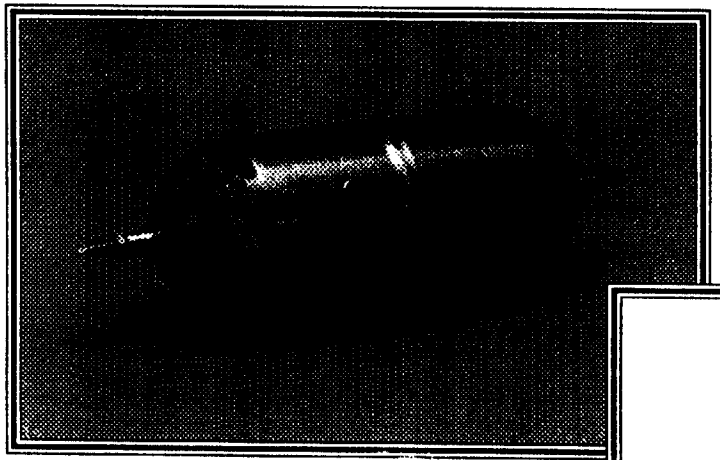

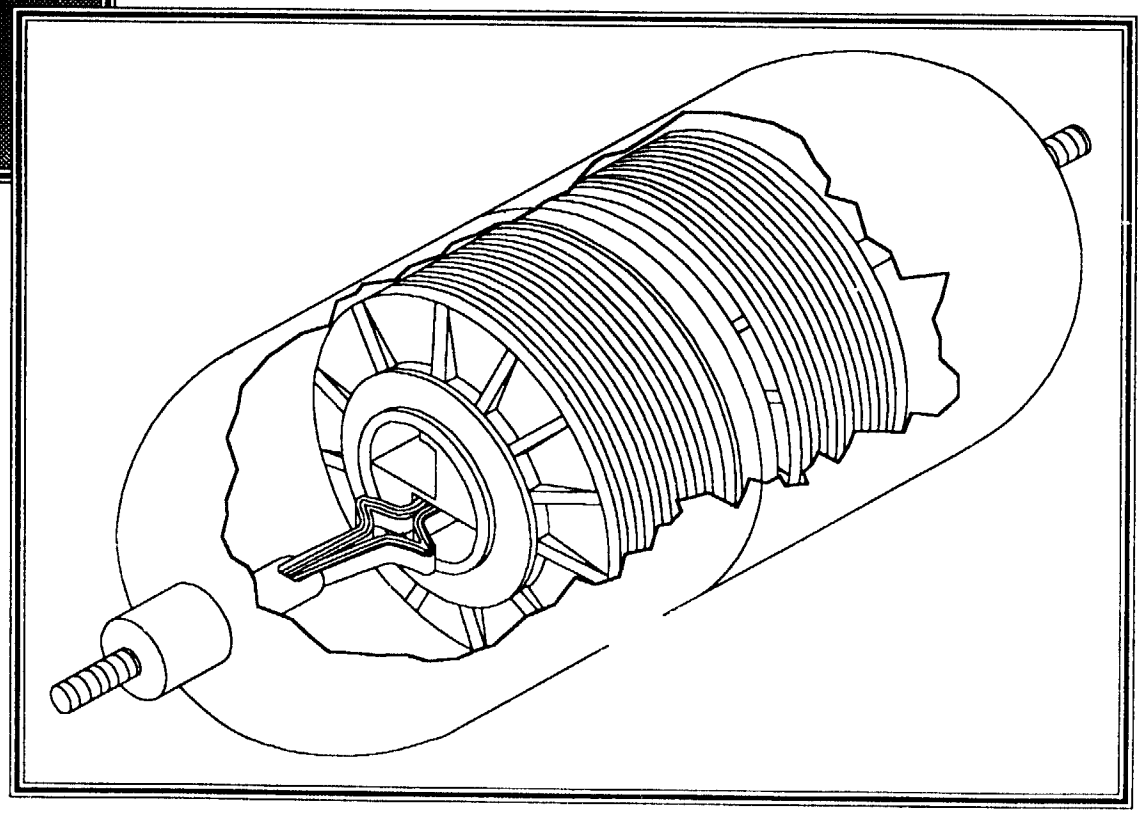

*RNHC-35-9
&
*RNHC-40-3

*See Design Details

CPV Designs Developed and Tested

RNHC-6-1 (CPV): Characterization Testing: Performance Summary

1. -10°C Std. Cap. Test
   Charge 0.6 Amps for 16 hrs.
   Discharge 3.0 Amps to 2.0 V: ..... 7.79 Ah
2. 10°C Std. Cap. Test
   Charge 0.6 Amps for 16 hrs.
   Discharge 3.0 Amps to 2.0 V: ..... 7.64 Ah
3. 10°C **Charge Retention Test**
   Charge 0.6 Amps for 16 hrs.
   72 hr. OCV
   Discharge 3.0 Amps to 2.0 V: ..... 6.60 Ah
   % Retention Compared to #2.: 86.4%
4. Life Test: RNHC-10-1: ..... 3300 40% DOD Cycles As of 11-1-91

See plots to follow

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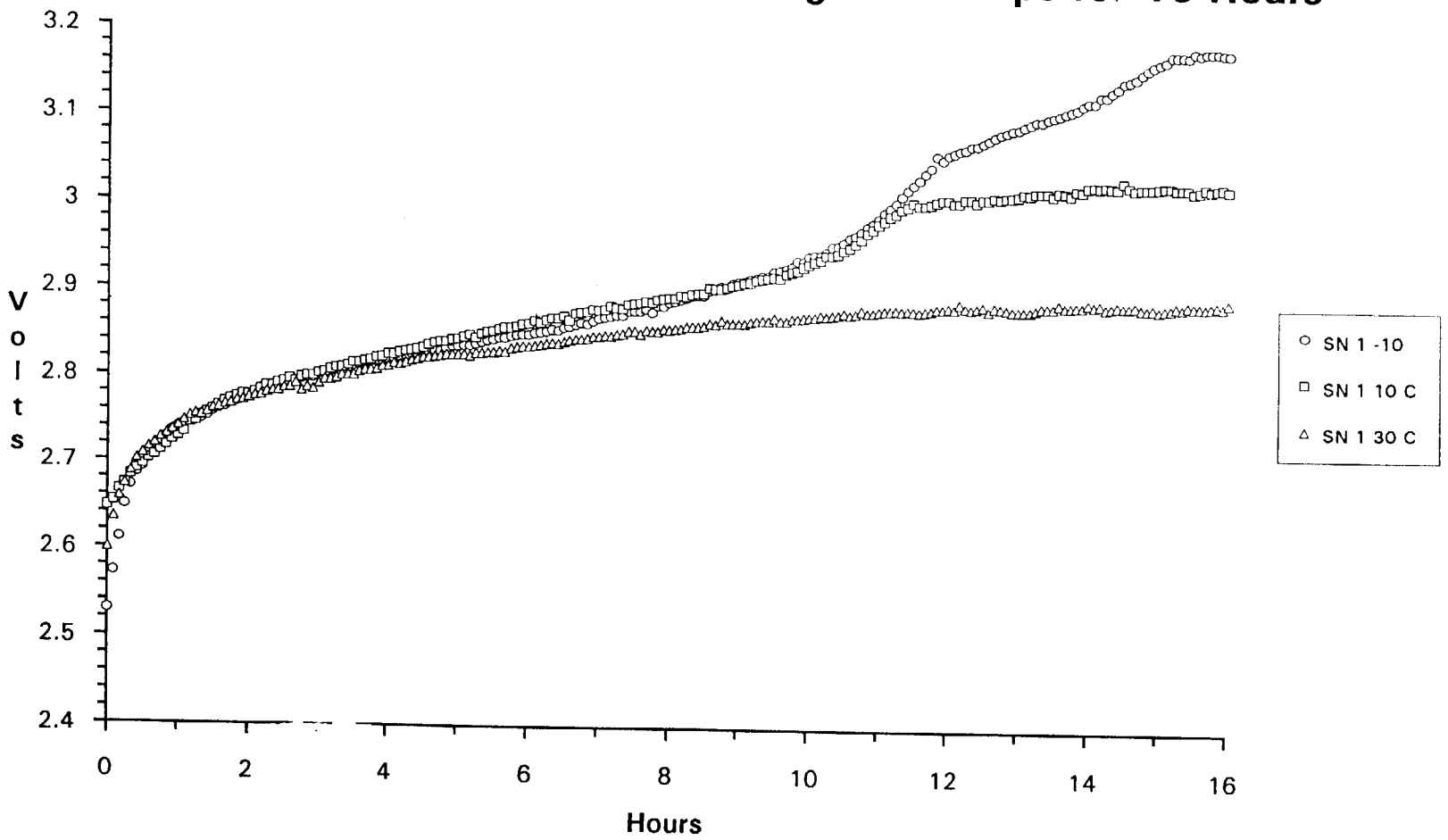
CPV Designs Developed and Tested

RNHC-6-1 (CPV) Characterization Tests: Comparison of Charge Voltage: -10°, 10° & 30°C: Charge 0.6 Amps for 16 Hours



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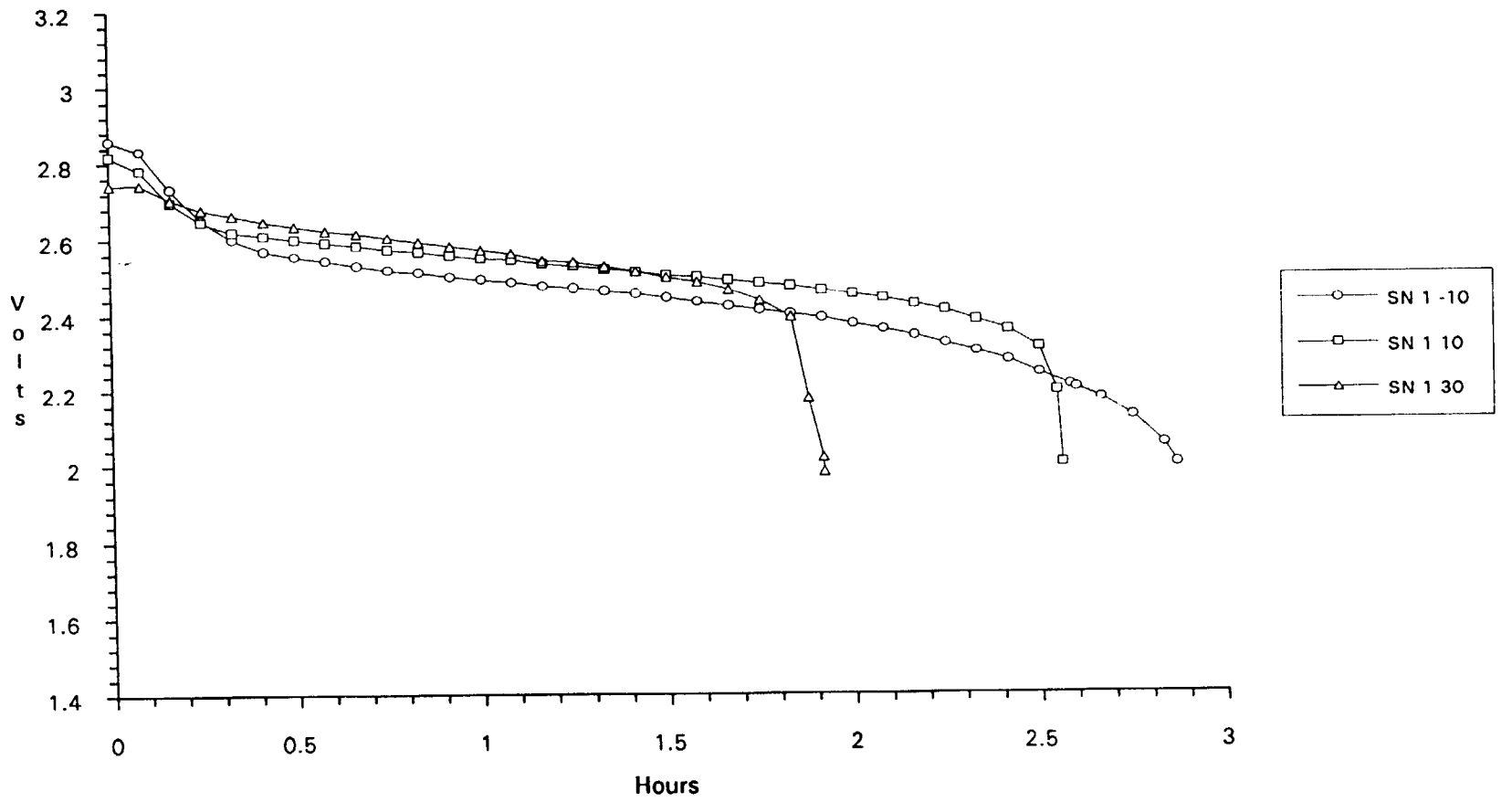
CPV Designs Developed and Tested

RNHC-6-1 (CPV) Characterization Tests: Comparison of Discharge Voltage: -10°, 10° & 30°C: Discharge 3.0 Amps to 2.0 Volts



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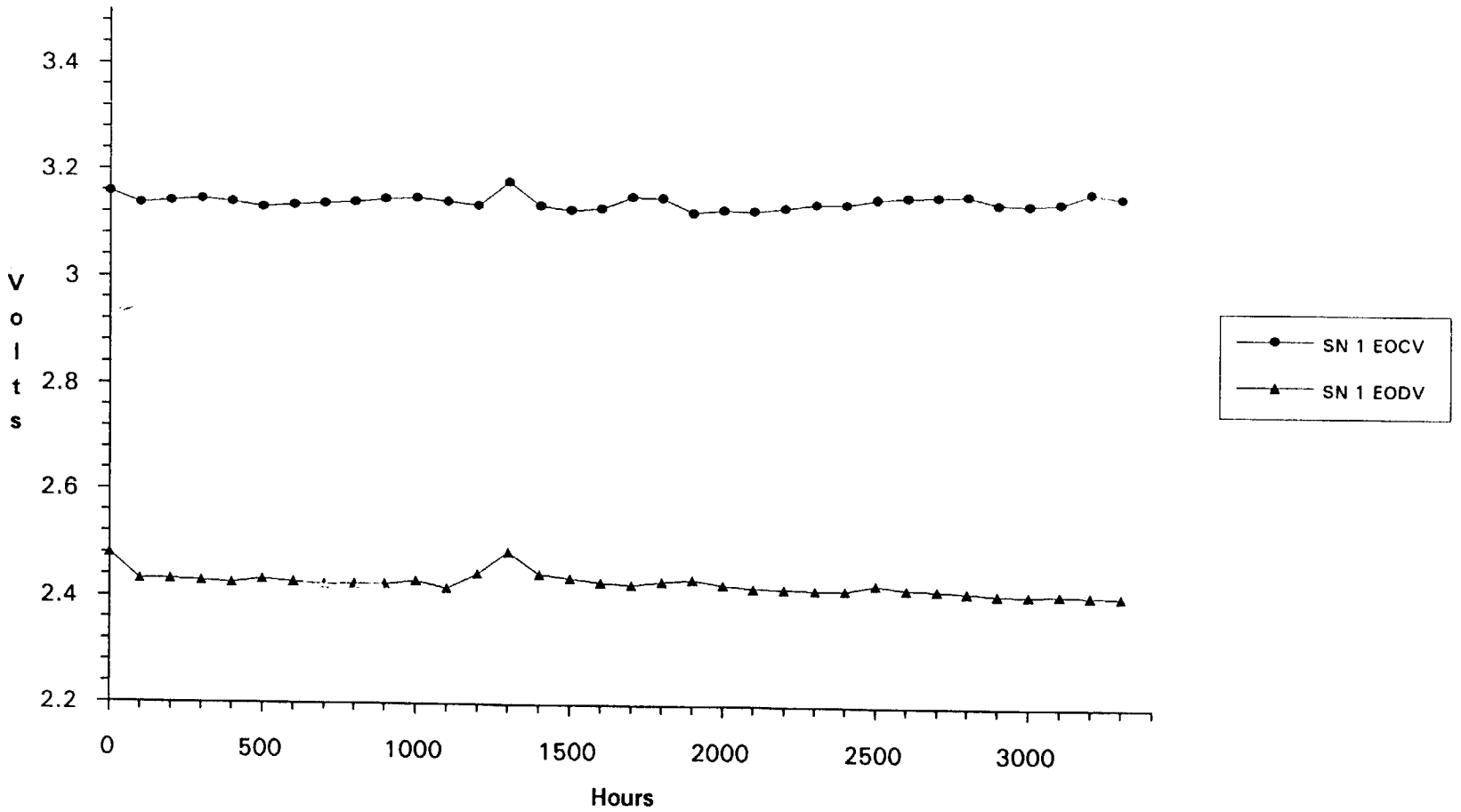
CPV Designs Developed and Tested

RNHC-10-1 (CPV) Life Test: 10°C: 40% DOD: 3300 Cycles As of 11-1-91



CPV Designs Developed and Tested

RNHC-12-1 (CPV) Characterization Testing:
Performance Summary

1. **Test Sequence "A": 5% DOD Cycles**
   10°C Charge at 1.2 Amps for 16 hrs.
   6 minute Discharge at 6.0 Amps
   10 minute Charge at 3.8 Amps
   Repeat Charge/Discharge above for 15 cycles
   Final Discharge at 6.0 Amps to 2.2 V: .....12.00 Ah
2. **Test Sequence "B": 80% DOD Cycles**
   10°C Charge at 1.2 Amps for 16 hrs.
   1.6 hr. Discharge at 6.0 Amps
   Repeat Charge/Discharge above for 15 cycles
   Final Discharge at 6.0 Amps to 2.2 V: ....12.75 Ah
   See following plots
3. Current Disposition: Delivered for flight program.

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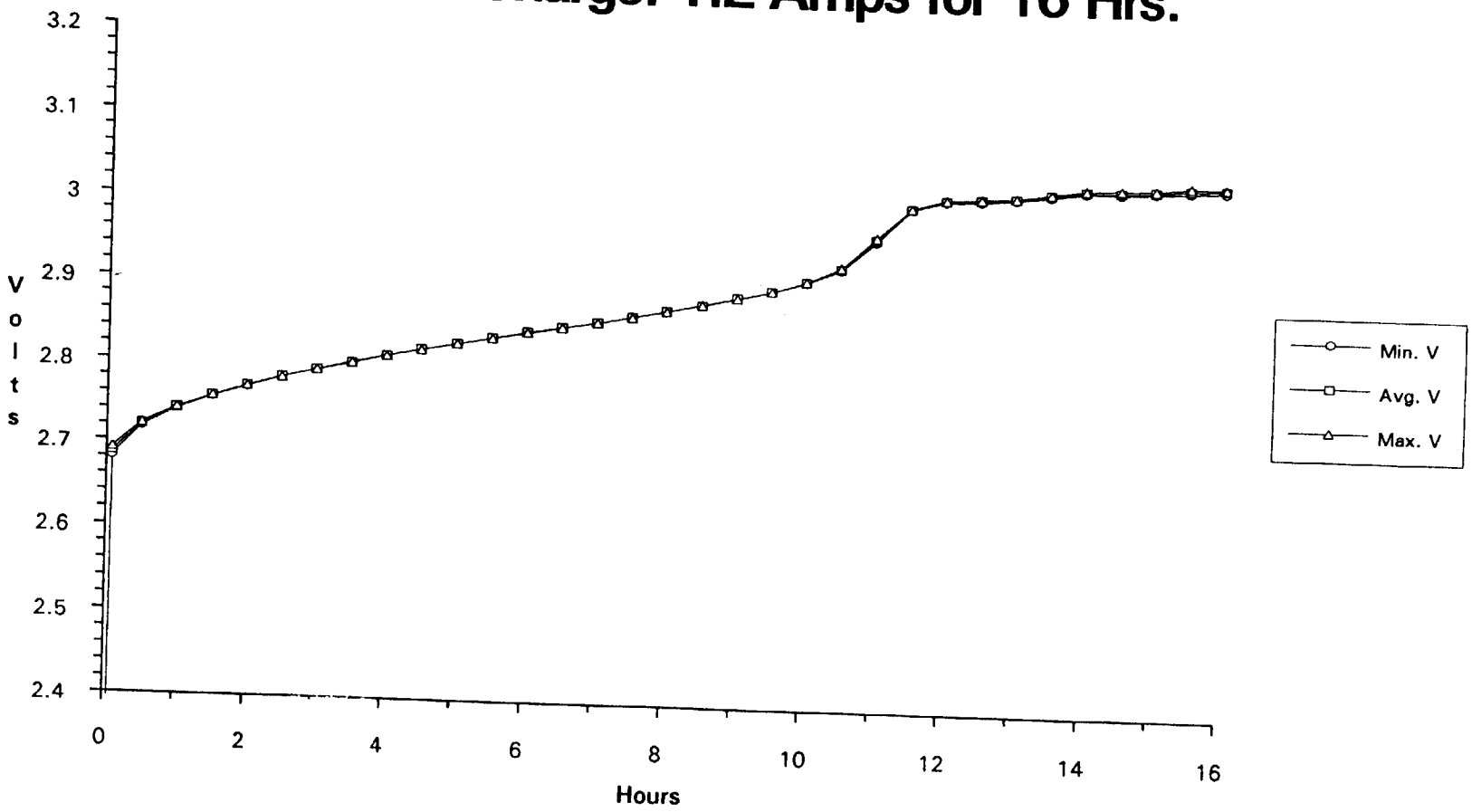
CPV Designs Developed and Tested

RNH-12-1 (CPV) Characterization Tests: Test Sequence "B": 10°C Charge: 1.2 Amps for 16 Hrs.



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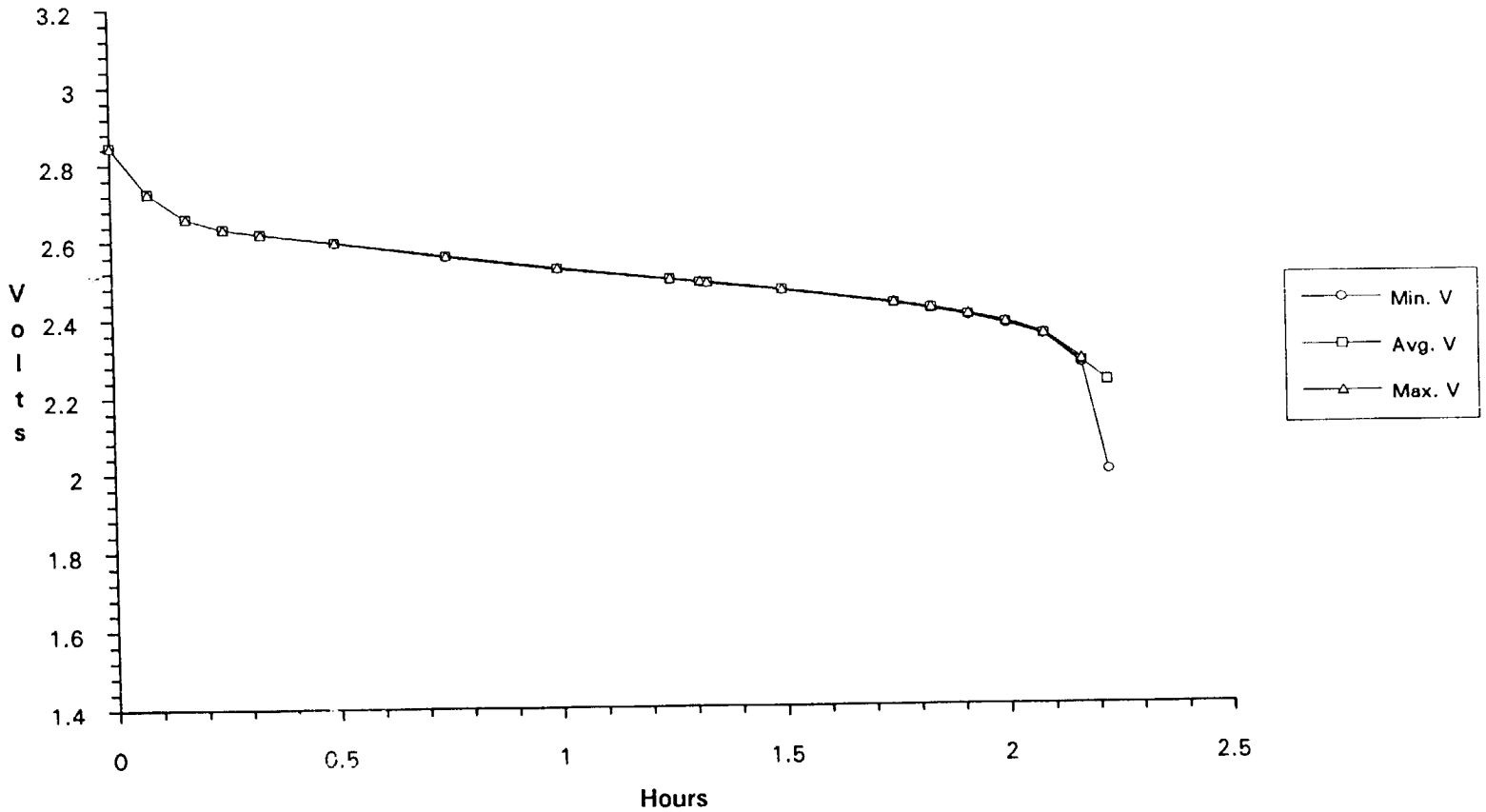
RNH-12-1 (CPV) Characterization Tests: Test Sequence "B": 10°C Disharge: 6.0 Amps to 2.0 Volts



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CPV Designs Developed and Tested

RNHC-35-9 (CPV): Characterization Testing: Performance Summary

1. 10°C Std. Cap. Test
   Charge 3.5 Amps for 16 hrs.
   Discharge 17.5 Amps to 2.0 V
   Cap. to 2.2 V: ..... 38.80 Ah
   Cap. to 2.0 V: ..... 38.88 Ah

2. Current Disposition:
   Under test at Martin Marietta

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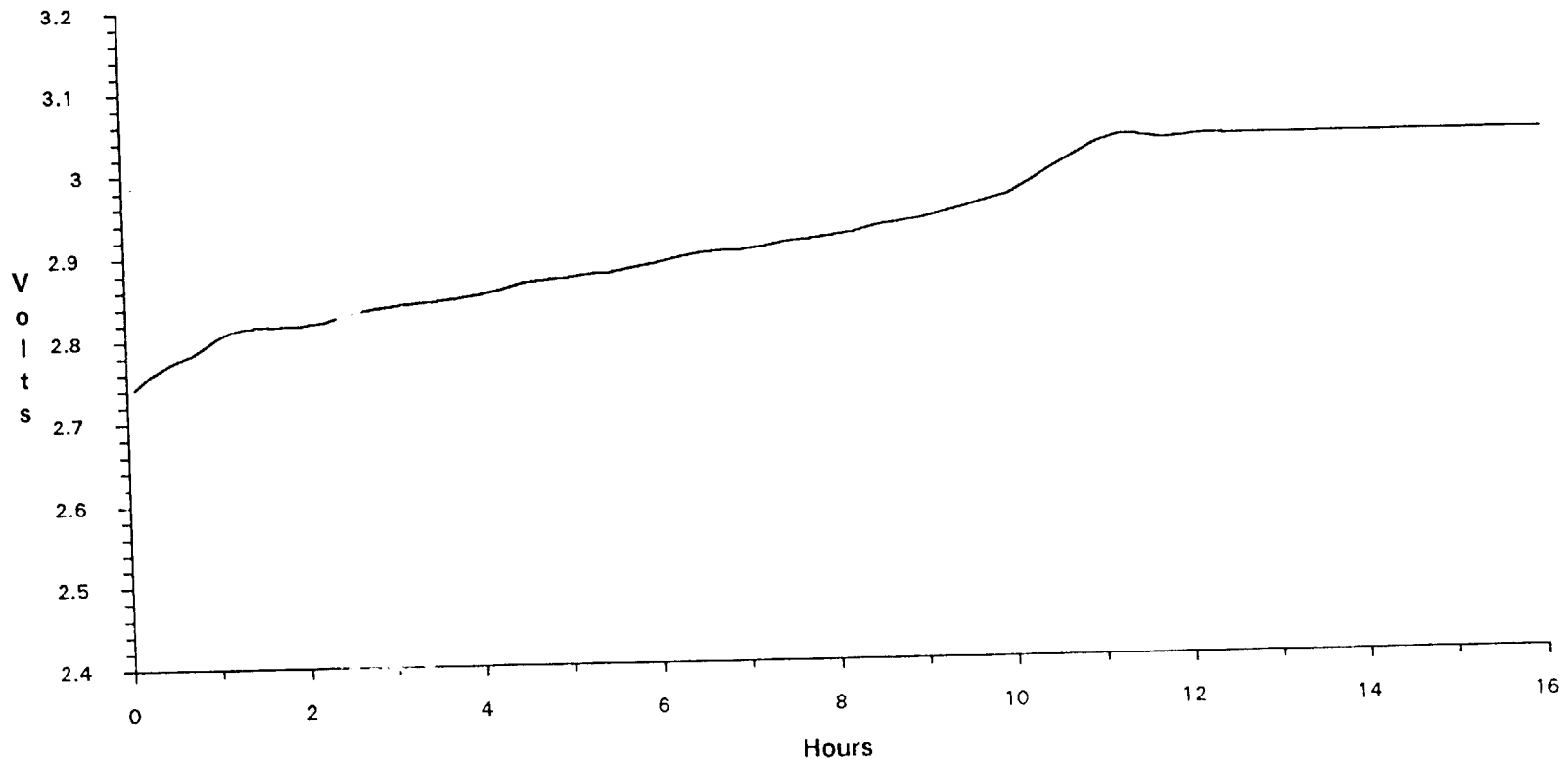
CPV Designs Developed and Tested

RNHC-35-9 (CPV) Characterization Test: 10°C Charge: 3.5 Amps for 16 Hours



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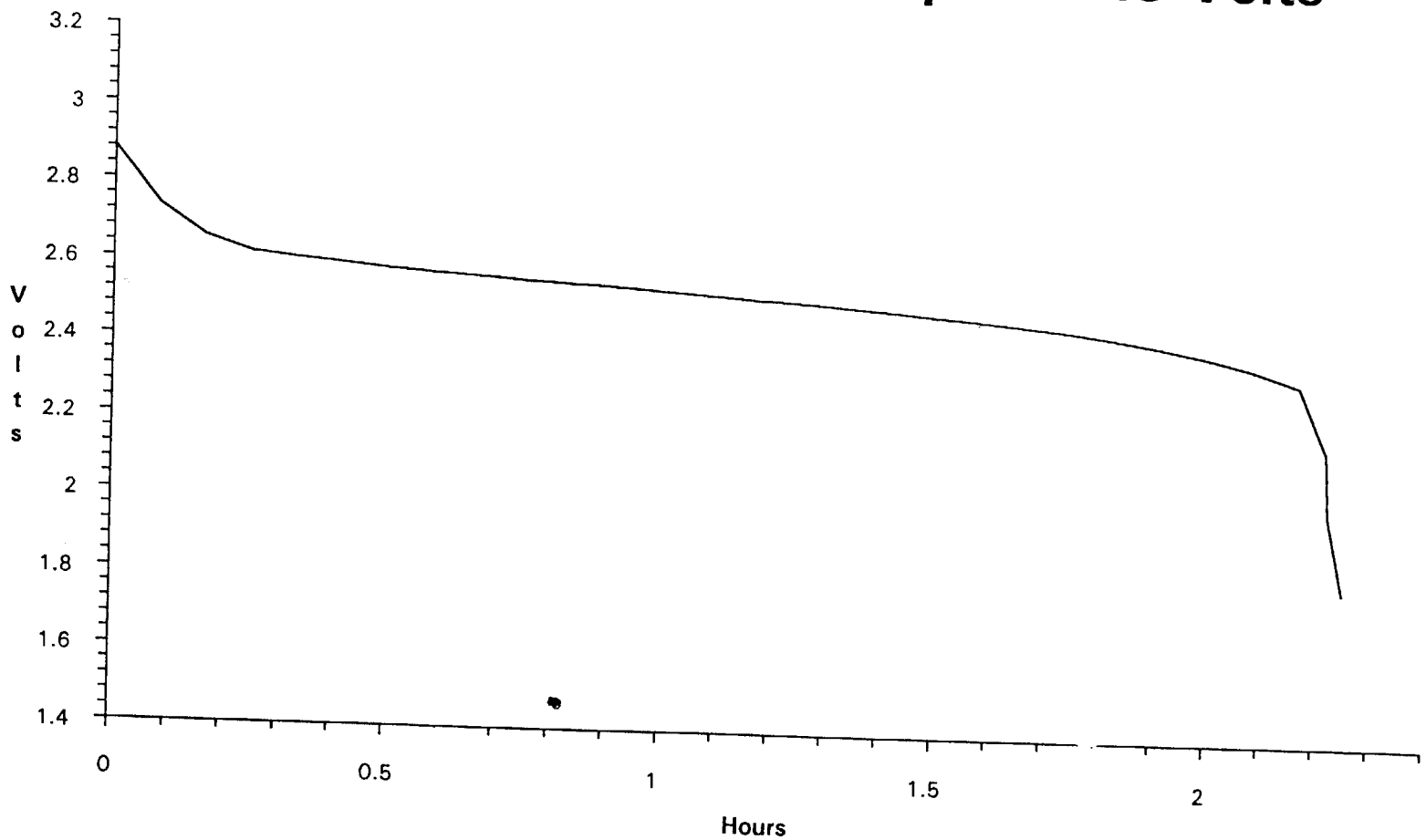
CPV Designs Developed and Tested

RNHC-35-9 (CPV) Characterization Test: 10°C Discharge: 17.5 Amps to 1.8 Volts



CPV Designs Developed and Tested

RNHC-40-3 (Prototype) (CPV): Characterization Testing/Life Test: Performance Summary

1. 0°C Std. Cap. Test
   Charge 4.0 Amps for 16 hrs.
   Discharge 20.0 Amps to 2.0 V: ..... **47.2 Ah**
2. 10°C Std. Cap. Test
   Charge 4.0 Amps for 16 hrs.
   Discharge 20.0 Amps to 2.0 V: ..... **45.4 Ah**
3. 10°C Charge Retention Test
   Charge 4.0 Amps for 16 hrs.
   72 hr. OCV
   Discharge 20.0 Amps to 2.0 V: ..... **36.6 Ah**
   % capacity retained vs. #2 above: **80.6%**

CPV Designs Developed and Tested

RNHC-40-3 (Prototype) (CPV): Characterization Testing/Life Test: Performance Summary (Cont.)

4. 20°C Std. Cap. Test
   Charge 4.0 Amps for 16 hrs.
   Discharge 20.0 Amps to 2.0 V: ..... **41.7 Ah**

5. 10°C Overcharge Test
   Charge 2.0 Amps for 72 hrs.
   Discharge 20.0 Amps to 2.0 V: ..... **53.8 Ah**

CPV Designs Developed and Tested

RNHC-40-3 (Prototype) (CPV): Life Test

Cycles: Charge 1.5 hrs. at C/3
Discharge 55 minutes at C/2
46% DOD

As of 6-91: 15,266 Cycles Completed (Rockwell)

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RNHC-40-3 (Prototype) (CPV): Characterization Testing/Life Test: Performance Summary (Cont.)

Capacity Retention Results: Life Test

Date (M/YY)	Cycle Number	Ini.Cap. Ah	Post 72 hr. (Ah)	Cap. Ret. %	Temp. °C
6-84	Accept. Test	45.4	36.6	80.6	10.0
8-87	8,201	54.7	46.3	84.6	10.0
10-87	8,303	54.5	48.2	88.4	5.0
4-89	9,592	46.1	39.7	86.1	12.5
6-89	10,003	47.3	40.4	85.4	10.0
12-89	11,546	45.6	39.2	86.0	8.6
7-91	13,425	41.7	35.5	85.1	9.7

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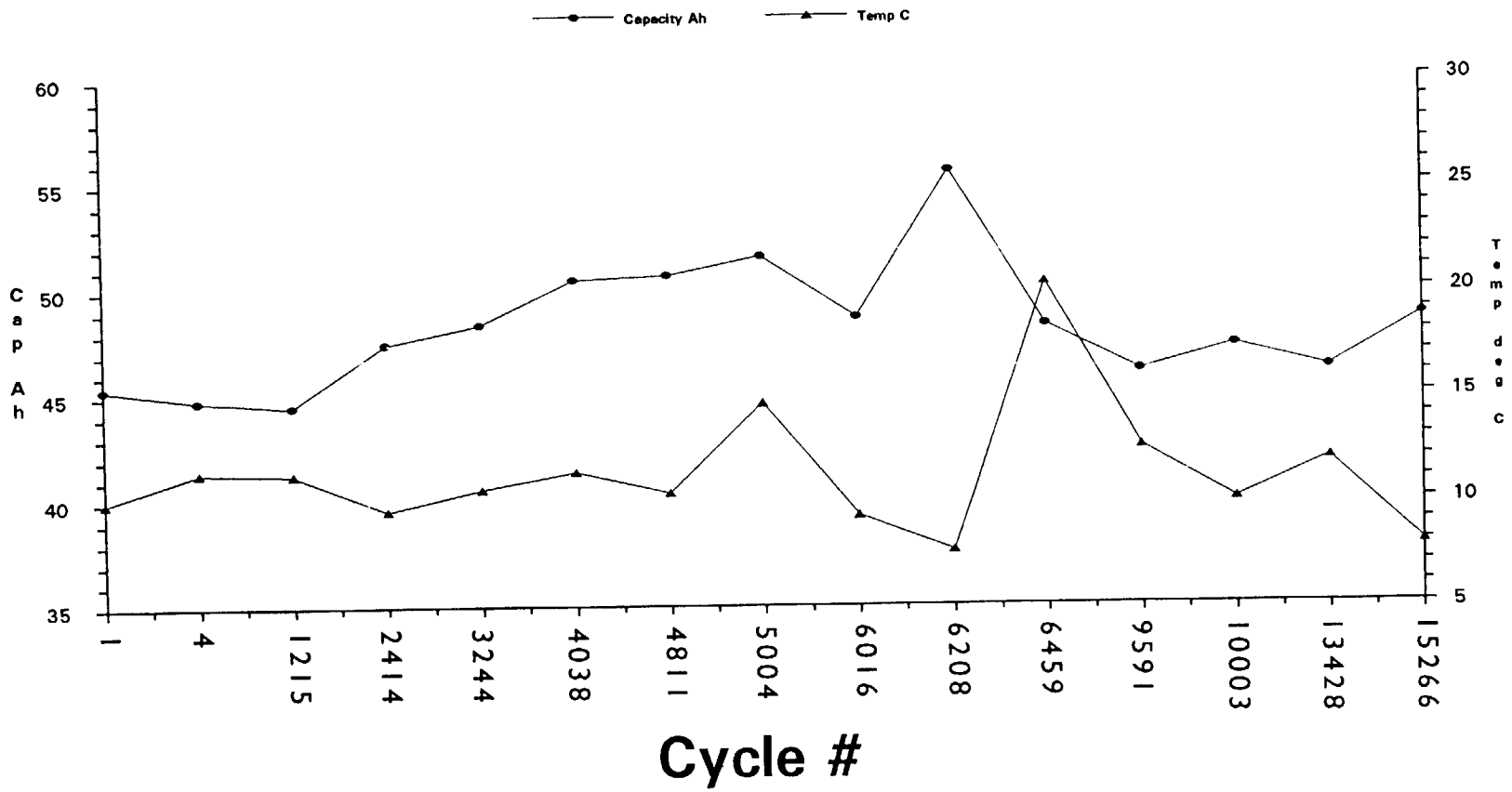
RNHC-40-3 (Proto.) (CPV) Life Test Data: Approx. 10°C Charge 4.0 Amps for 16 Hours: Discharge 20.0 Amps to 2.0 Volts



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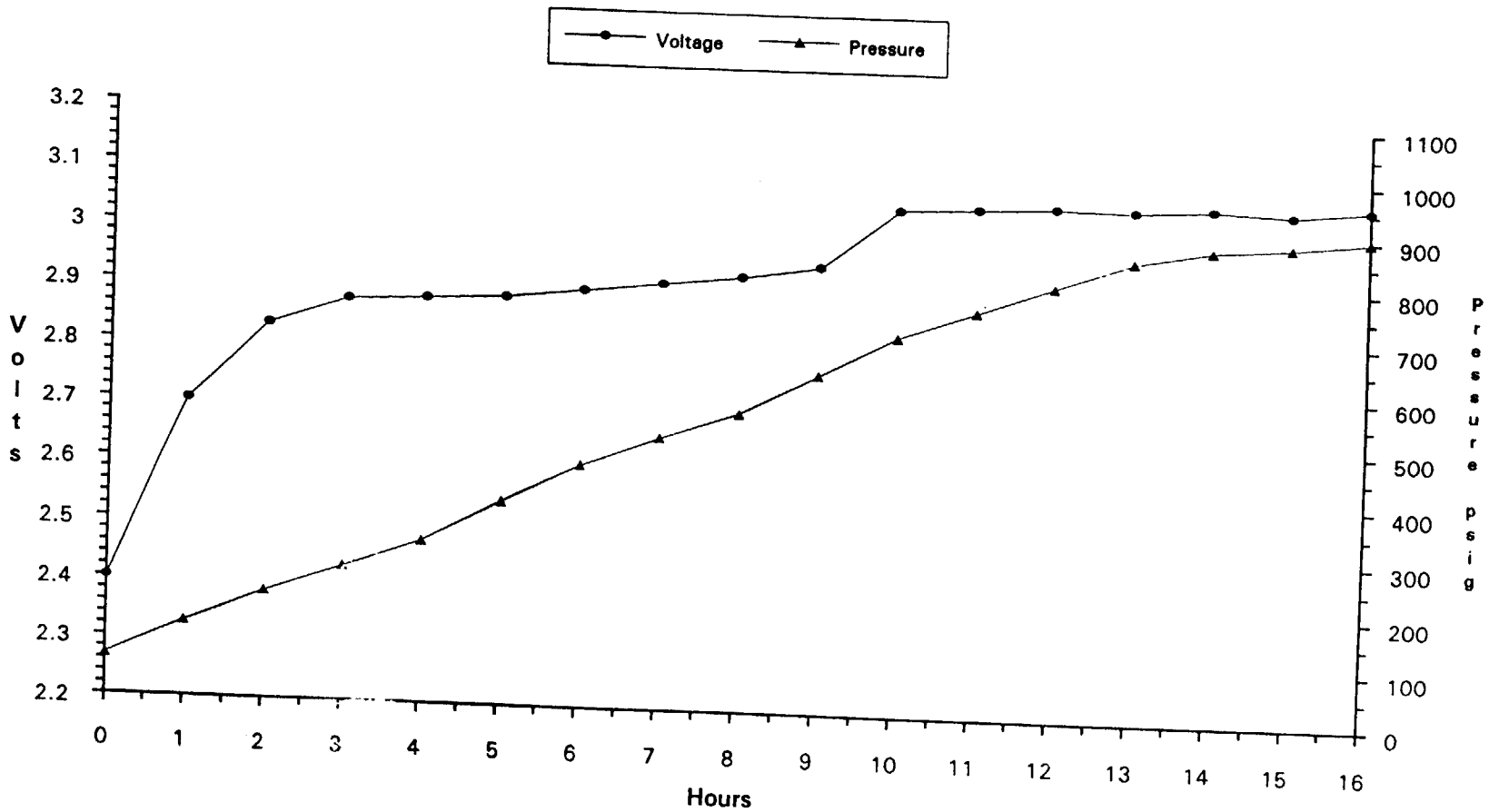
RNHC-40-3 (Proto.) (CPV) Life Test: Approximately 10°C: Cycle # 15,266: Charge 4.0 Amps for 16 Hours



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RNHC-40-3 (Proto.) (CPV) Life Test: Approximately 10°C: Cycle # 15,266: Discharge 20.0 Amps to 2.0 V