

On-Orbit Health Check of Hubble Space Telescope Nickel-Hydrogen Batteries



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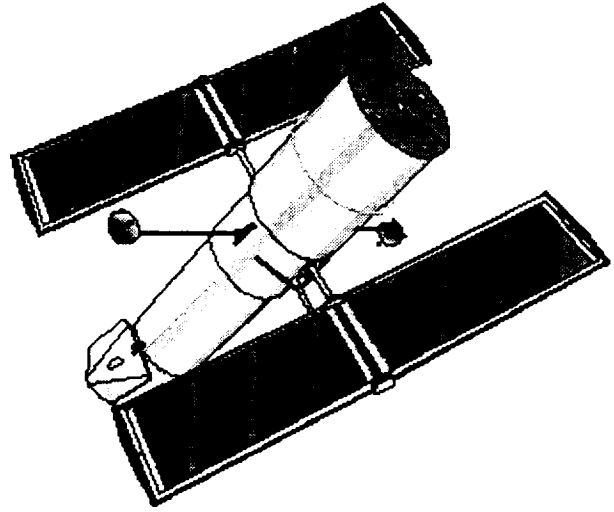
NASA AEROSPACE BATTERY WORKSHOP

Dec. 3 - 5, 1996



Introduction

- Background
- Objective of Capacity Check/Reconditioning
- Battery Reconditioning Circuitry
- Reconditioning Procedure
- Results of Reconditionings
- Conclusions





Background

- The Hubble Space Telescope is a one-of-a-kind spacecraft that pushes technology to its limits. Housing an 8-foot (2.4 meter) mirror and several sophisticated cameras and detectors, the telescope is the largest orbital astronomy observatory ever placed in space.
 - Launch date - April 24, 1990
 - Deployment - April 25, 1990
 - First Servicing Mission - December 4, 1992
 - Second Servicing Mission - February, 1997



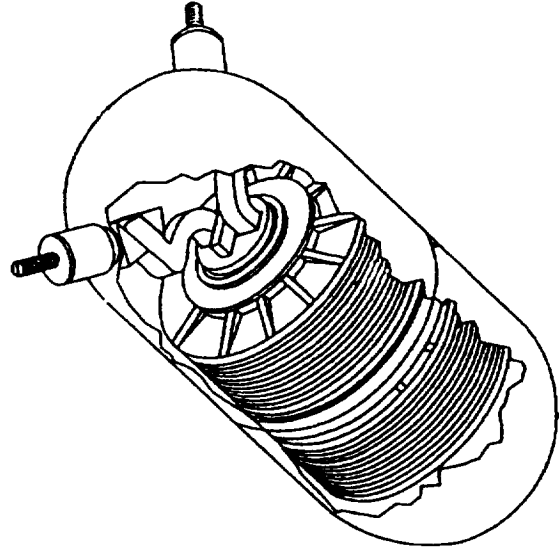
Background

- Battery Design
 - Two Modules Each Containing Three 88 Ah NiH₂ Batteries (Six total)
 - Manufactured by: Eagle Picher / Lockheed
 - 23 Cells in Each, Only 22 Cells Are Electrically Connected (Position #22 Inactive)
 - Dry sintered nickel positive electrodes stacked with the platinum negative electrodes, zirconium oxide cloth separators and gas screens on a polysulfone core.



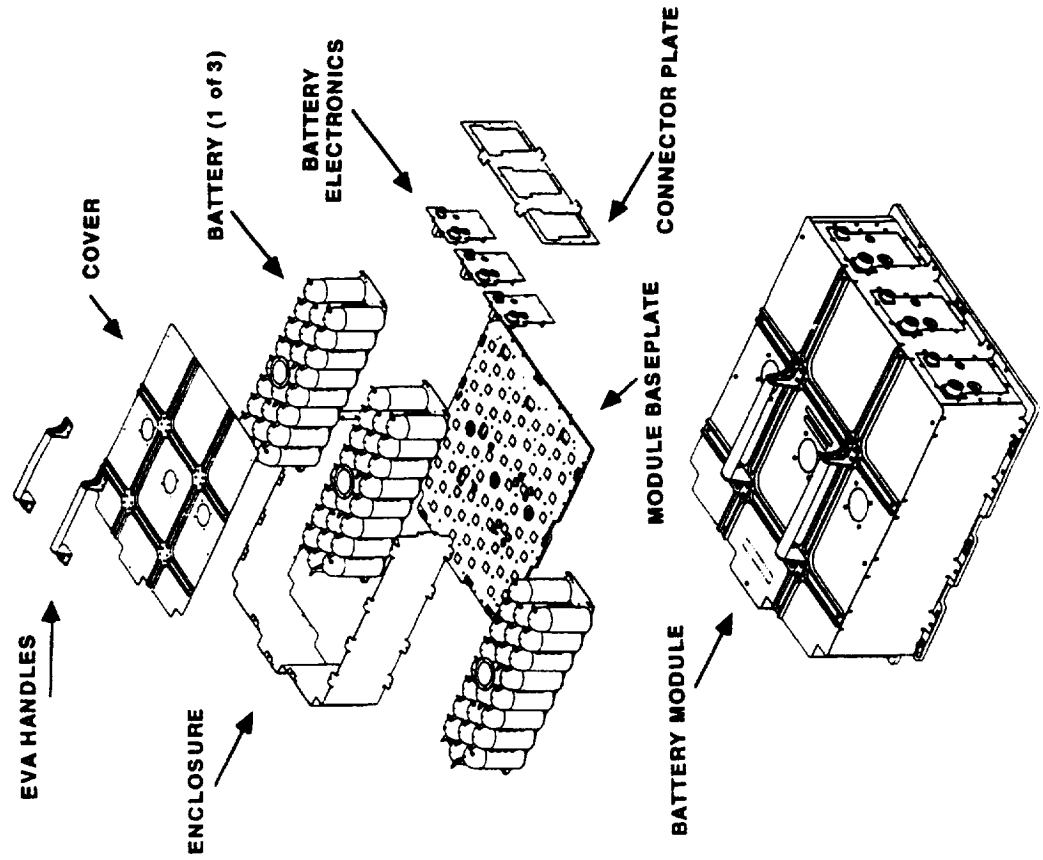
Background

- Positive Plate Fabrication
 - Flight Spare Module (FSM) in Feb. - June, 1988
 - Flight Module 2 (FM2) in June - Nov. 1988
- Cell Activation
 - FSM in Jan. 1989
 - FM2 in Mar. 1989





Background





Background

- Each Battery Has the Following Dedicated Monitors and Controls:
 - One Temperature Monitor for Telemetry
 - Four Charge Control Thermistors
 - One Primary and One Backup Heater System With Controllers
 - One Current Monitor (-25 to +25 Amps)
 - Two Cell Pressure Monitors (0 to 1500 PSI)
 - One telemetered through the Data Interface Unit (DIU) A side, the other through the DIU B side
 - Only one read at a time



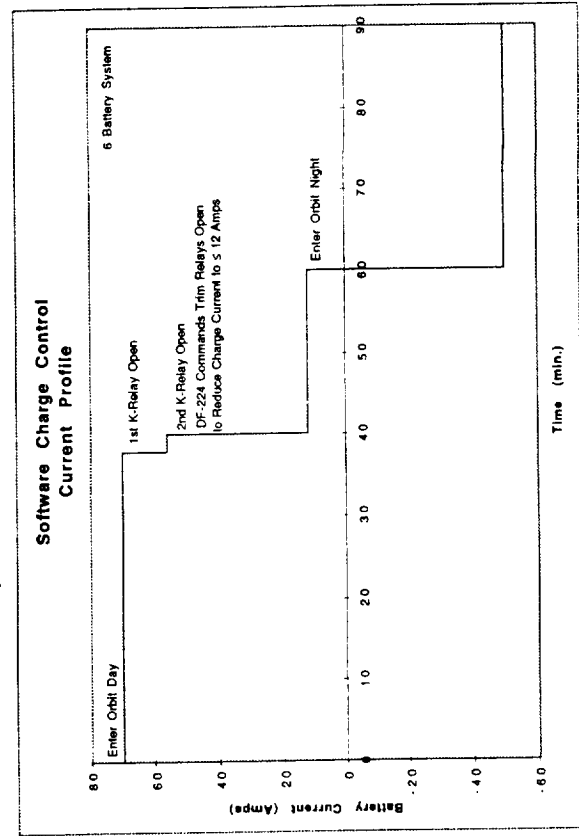
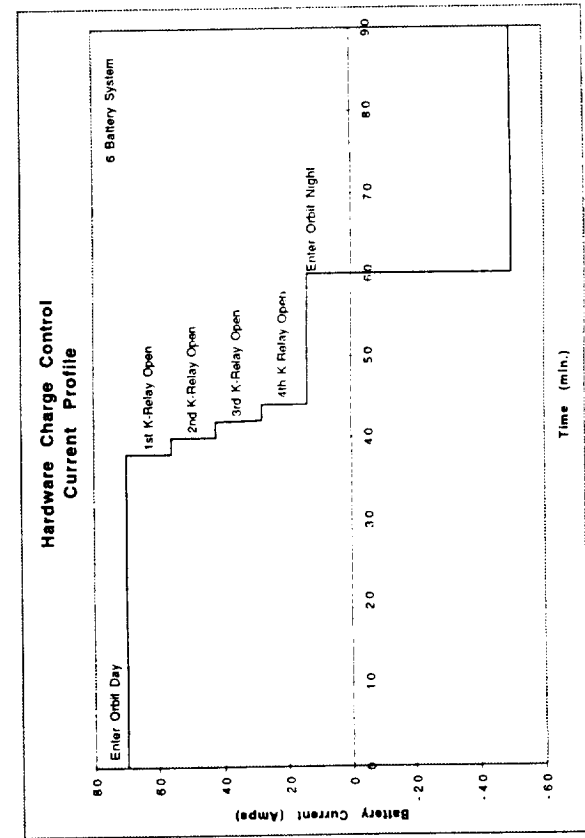
Background

- Charge System
 - Charge Managed for Each Battery by Charge Current Controllers (CCC)
 - Provide Multilevel Control of Battery Charging Based on Voltage and Temperature Characteristics
 - Control Relays Inside the Power Control Unit (PCU)
 - Charge Modes
 - Hardware Charge Control
 - Utilizes CCC “K” relays to remove Solar Panel Assemblies (SPA’s) from batteries
 - Relays open based on battery voltage & temperature (Taper Charge)



Background

- Software Charge Control
 - DF-224 controlled
 - Initiated when two CCC “K” relays open
 - Commands SPA Trim Relays open to drop charge current down to the database defined level (Trickle Charge)





Background

- **Battery History**
 - Batteries were Charged and Installed Prior to Transfer to Launch Pad
 - Standard Baseline Charge used During Development and Testing of Cells and Batteries
 - Charge 10 Hours @ 9 amp rate (~C/10)
 - Charge 14 Hours @ 4 amp rate (~C/24)
 - **Launch Delay**
 - Batteries Removed for Reconditioning and Recharge
 - At Time of Release in Orbit, Pressure-based Capacity $\approx 61.7\text{Ah}$ / battery



Background

- Current Status
 - Six and One Half Years of Nominal Performance
 - Hardware Charge Control Operation Mode @ K1L4, K2L3
 - Completed 35982 Eclipse Orbits
 - Depth of Discharge Ranges Between 5 and 8.5%
 - System Capacity \approx 461 Ah
 - Average Recharge Ratio \approx 1.05
 - Last Reconditioning - March 25, 1996
 - Battery 3, Coulombic Capacity to 26.4V \approx 74.7 Ah



Objective of Reconditioning

- **The Reconditionings:**
 - **Determine Actual Battery Capacity for Trend Analysis and Mission Planning**
 - **Provide Verification of the Accuracy of the Pressure Transducers**
 - **Provide Data to Assess Battery Health**
 - **Reduce Battery Pressure**
 - **Restore Cell Balance**



Battery Reconditioning Circuitry

- Switching Circuitry
 - Contained in the HST Power Control Unit
 - Two Parallel 25 Amp Latching Relays Isolate the Test Battery by Connecting the Solar Array (SA) Section Directly to the Diode Bus
 - Two 15 Amp Latching Relays Connect the Battery to Either the “High Rate” or “Low Rate” Reconditioning Resistor
 - SA section must be switched from the battery first
 - Discharge is autonomously terminated if HST enters safemode

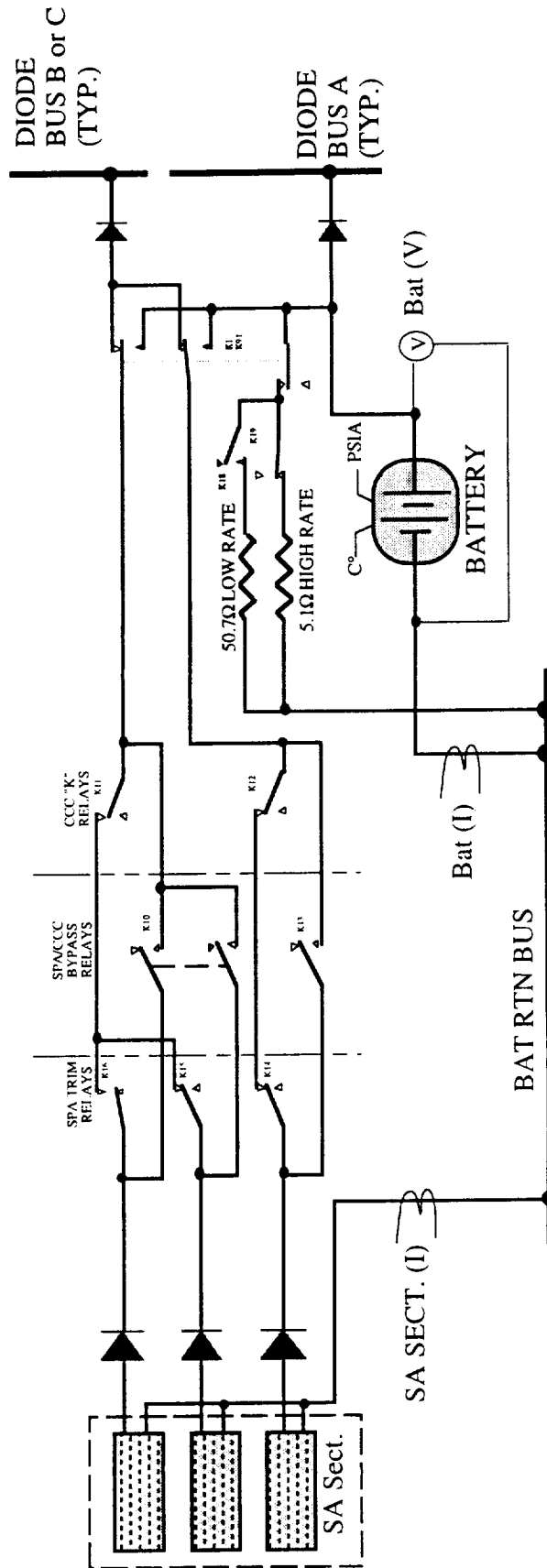


Battery Reconditioning Circuitry

- Reconditioning Resistors
 - Constructed Using Heater Elements
 - “Low Rate” $50.7\Omega \pm 3\%$
 - “High Rate” 5.1Ω (10 X $50.7\Omega \pm 3\%$ in parallel)



Battery Reconditioning Circuitry





Reconditioning Procedure

- Test Preparation
 - Normalize Test Conditions to Previous Test of the Specified Battery
 - Sun-to-Orbit Ratio (within ± 2 minutes)
 - SA / Sun Incidence angle ($\pm 10^\circ$)
 - Other Preparations
 - Schedule TDRSS Support to Configure, Initiate, Monitor and Reconfigure HST for the Test



Reconditioning Procedure

- Schedule At Least One 15 min. Forward Link / Orbit During Discharge for Contingency Test Termination.
 - “Go For Test” Conditions
- Two Orbits of Charge In Which Full Charge Cut-off Attained
- **DO NOT Interrupt Science!**



Reconditioning Procedure

- Test Procedure
 - The Battery is Reconditioned to 15V
 - Autonomously Terminated by the “Special Hardware Limit Test”
 - Battery is Discharged “High Rate” Through the 5.1 Ω Resistor
 - Average current = 5.4 Amps
 - Duration of discharge is about 15 to 18 hours
 - Data is Monitored and Collected During Discharge
 - Current, Voltage, Temperature and Pressure



Reconditioning Procedure

- Criteria For Test Termination
 - Flight Software State of Charge (SOC) Below 275 Ah for the 5 Battery System *
 - Benchmark SOC for 5 Battery System = 345 Ah
 - -8.0°C > Test Battery Temperature > 7.0°C **
 - 15.0V > Test Battery Voltage > 33.5V **
 - HST Safemode Entry ***

* Terminated Manually

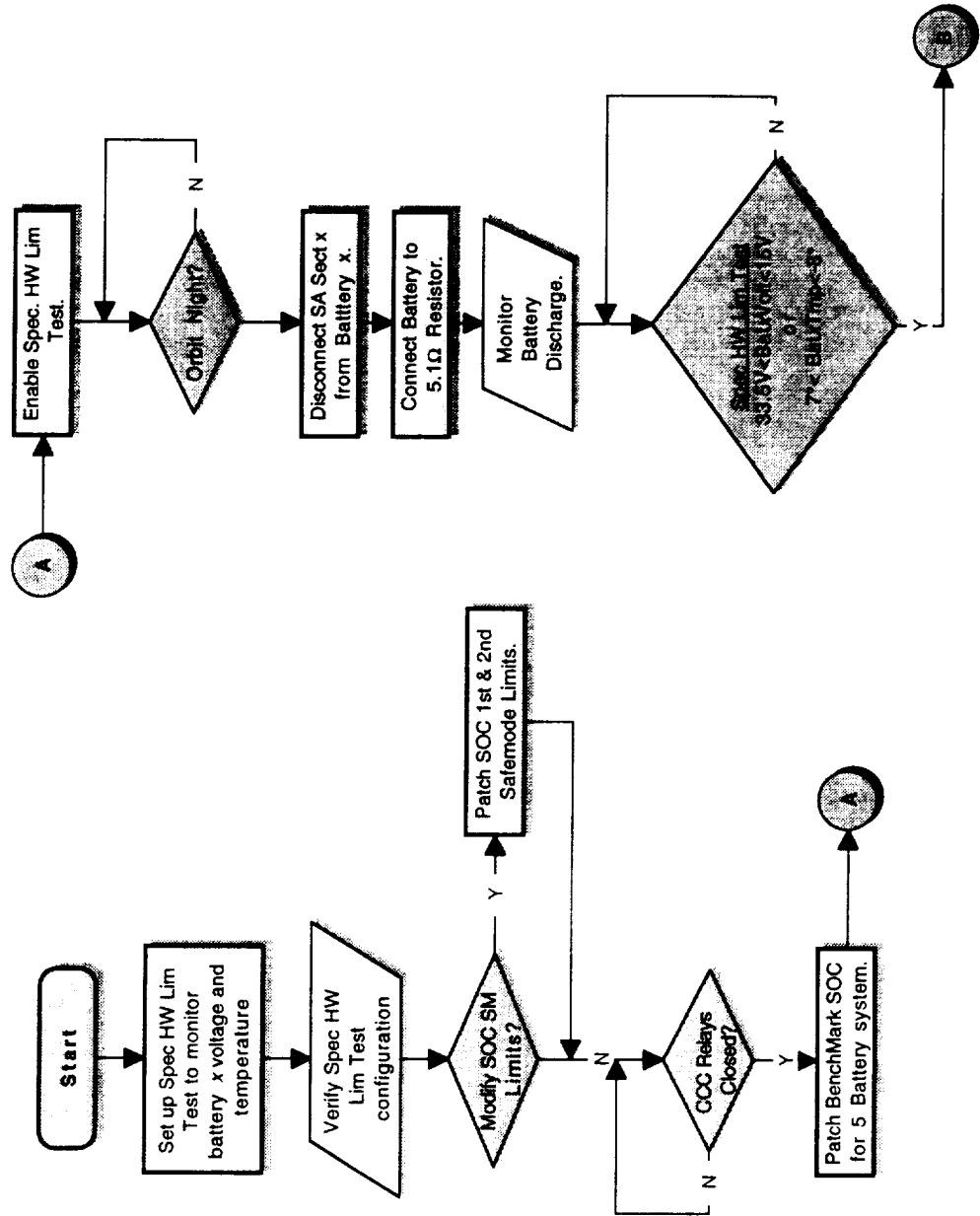
**Terminated by Special HW Limit Test

***Terminated by Safemode Macro



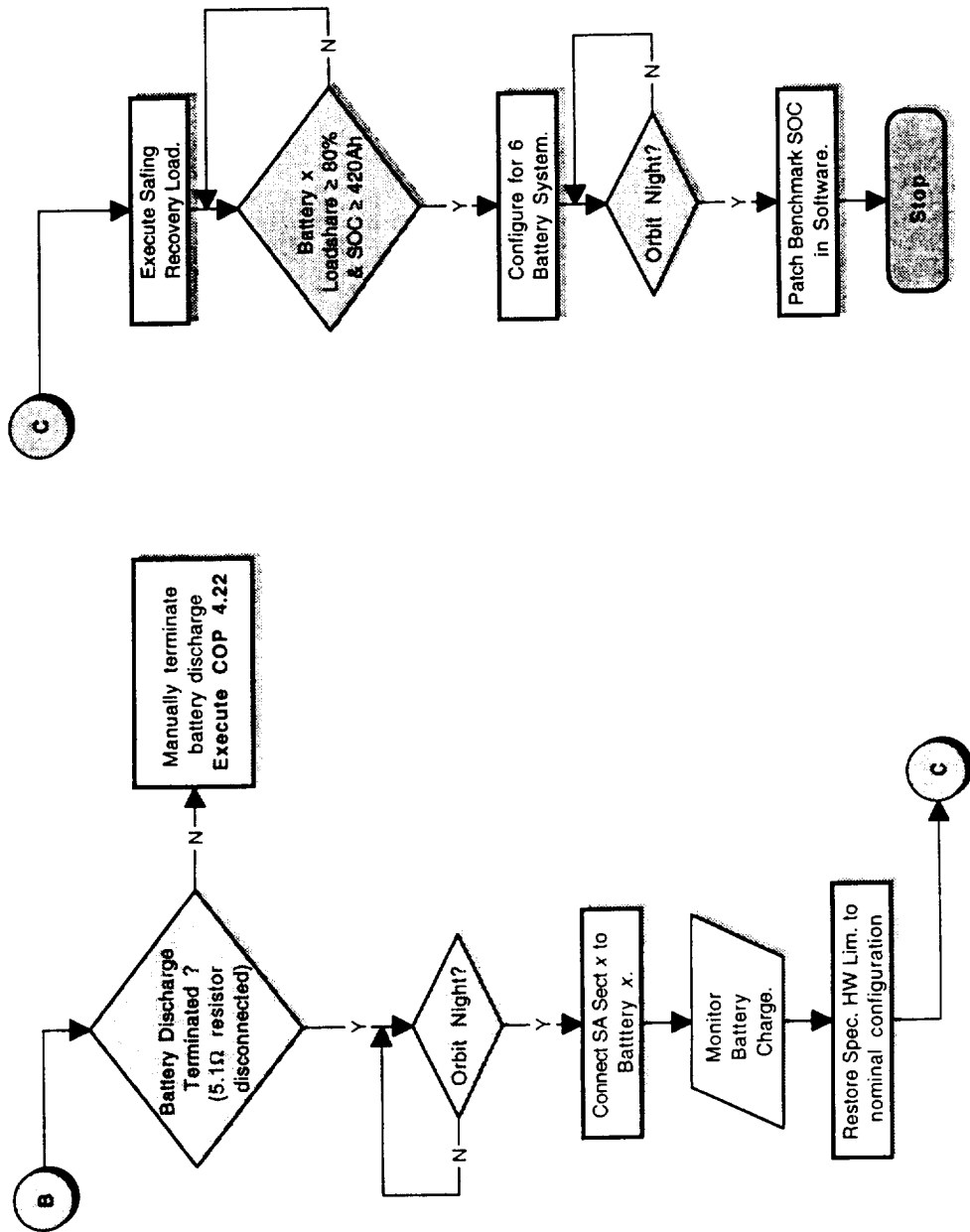
Reconditioning Procedure

BATTERY CAPACITY TEST FLOW





Reconditioning Procedure





Results of Reconditionings

- Capacity
 - Batteries Reconditioned During April 1990 through Sept. 1992 Yielded (Current Integrated) Capacity Between 85.6 and 94.2 Ah
 - Indicated (Pressure Based) Capacity Prior to Reconditioning Ranged Between 88 and 102.6 Ah
 - Pressure transducers are recalibrated following each battery reconditioning
 - Capacity Recovery Very Gradual, Never Reached Original Level
 - Average Loss of \approx 4.8 Ah/bat/year



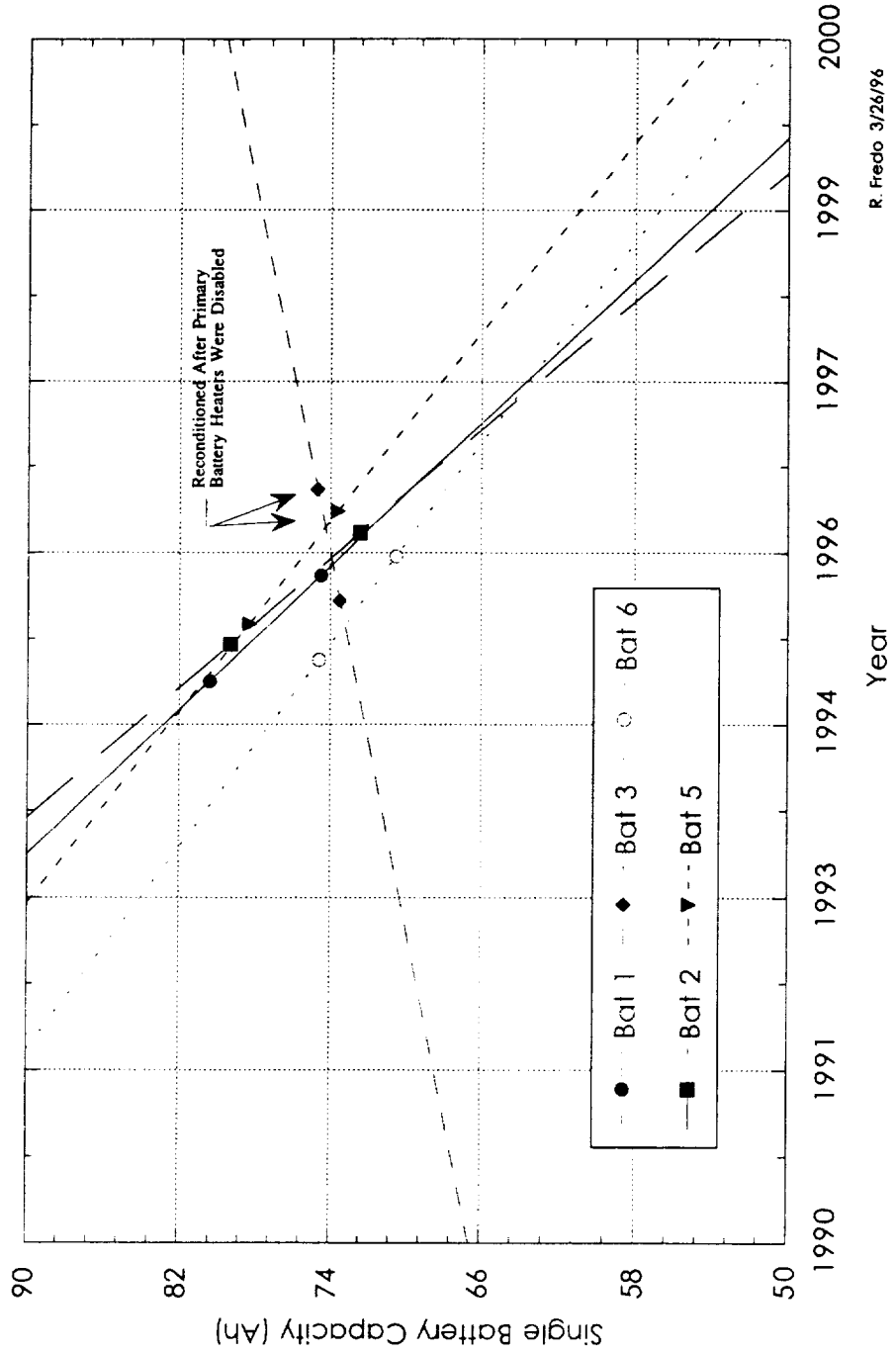
Results of Reconditionings

- Decrease in Capacity Led to Disabling Primary Battery Heaters, Nov. 1995
 - Two Battery Reconditionings Since Heaters Disabled
 - Battery #5, yielded a decrease of 4.6 Ah in capacity, Jan. 1996 (previously tested Feb. 1995)
 - Battery #3, yielded an increase of 1.2 Ah in capacity, Mar. 1996 (previously tested April 1995)



Results of Reconditionings

BATTERY CAPACITY TEST DATA
SLOPE COMPARISON



R. Fredo 3/26/96



Results of Reconditionings

- Cell Balance
 - Reconditionings Following the Lowering of Charge Levels (Dec. 1993) Exhibit a Sluggish Voltage Knee in Contrast to an Earlier Sharp Knee
 - Indicates Cell Imbalance in the Battery
- Residual Pressure
 - Increases in Residual Battery Pressure @ 15V Typically Range Between 6 and 19 PSI
 - Most Recent Data Yielded an Increase of 0 PSI



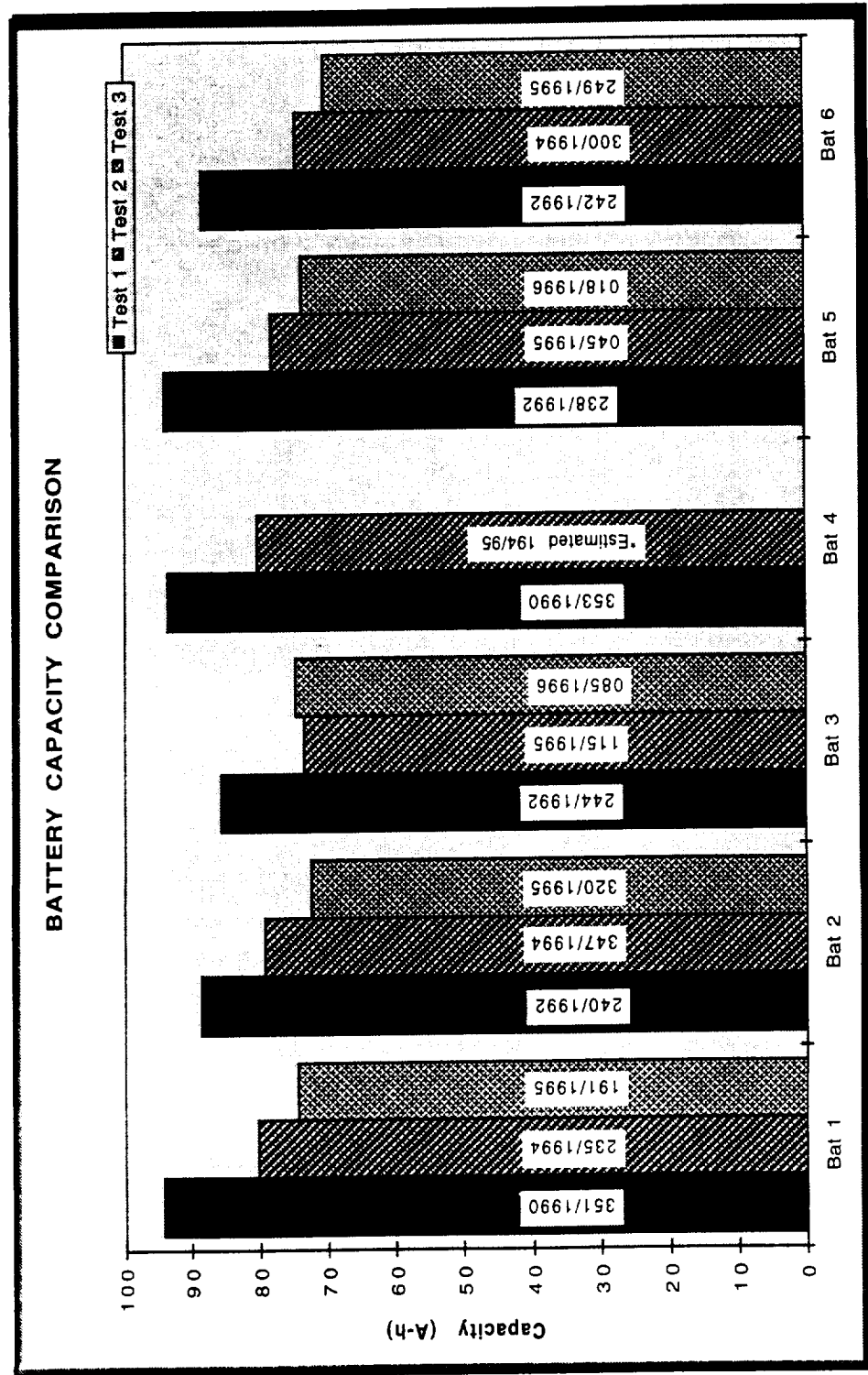
Results of Reconditionings

Battery #	Date of Test (MM/YY)	Battery Pressure min - max (psi)	Pre-test Cap Pressure Based (A-h)	Post-test Cap Current Integrated (A-h)
Launch - CCC 1-6 K2 V-T level 2, CCC 1-6 K1 V-T level 3, Software Charge Ctri: 4/28/90 - CCC 1-6 K2 V-T level 3				
1	Dec-90	980 - 1115	93	94.2
4	Dec-90	937 - 1044	88	93.4
5	Aug-92	991 - 1101	102.6	94
2	Aug-92	1053 - 1163	94	88.5
6	Aug-92	977 - 1094	93.9	88.3
3	Aug-92	951 - 1071	92.3	85.6
3/25/93 - CCC 1-6 K1 V-T level 4, Hardware Charge Ctri				
12/10/93 - CCC 4 K2 V-T level 2; 1/31/94 - CCC 4 K2 V-T level 1				
4/5/94 - CCC 5 K1 level 3 (short between +E hot and +B return.)				
1	Aug-94	1017 - 1136	94.4	80.4
6	Oct-94	979 - 1079	86.5	74.6
2	Dec-94	895 - 1046	82.2	79.3
1/8/95 - SA Slew minimization				
1/20/95 - CCC 5 K1 level 4 (healed short between +E hot and +B return.)				
5	Feb-95	1036 - 1032	94.8	78.3
3	Apr-95	956 - 1035	82.1	73.5
1	Jul-95	1011 - 1119	81.5	74.5
4	*	999 - 1085	100.1	80.4
6	Sep-95	979 - 1052	74.2	70.5
2	Nov-95	885 - 962	76.4	72.4
11/27/95 - Pri Battery heaters disabled				
5	Jan-96	863.9 - 1094	78.7	73.7
3	Mar-96	945 - 1029	74.5	74.7

* The Battery 4 Capacity is an estimate based on the other 5 battery tests. No test of battery 4 was conducted due to PCU relay failures.



Results of Reconditionings





Results of Reconditionings

LoTTS for the Hubble Space Telescope
RECONDITIONING COMPARISON - BATTERY 3
1992:244 vs 1995:115 vs 1996:085:01:45-1996:085:18:00 Minor frame quality: 100.00%
Data for day: 1996:085

Page: HIST004.PS

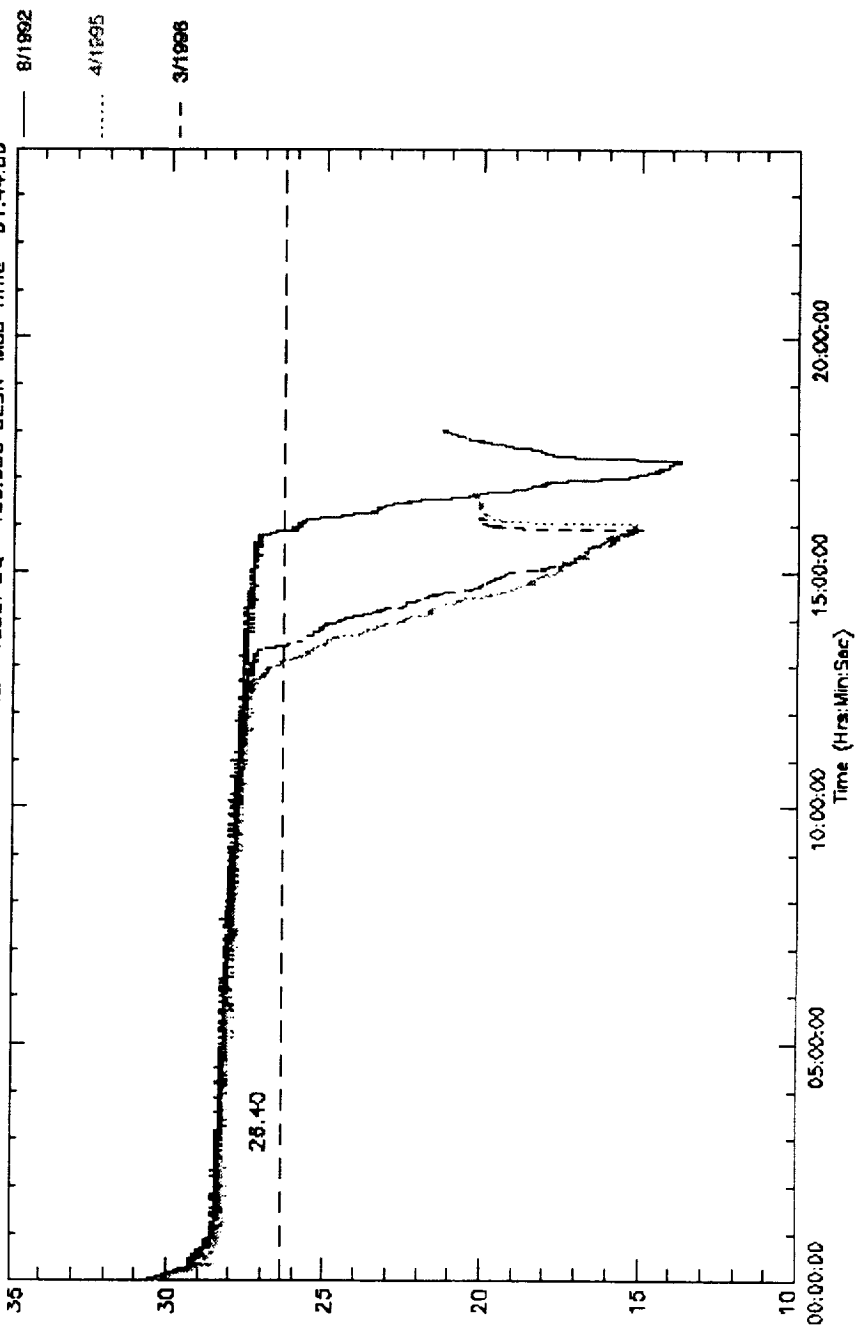
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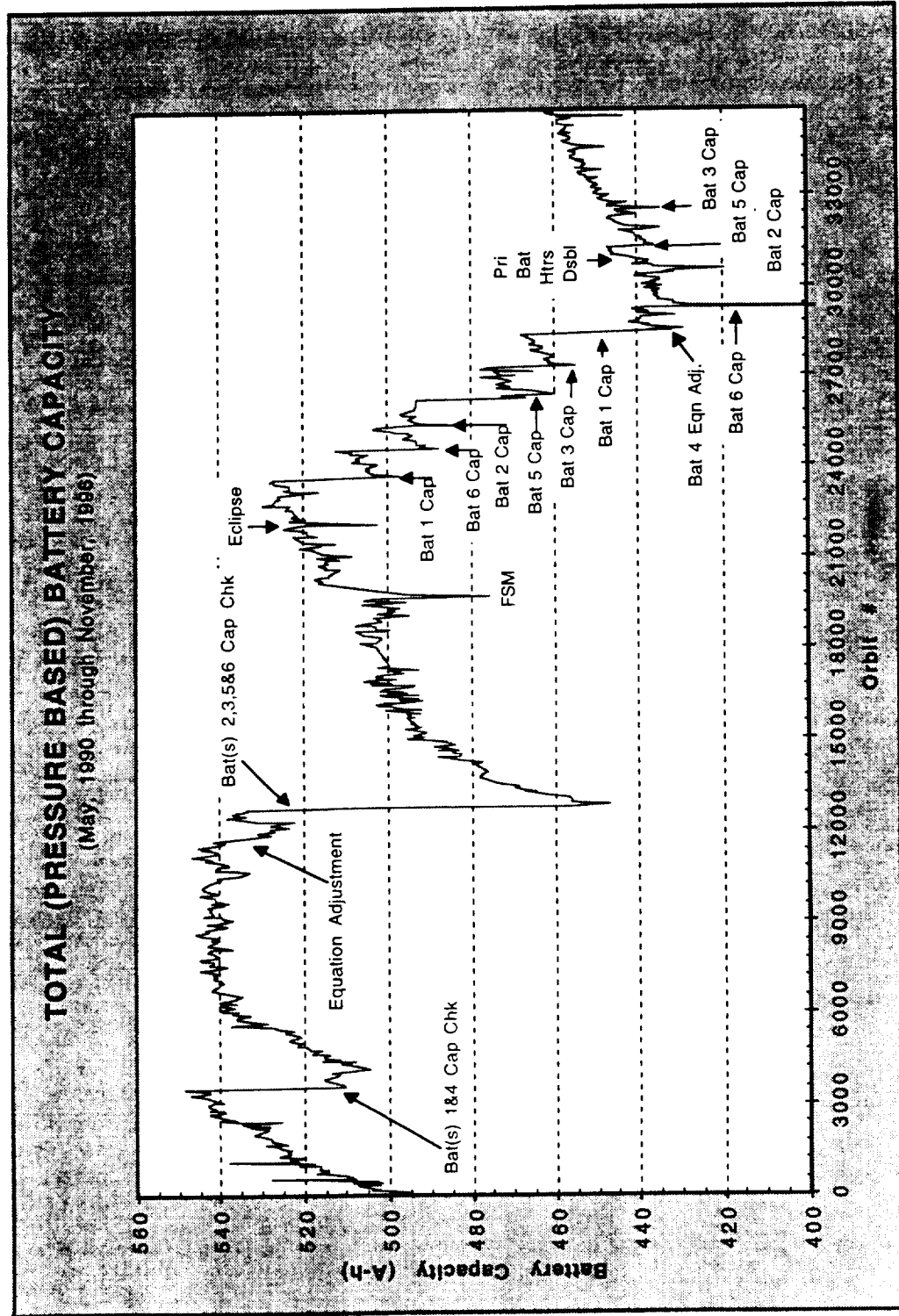
TITLE: Battery 3 Voltage (volt)

MIN = 13.68 MAX = 30.60 AVG = 26.95 STD = 3.220 MED = 28.06 PTS = 7646 DQ = 100.000 DESR = Mod Time --00:49:32
MIN = 15.00 MAX = 30.32 AVG = 26.06 STD = 3.750 MED = 27.92 PTS = 8803 DQ = 100.000 DESR = Mod Time --00:49:32
MIN = 14.81 MAX = 30.60 AVG = 26.69 STD = 3.293 MED = 27.92 PTS = 1630 DQ = 100.000 DESR = Mod Time --01:44:00





Results of Reconditionings





Conclusions

- Battery Capacity, From Reconditioning Data, Decreased Over Time (1990 - 1996)
 - Battery Temperatures Were Decreased by Disabling Primary Heaters, Nov. 1995
 - Allows Batteries to be Charged to Higher Voltage
 - Last Reconditioning Indicated Improvement, Mar. 1996
 - Development of New Charge Scheme is in Progress to Mitigate the Battery Degradation



Conclusions

- Health-Check, Capacity Data Indicated no Need to Refurbish Batteries in the Second Servicing Mission - Feb. 1997
- Reconditioning Decreased the Battery Operating Pressures
- Calculated Battery Capacity, Based on the Pressure Transducers, was Found to be Inaccurate
 - Recalibrated Pressure the Transducers

