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Long Term Performance Retention Test Using High Power COTS NiCd and NiMH Cells

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by

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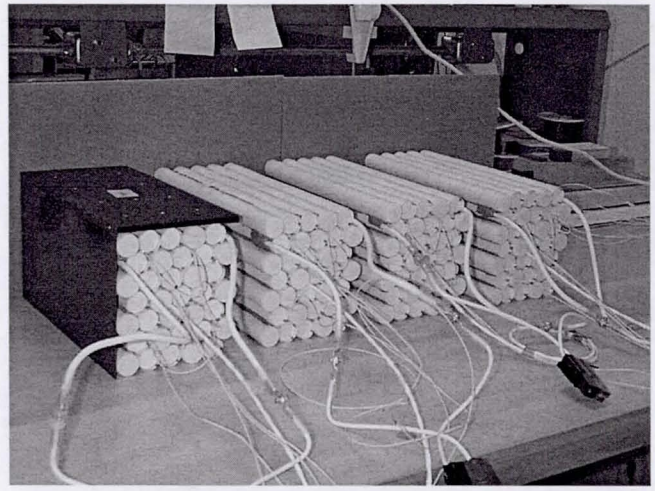
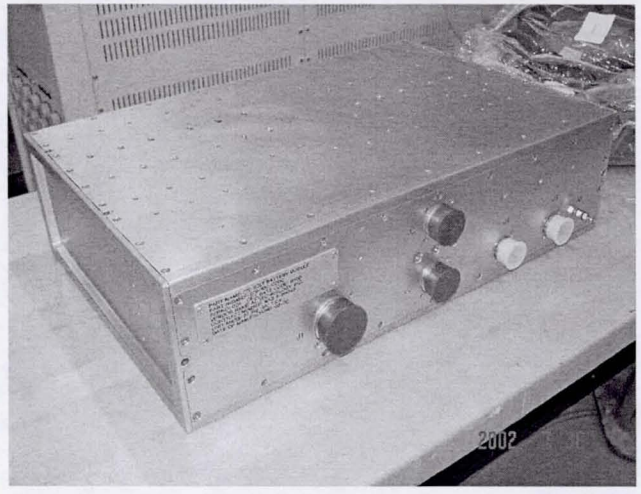
Presentation Objectives

- Introduction to Space-Flight High Power Applications
- Problem Description for Current Designs
- Test Plan for NiCd and NiMH
- Results and Analysis
- Conclusion

Introduction

- Space Flight electromechanical actuators will require short duration high power batteries
- X-38 Crew Return Vehicle electromechanical actuators
  - Qualified the first 270V, 5 Ah (8.4Ah Actual) NiCd battery module for single use application
  - Requires 41.5W/Cell @ 1.0V
  - NiCd and NiMH ~40-50Wh/kg for commercial SubC cells have demonstrated capability
  - Cell charging maintenance development is needed to meet the 3 year on-orbit CRV mission
- Orbital Space Plane OSP will also need to maintain battery performance readiness > 6 months requiring similar maintenance regime development





Problem Description for Current Designs

- NiCd designs demonstrate unfavorable power degradation after long periods of inactivity
    - Up to 35% and 45% reversible and irreversible capacity losses were experienced after 4 and 7 months of charged storage (monthly maintenance charge)
    - Up to 70 and 85 mV/cell of voltage depression (impedance growth) after 4 and 7 months (monthly maintenance charge)
- Although some of the decay is recoverable with cycling, this adds a heavy interface requirement thereby reducing battery readiness
- Charging development options are limited by contactor life (100,000 cycles) for X-38 270V Battery.

Test Plan Objective

- A 5-cell SubC stick test vehicle was chosen using NiCd (CP-2400SCR) vs NiMH (HR-SC2600) both by Sanyo
- Compare differences at different charge maintenance regimes for NiMH as an alternative to NiCd
  - Capacity to 1.0V
  - Voltage after 1.2Ah discharge
  - Resistance @ 100 ms
  - Available pulse power @ 1.0V
- Identify regimes that provide acceptable performance

Continuous Charge Maintenance Test Plan

Regime Type	Charge Method	Continuous Maintenance	Duration	Rest	Discharge	Pulse after 1.2Ah	Rest
Daily	@ 2.4A; Peak V-10 mV/cell(-5mV/cell for MH)	0.24A, 1sec on, 10 sec off	Daily	1 hr	@ 3.5A to 1.0V	24A @ 0.1 sec / 2.4A @ 2 min	3 hr
Continuous Maintenance Groups (4)							
Weekly	@ 2.4A; Voltage Cutoff, -10 mV/cell (-5mV/cell for MH) less than peak	0.24A,11 sec period, 1sec on, 10 sec off	Week	1 hr	@ 3.5A to 1.0V	24A @ 0.1 sec / 2.4A @ 2 min	3 hrs
Monthly			Month				
3 Month*			3 Months				
6 Month*			6 Months				

* Note: Includes monthly check-out (0.5A for 3min, 10A, 0.1sec, recharge @ 2.4A to –dV)

- Discharge interval ladder with C/110 Charge
  - Daily cycle (Two 3-cell sticks)
  - Weekly, monthly, quarterly, semi-yearly cycle (4 groups; one 5-cell stick each)

Periodic Charge Maintenance Test Plan

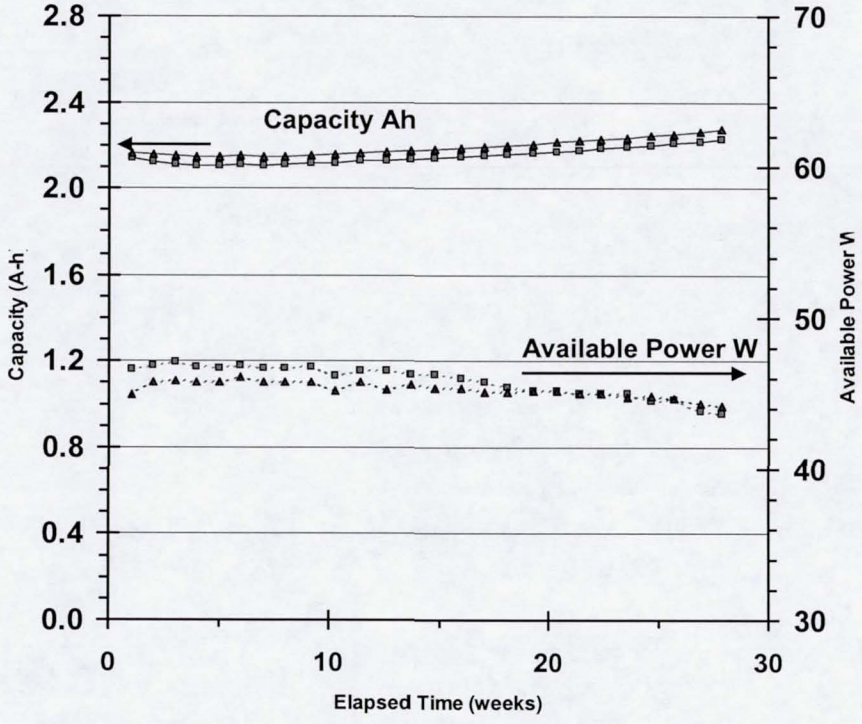
Regime Type	Charge Method	Rest	Topping Frequency	Discharge	Pulse after 1.2Ah	Rest
Periodic Charge Maintenance Groups (4)						
No Topping	@ 2.4A; Voltage Cutoff, -10 mV/cell (-5mV/cell for MH) less than peak	1 month	None	@ 3.5A to 1.0V	24A @ 0.1 sec / 2.4A @ 2 min	3 hrs
Weekly Topping			0.24A @ 1.5 hour/week			
Mid-month Topping			0.24A @ 2 hours/mid-month			
Constant Voltage	CC/CV @ 2.4A to 1.44V, 1.44V to 0.24A		None			

- Intermittent maintenance interval ladder
  - None, weekly, mid-monthly maintenance groups (3 groups; one 5-cell stick each)
  - No maintenance with constant voltage charge @ 1.44V (1 group; one 5-cell stick)

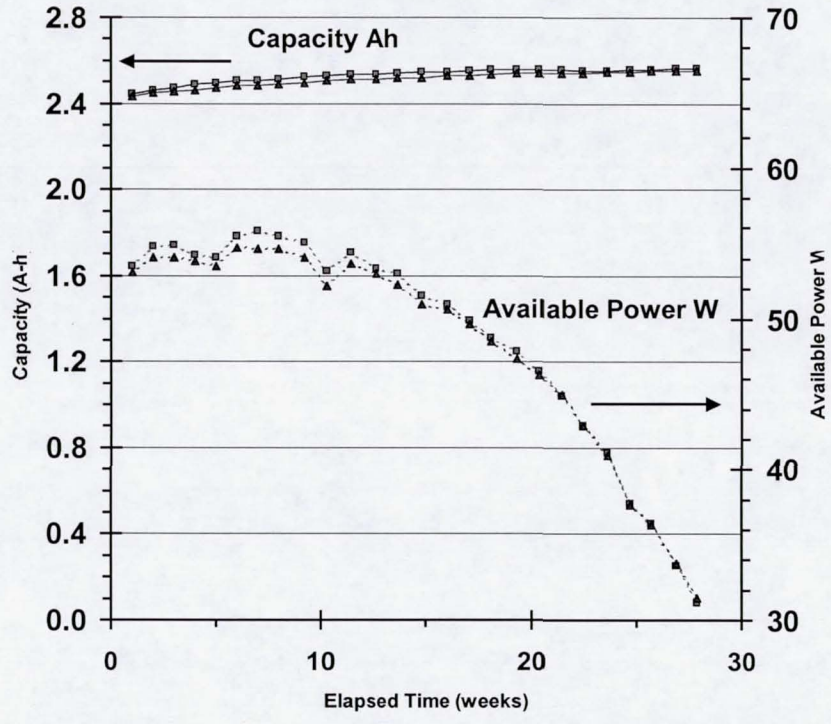
Control for Continuous Charge Maintenance

Daily Charge, Capacity and On-Demand Power at 1.0V

Sanyo HR-SC 2400 NiCd Control



Sanyo HR-SC 2600 NiMH Control

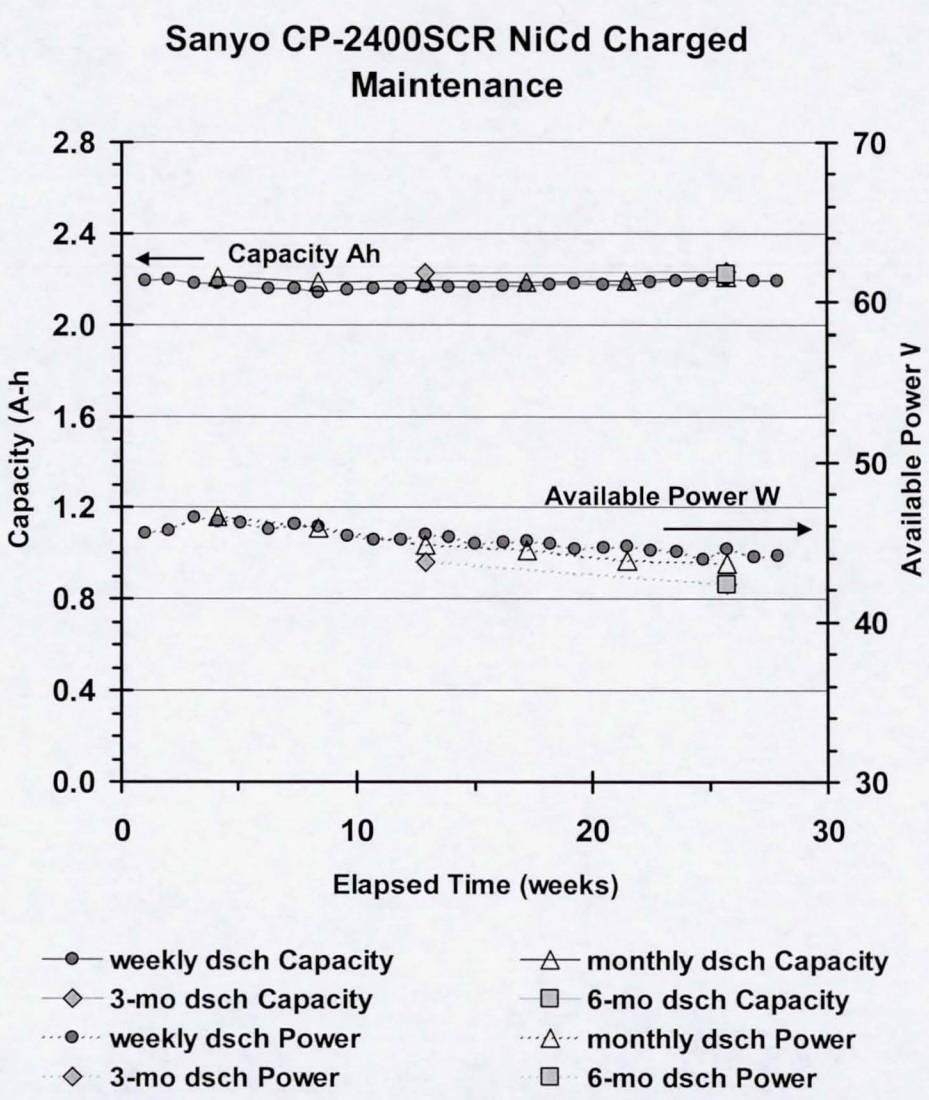


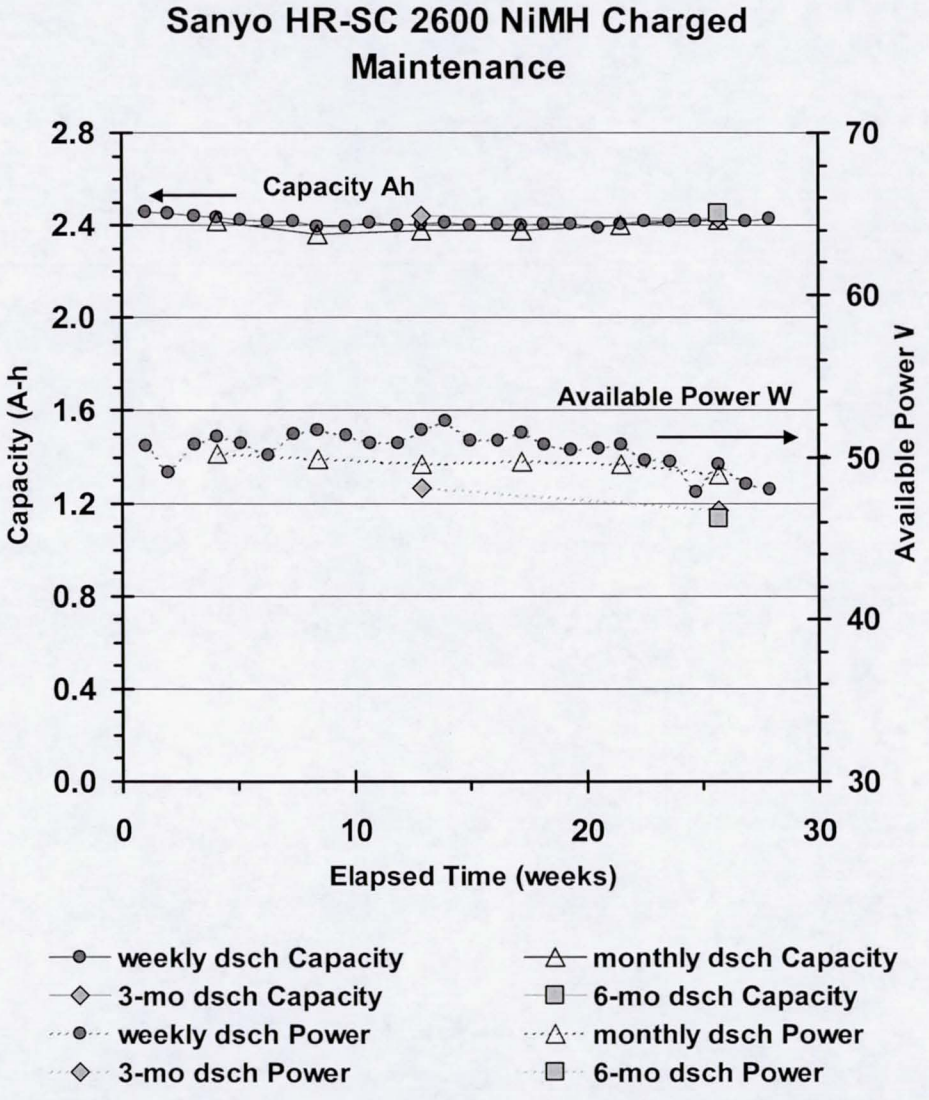
Results of Control

- For capacity to 1.0V after 6 months of daily cycling NiMH is favored over NiCd
- For available pulse power at 1.0V after 6 months of daily cycling NiCd is favored over NiMH
- Rapid power fade with daily cycles for NiMH is attributed to increase of internal resistance

Continuous Charge Maintenance

Capacity and On-Demand Power at 1.0V





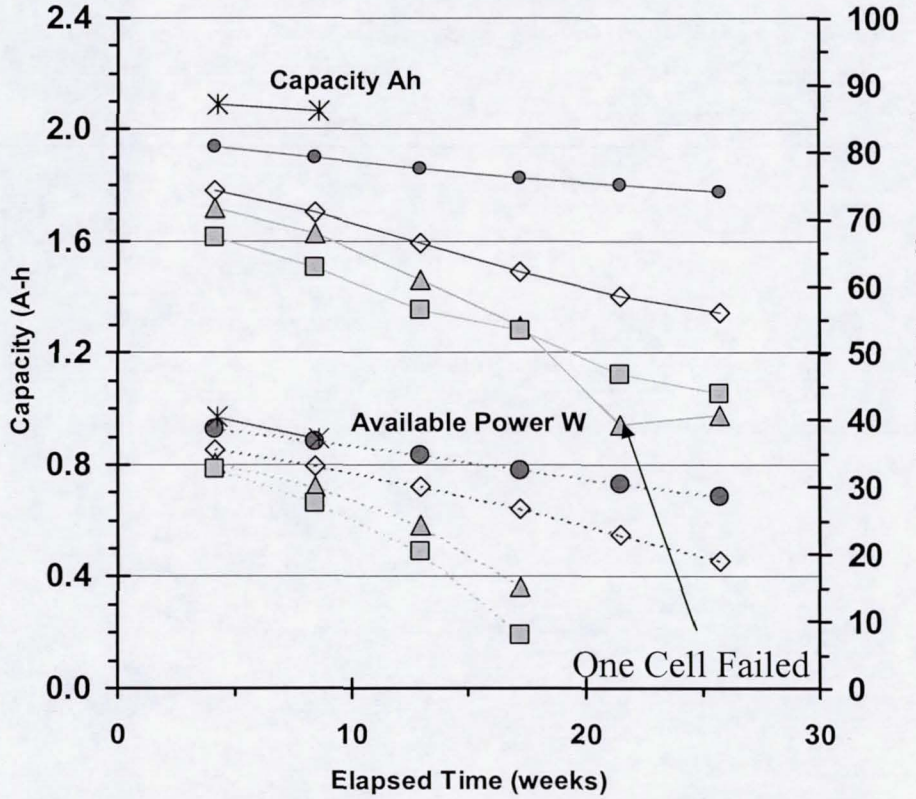
Results of Continuous Charge Maintenance

- For capacity to 1.0V after 6 months for all continuous maintenance groups NiMH is favored over NiCd
- Capacity and power trends after 6 months appear stable for both chemistries
- For available pulse power at 1.0V after 6 months of continuous maintenance NiMH is slightly favored over NiCd

Periodic Charge Maintenance

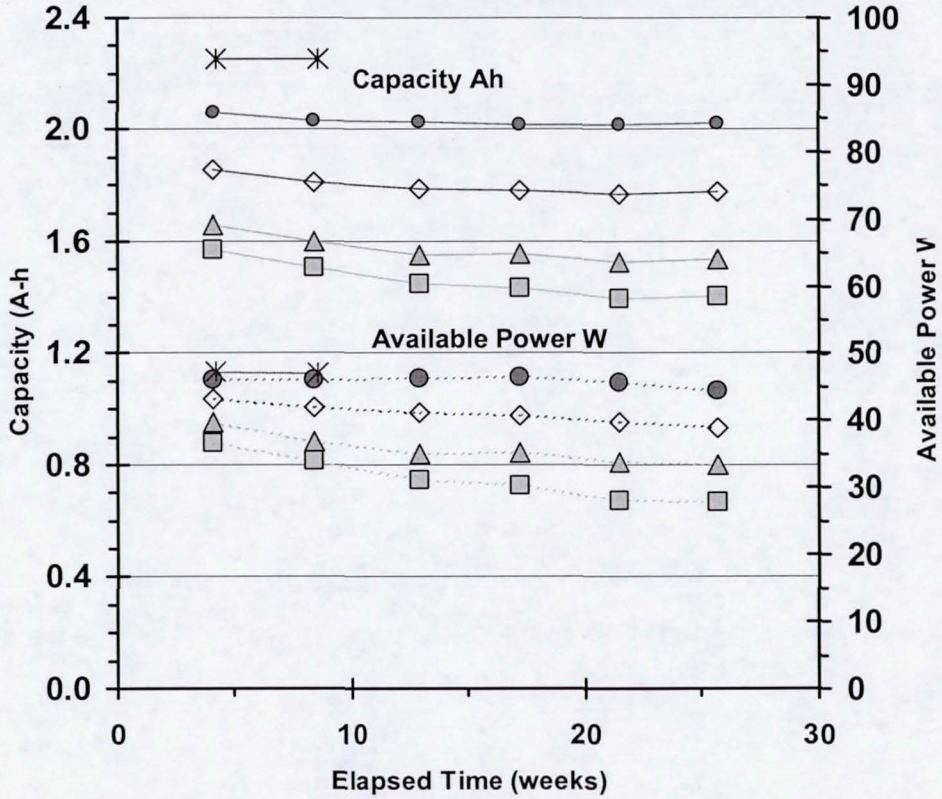
Capacity and On-Demand Power at 1.0V

Sanyo CP-2400SCR NiCd Periodic Maintenance



weekly top chg Capacity
semi-monthly top chg Capacity
no top chg Capacity
cc/cv, no top Capacity
Daily top chg Capacity
weekly top chg Power
semi-monthly top chg Power
no top chg Power
cc/cv, no top chg Power
Daily top chg Power

Sanyo HR-SC 2600 NiMH Charged Maintenance Tests



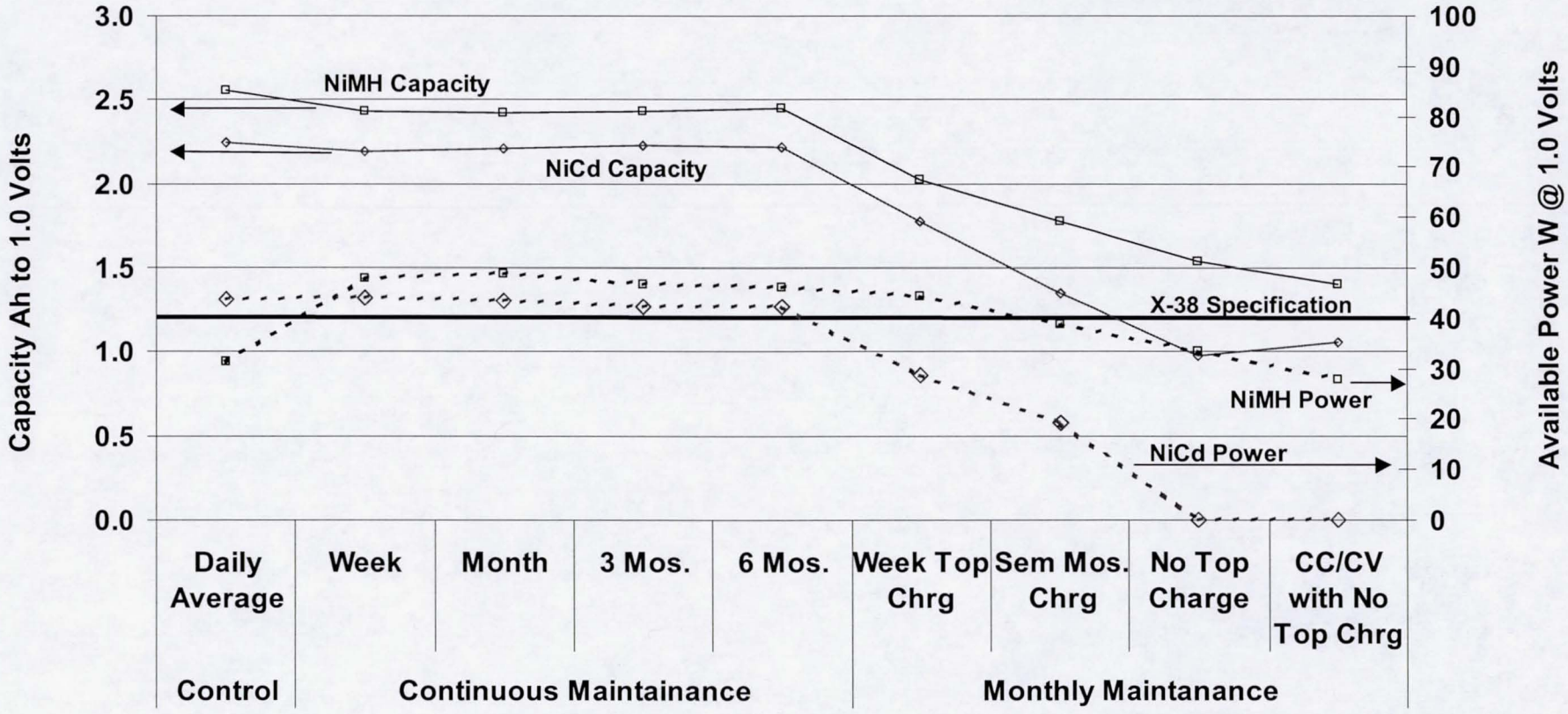
weekly top chg Capacity
semi-monthly top chg Capacity
no top chg Capacity
cc/cv, no top Capacity
Daily top chg Capacity
weekly top chg Power
semi-monthly top chg Power
no top chg Power
cc/cv, no top chg Power
Daily top chg Power

Results of Periodic Charge Maintenance

- For capacity to 1.0V and available power at 1.0V after 6 months, NiMH is strongly favored over NiCd
  - Capacity and power trends in all groups are decreasing for NiCd and stabilizing for NiMH
  - Power fade in periodic charge maintenance groups is predominantly attributed to decrease of capacity and voltage
- NiCd groups with no maintenance including the constant voltage charge failed to deliver 1.2 Ah after 4 months

Available Power and Capacity vs Regime

@ 6 months, Power at 1.0V/Cell



Conclusions

- Continuous Charge Maintenance @ C/110 after 6 months
  - For daily discharge intervals only NiCd delivered greater than 41.5W
  - For weekly monthly, quarterly and semiannual discharge intervals both NiMH and NiCd delivered greater than 41.5W
  - Continuous duty cycle regimes impractical due to contactor design
- Periodic Charge Maintenance after 6 months
  - Only the weekly topping for NiMH performed greater than 41.5W
  - All NiCd periodic groups failed to deliver needed power
  - No-topping group experienced one high impedance short in a NiCd 5-cell stick, raising concerns over charge regime stability

Acknowledgements

- Eric Darcy-NASA-JSC
- Brad Strangways and Tim Nelson- Symmetry Resources