HUBBLE SPACE TELESCOPE PROJECT

HST SM4 Cell Verification Studies

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HUBBLE SPACE TELESCOPE PROJECT
SM-4 Battery Shelf Life Study

Shelf Life Requirements

- **Battery Module Specification (4177751) requires:**
  - Useful Life: The Battery Shall Perform Satisfactorily Over ***Five Year Operational Life*** In Orbit After Having Been **Activated And Stored For A Period Not More Than Four Years**

- **Battery Cell Specification (P106652) requires:**
  - Useful Life: The Cell Shall Capable Of **Ten (10) Years Of Useful Life, Including Storage, Test, And Operation.** The ***Design Goal Capacity After 5 Years Of Operation Shall Be 73 Ah At 32 °F***
  - Design Life: The **Orbital Life Shall Be 5 Years While Operating At 14% DOD**
  - Operating And Storage Life: The Cell Shall Ensure Satisfactory Performance Over The 5 Year Operational Life After **Not More Than 5 Years Of Wet Life**
  - Dry Storage Life: **Dry Cells Can Be Stored With Inert Gas For Up To 2 Years**

- **SM-4 Battery cells**
  - Fabricated In 1995-96 & **Dry Stored With Helium Four Years**
  - Activated In 2000 & Will Be **Wet Stored Eight Years When Deployed**

After 4 Year Dry Storage and 8 Year Wet Storage Will 5 Year Mission Life Requirement be Met ?

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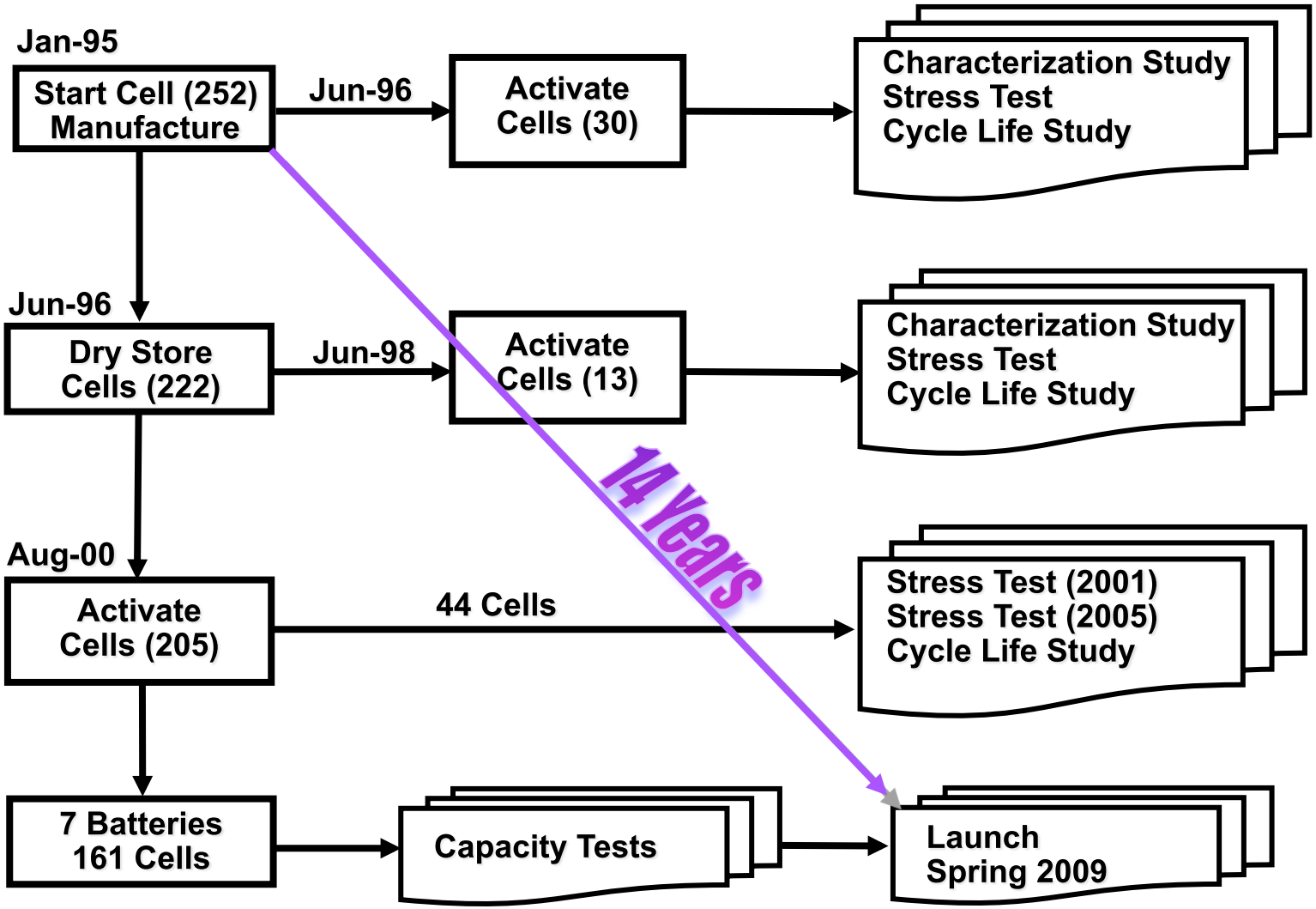
SM-4 Battery Shelf Life Study

HST SM4 Cell Shelf Life Studies



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Dry Cell

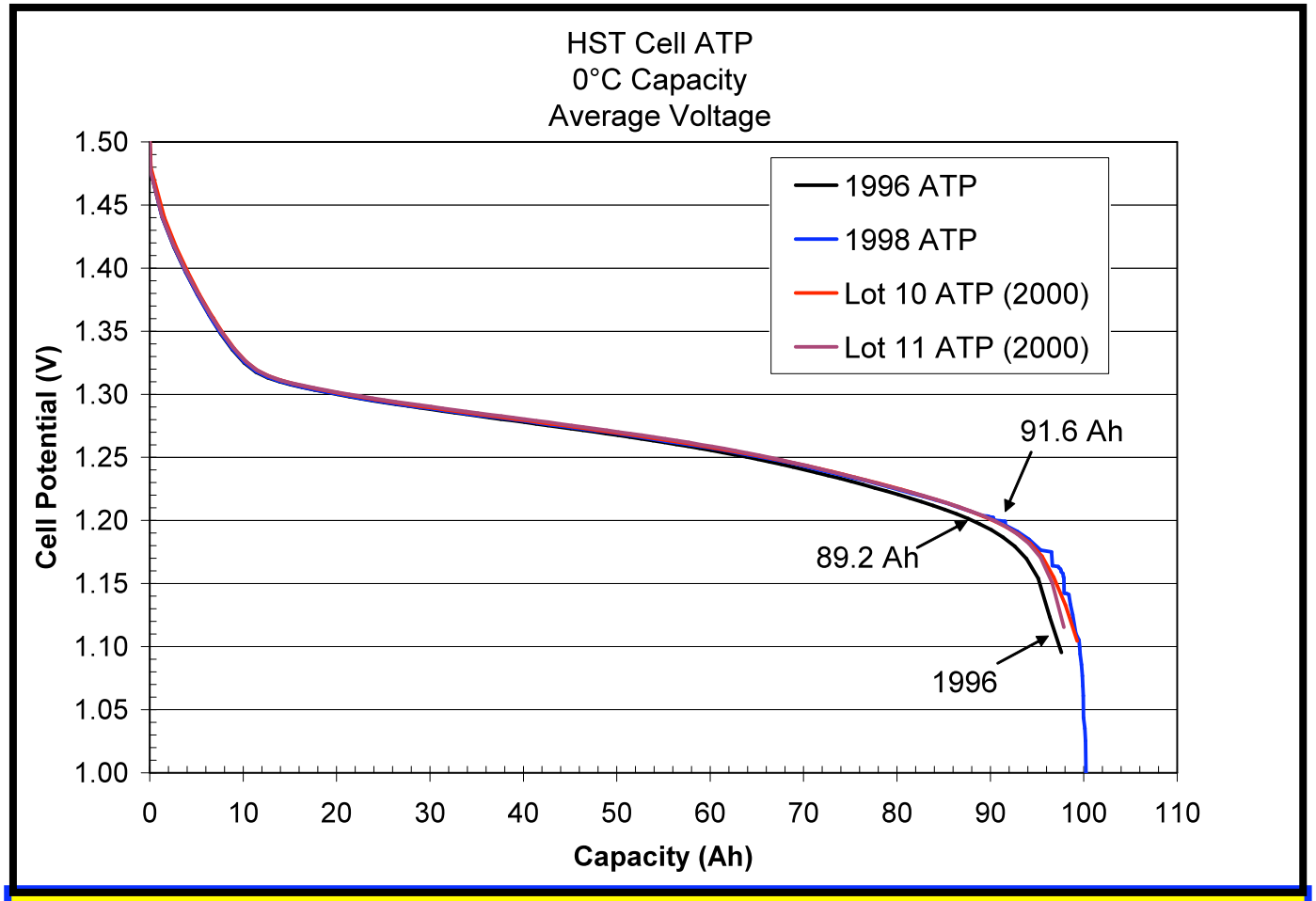
Shelf Life Study

"Effects Of Wet And Dry Storage On Ni-H2 Slurry Electrode Cells", J.D. Armantrout, R.A. Brown, D.V. Gordon and G.M. Rao, IECEC-1999, 1999

"Effects Of Dry Storage On Ni-H2 Slurry Electrode Cells", J. Armantrout & D. Gordon, NASA Aerospace Battery Workshop, Nov. 2000

HUBBLE SPACE TELESCOPE PROJECT
SM-4 Battery Shelf Life Study

Impact upon Cell ATP Capacity Due To Dry Storage Life



No Serious Impact To Flight Cell Capacity Attributable To 4 Year Dry Storage Observed

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Cell Capacity Characterization Study

Dry Sinter *vs*. Wet Slurry

”Voltage *vs.* Temperature Characterization Of Standard 80 Ah Eagle-Picher Ni-H2 Cells”, G.M. Rao, J.D. Armantrout, D.P Hafen, and R.A. Brown, 1990 IECEC

“Performance Characterization of An 80 Ah Nickel-Hydrogen Cell”, D.P Hafen and J.D. Armantrout, 1993 IECEC, Paper 93117

“Performance Comparison Between Ni-H2 Dry Sinter And Slurry Electrode Cells”, J.D. Armantrout, NASA Aerospace Battery Workshop, Nov. 1997

Mission Profile Testing

14% DOD Spec

HUBBLE SPACE TELESCOPE PROJECT
SM-4 Battery Shelf Life Study

HST Mission Profile Cycle Life Tests

- **1996 Pre-Production Cells**
  - MSFC Six 5-cell Pack Test Demonstrated 1,700 LEO Cycles At 10% DOD
  - Placed Into Cold Storage For 5 Years
  - Exhibited Additional 5,500 Cycles At 10% DOD After Cold Storage
  - HST Cells Exhibited Second Plateau Capacity (3 Packs)
  - LM Cells Did Not Exhibit Second Plateau Capacity (3 Packs)

2nd Plateau Likely Result Of Temperatures Up To 30 °C (86 °F) During Cell Characterization

- **2000 Flight Cells**
  - MSFC Six 5-cell Pack Test Demonstrated 30,700+ Cycles At 10% DOD
  - No Signs Of Second Plateau Formation
  - After Five Years Of Cycling
    - Packs Demonstrated Discharge Capacity Of 61.1 Ah
    - Battery Cell Spec (P106652) Design Goal 73 Ah After 5 Years

5 Years of 10% DOD Cycles Demonstrated Did Not Meet 73 Ah Capacity Goal After 5 Years Cycling

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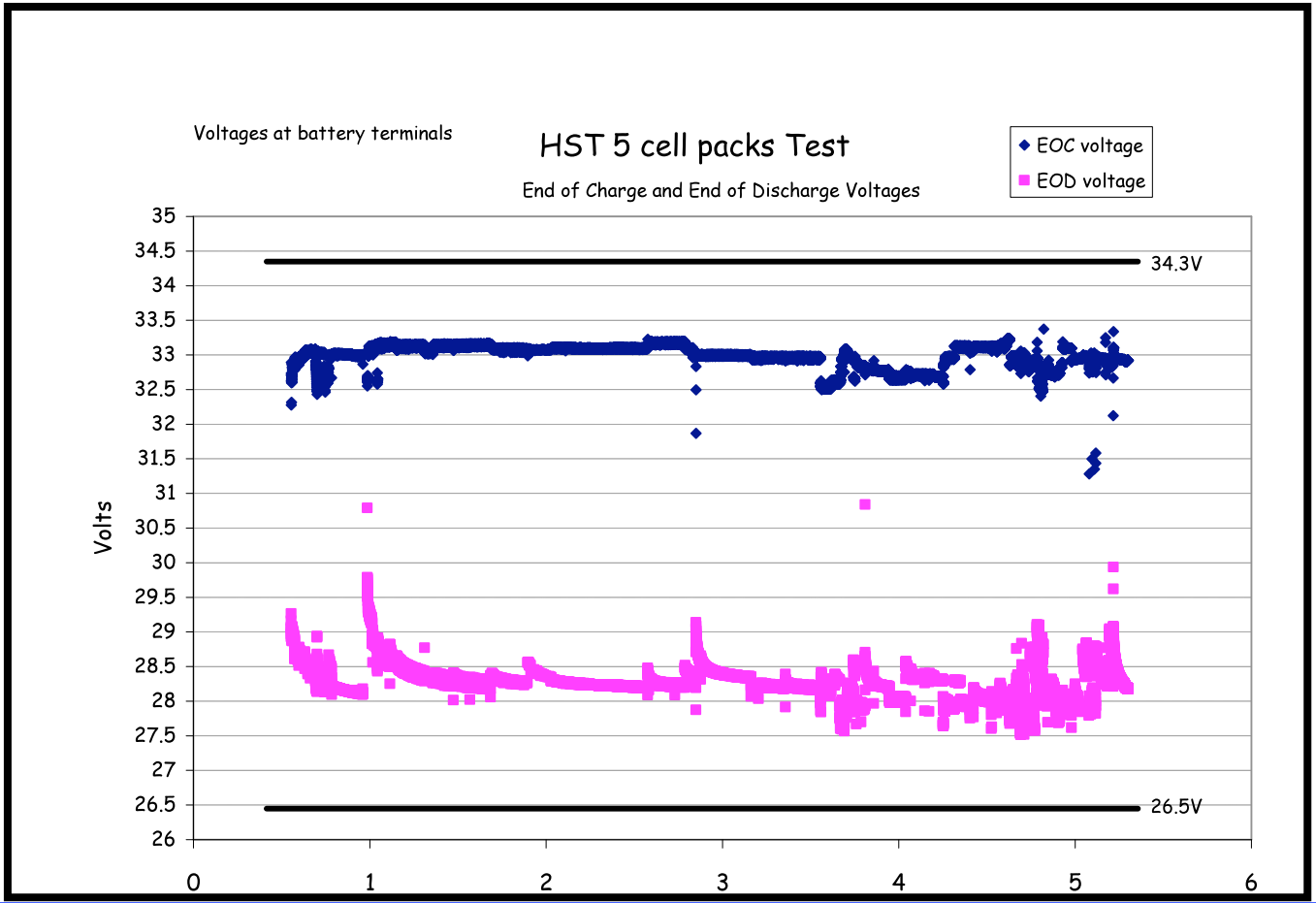
HUBBLE SPACE TELESCOPE PROJECT
SM-4 Battery Shelf Life Study

MSFC 10% DOD Mission Profile Cycle Life Study
5 Year EOCV – EODV Trend



EOCV and EODV Within Specified Voltage Limits

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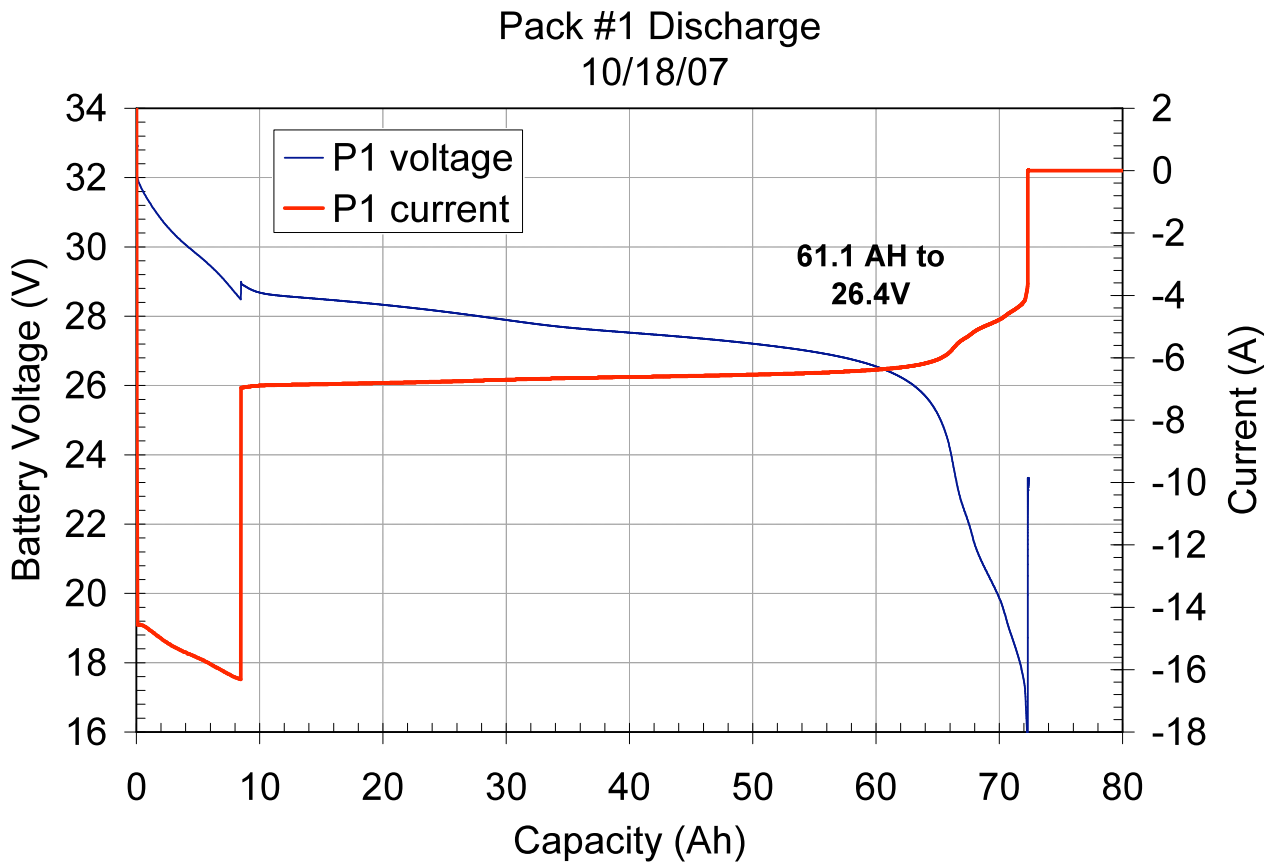
SM-4 Battery Shelf Life Study

MSFC 10% DOD Mission Profile Cycle Life Study
Battery Recondition After 5 Years Mission Cycles



Capacity Test (Letdown) After 5 Years 10% DOD Mission Profile Cycling – Cell Spec Goal = 73 Ah

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60 % DOD

LEO Stress Test Studies

HUBBLE SPACE TELESCOPE PROJECT
SM-4 Battery Shelf Life Study

60% DOD LEO Stress Test Studies

- **1996 Pre-production Cells**
  - 6-cell Pack Demonstrated 9,000 Cycles "Failure" At COMSAT.
  - Failure Is Defined As Cell Voltage Below 1.00 V At End Of 60% DOD LEO Eclipse Period
- **1998 Pre-production Cells**
  - 6-cell Pack Demonstrated 7,500 Cycles "Failure" At COMSAT
  - Pack Demonstrated Additional 7,000 HST LEO Cycles at 12% DOD Following Stress Test
- **2000 Flight Cells**
  - 5-cell Pack F602H (NAVSEA-Crane) Demonstrated 17,500 Cycles "Failure"
    - Pack Demonstrated Additional 14,800+ LEO Cycles At 15% DOD Following Stress Test
  - 5-cell Pack E603H (NAVSEA-Crane), Stored Cold (32 °F) For 5 Years
    - 60% DOD Stress Demonstrated 7,000 Cycles "Failure"
    - Pack Demonstrated Additional 2000+ LEO Cycles at 15% DOD Following Stress Test

Results Impacted By Inconsistent Thermal Control

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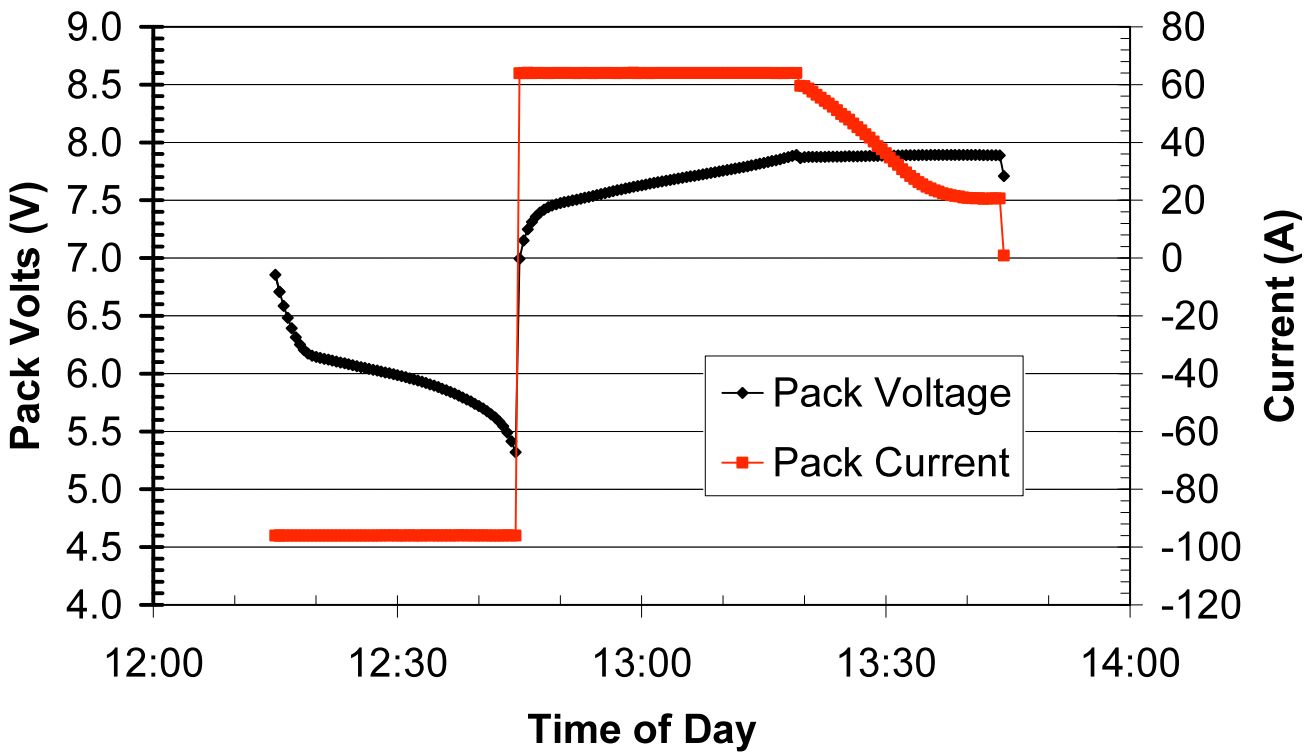
HUBBLE SPACE TELESCOPE PROJECT
SM-4 Battery Shelf Life Study

60% DOD LEO Stress Test (10 °C)
Typical Cycle

Cycle 7200



- High Discharge Rate (96A) and High Charge Rate (64A) Result in High Heat
  - Stresses Electrodes
  - Stresses HST 0.25 inch Terminals & Zytel Seals

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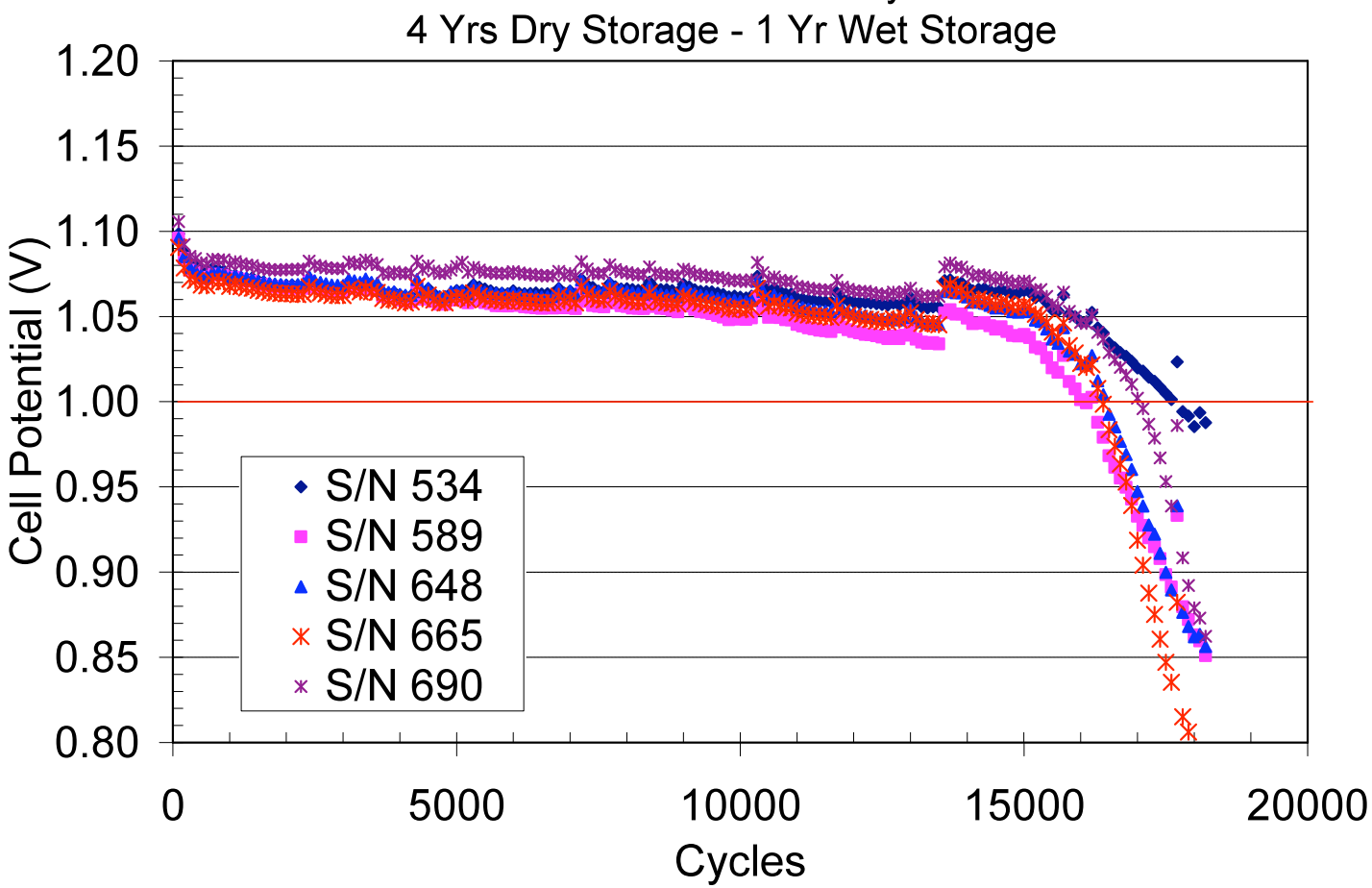
HUBBLE SPACE TELESCOPE PROJECT
SM-4 Battery Shelf Life Study

60% DOD LEO Stress Test (Crane Pack F602H)
End of Discharge Cell Voltage Trend



>17,500 Cycles at Voltages Above 1.00 V Cutoff

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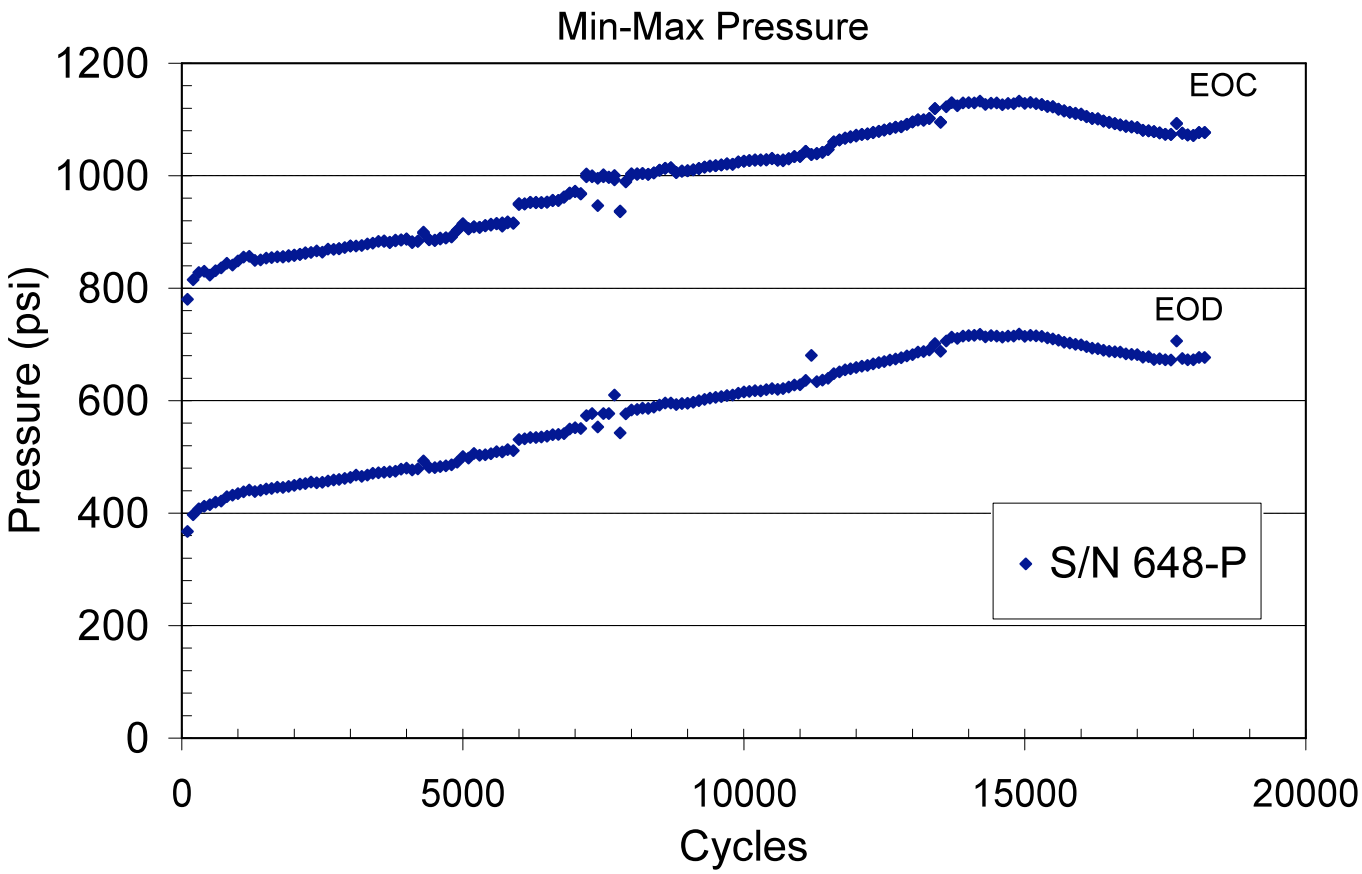
SM-4 Battery Shelf Life Study

60% DOD LEO Stress Test (Crane Pack F602H)
End of Charge/Discharge Pressure Trending



Pressure Increases as Nickel Precharge is Consumed

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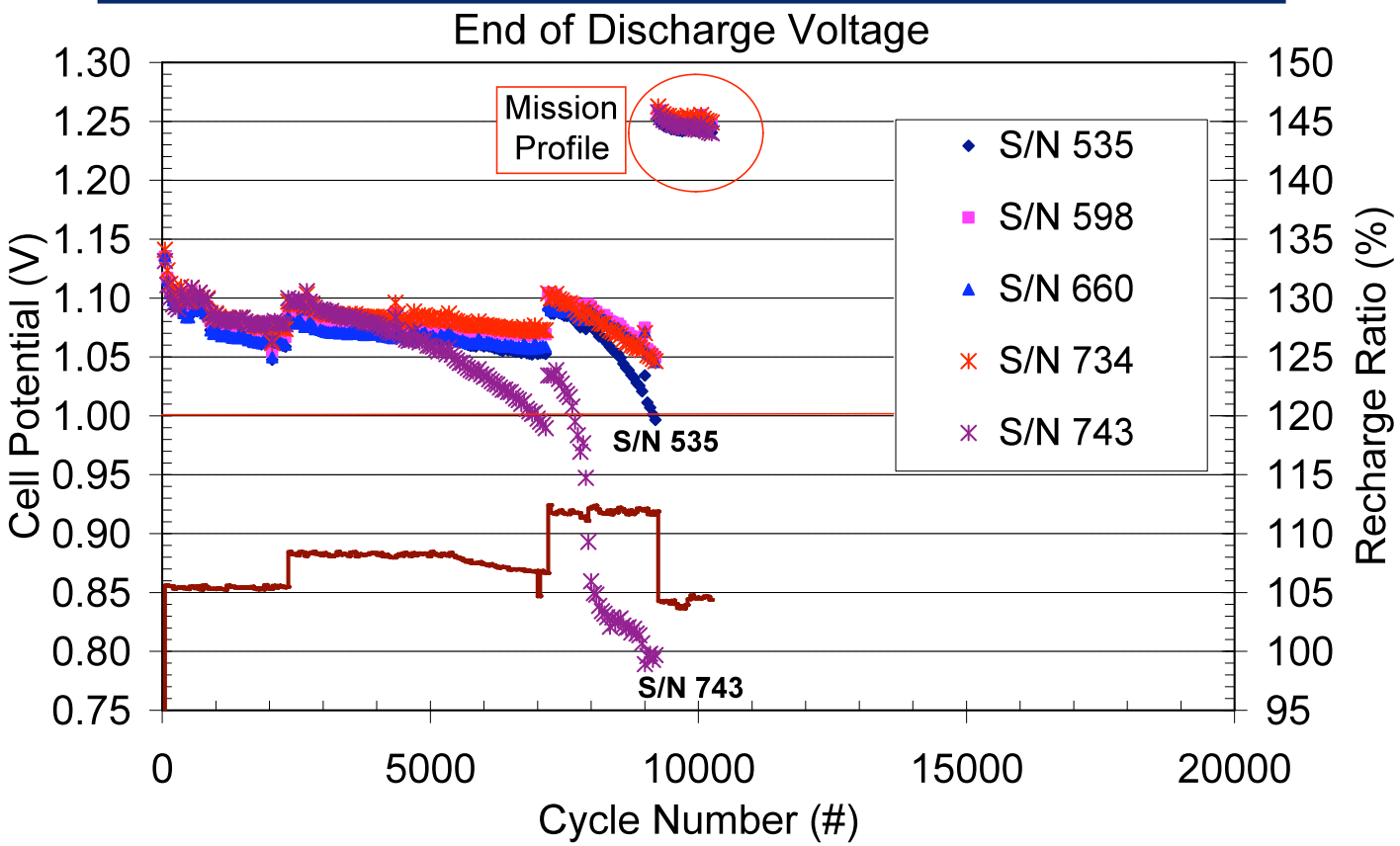
HUBBLE SPACE TELESCOPE PROJECT
SM-4 Battery Shelf Life Study

60% DOD LEO Stress Test (Crane Pack E603H)
End of Discharge Cell Voltage Trend



>7,000 Cycles at Voltages Above 1.00 V Cutoff
Significant 2nd Plateau Capacity on S/N 743

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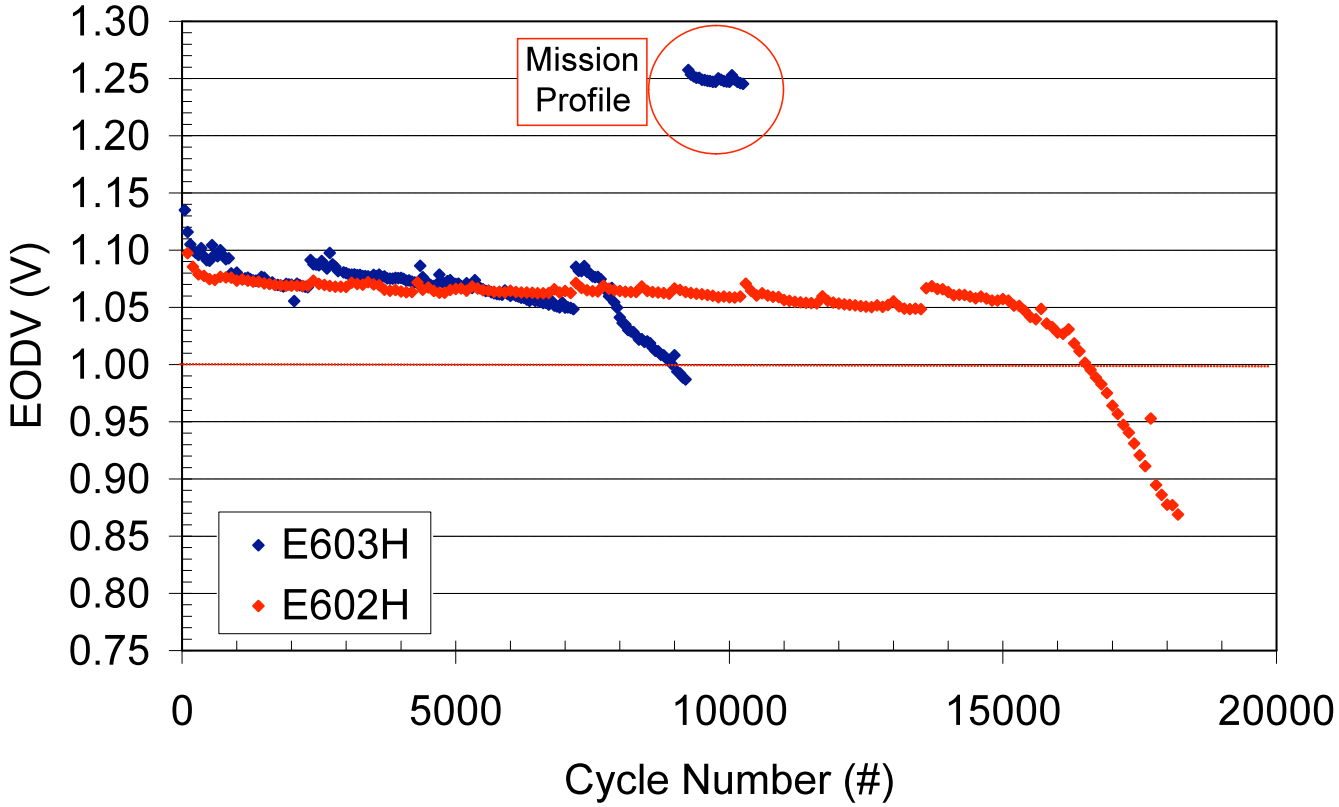
SM-4 Battery Shelf Life Study

Comparison of 60% DOD LEO Stress Test Results
Average End-of-Discharge Voltage Trend



Significant Cycle Life Impact Due To Storage Traced to Possible Environmental Differences And Wet Storage Life

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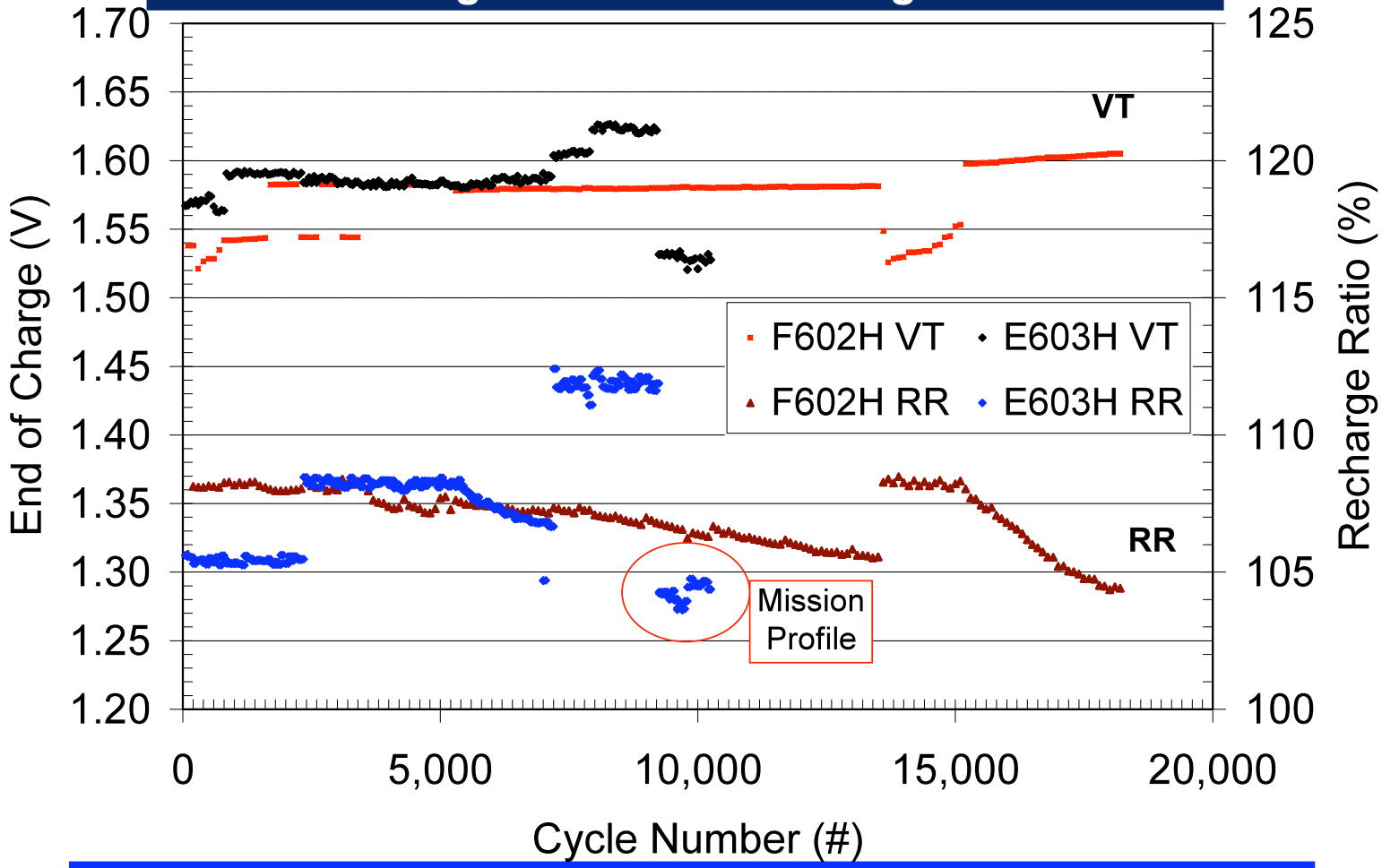
SM-4 Battery Shelf Life Study

Comparison of 60% DOD LEO Stress Test Results
Recharge Ratio and VT Charge Level



VT and Recharge Ratio Settings Similar

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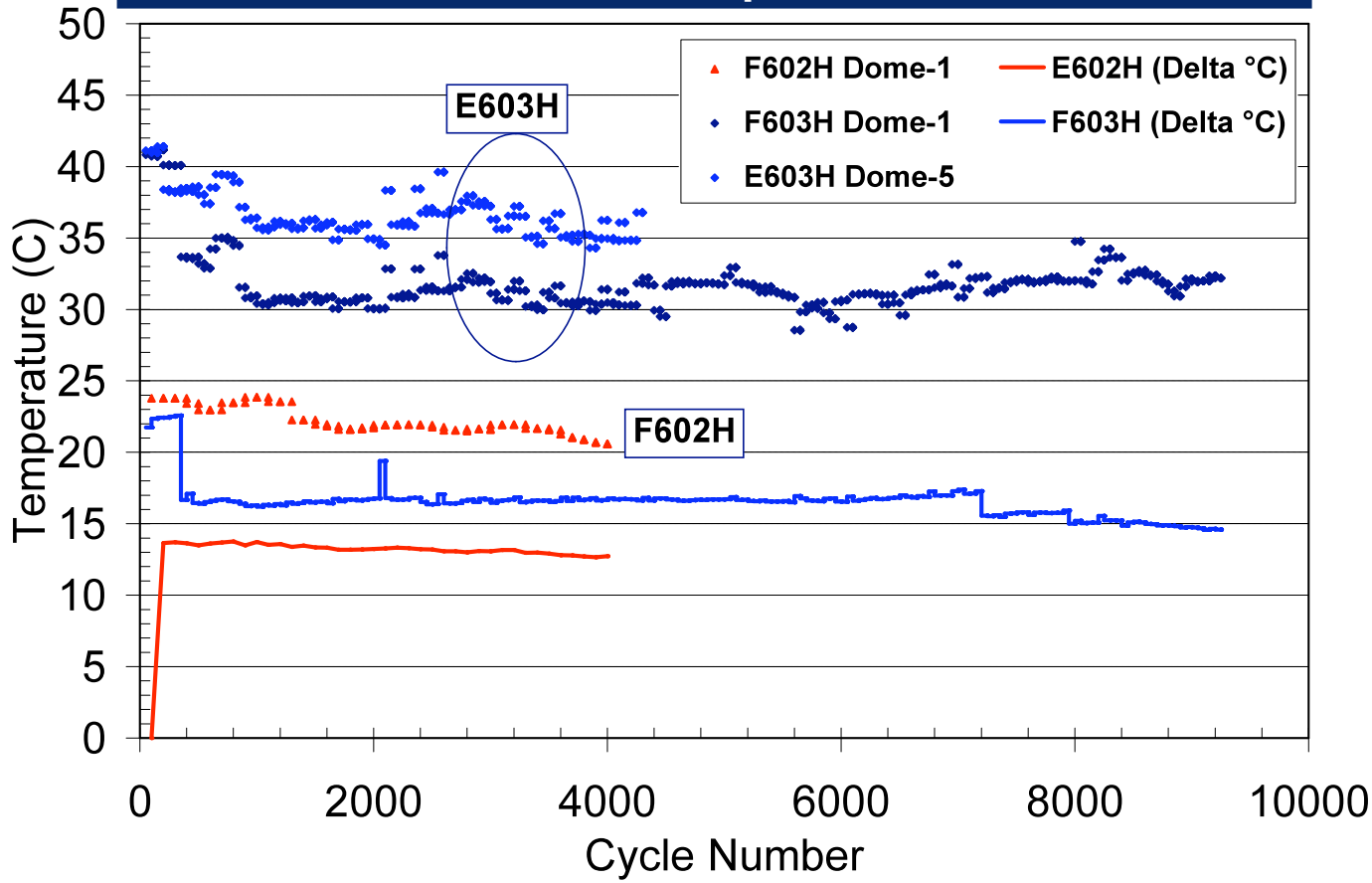
SM-4 Battery Shelf Life Study

Comparison of 60% DOD LEO Stress Test Results Dome Temperature



Dome Temperatures of 5-Yr Cold Stored Cells Higher Different Ambient Environment

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HST Cycle Life Projection

For

SM4 Flight Modules

"Cycle Life vs. Depth of Discharge Update on Modeling Studies", Lawrence Thaller, NASA Aerospace Battery Workshop, p. 377, Nov. 1993

"Ni-H2 Battery Reliability Update", D.P. Hafen, 1998 NASA Aerospace Battery Workshop, Oct. 27, 1998

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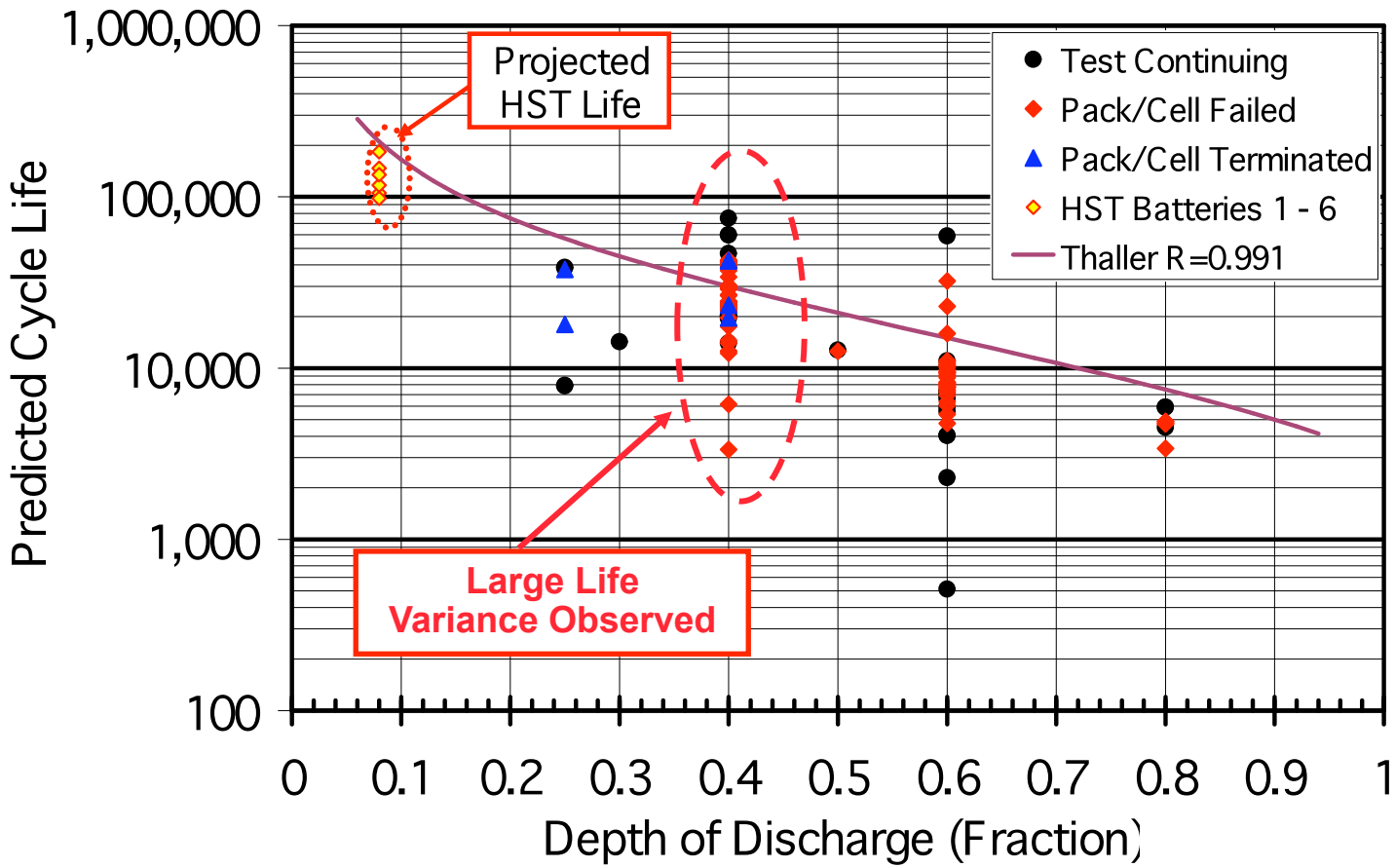
SM-4 Battery Shelf Life Study

NiH_2 Cycle Life Projection
Thaller & Hafen



Many Test Assets in Cycle Life Analysis

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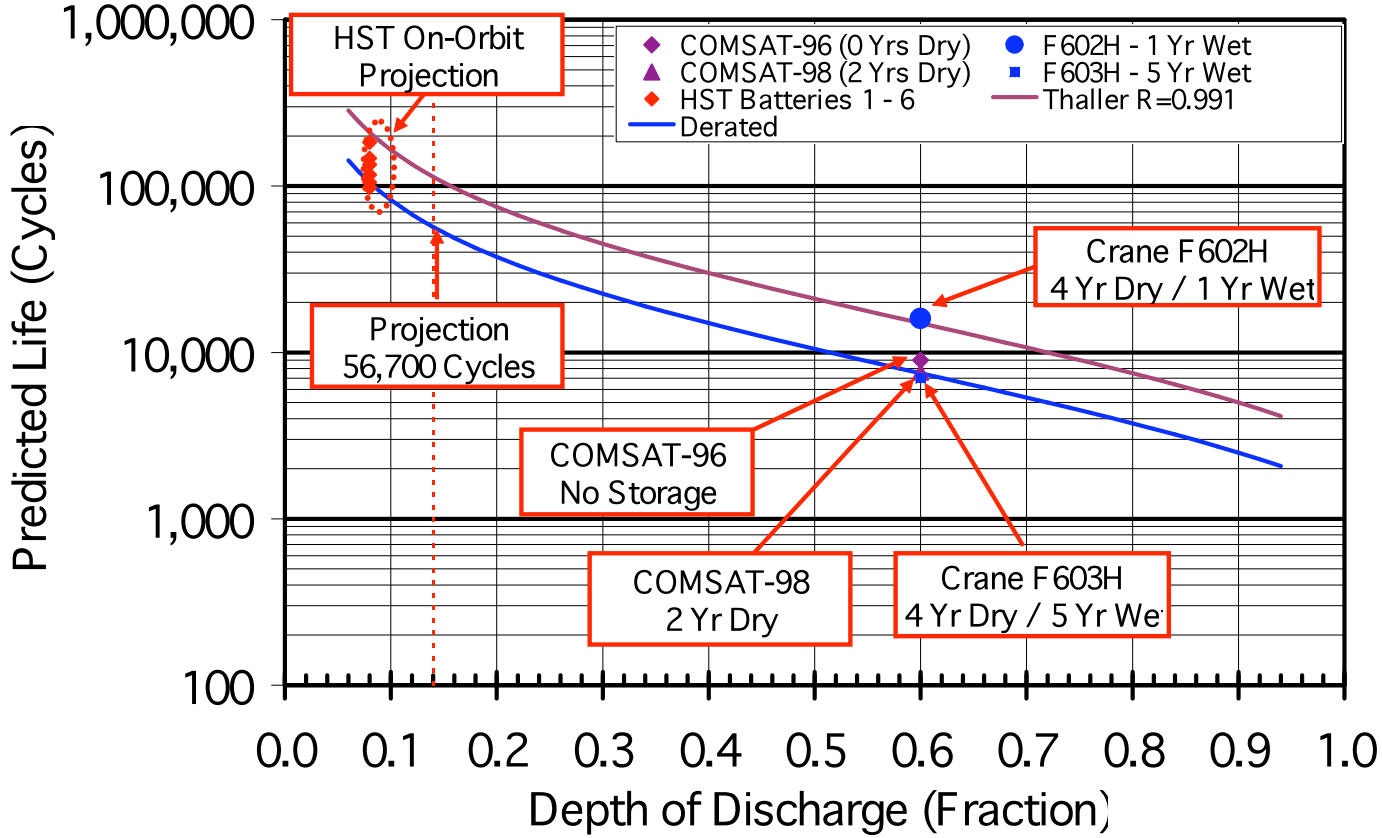
SM-4 Battery Shelf Life Study

Cycle Life Projection
Modified For HST Stress Test Data



HST SM4 Cycle Life Projects at ~10 Yrs Based Upon 5 Yr Wet Storage

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HUBBLE SPACE TELESCOPE PROJECT
SM-4 Battery Shelf Life Study

Summary of HST Cell Studies

- **4 Year Dry Stored Cell Studies**
  - No Capacity Impact due to Dry Storage

- **HST Duty Cycle Life Studies**
  - 5 Year Cycle Life (30,700+ Cycles) Demonstrated at 12% DOD
  - 61 Ah Capacity Check, After 5 Years
    - Does Not Meet 73 Ah BMA Spec "Goal"
    - Goal Only

- **60% DOD LEO Stress Cycle Life Studies**
  - 17,500 Cycles for Cells Dry Stored 4 Years
  - 7,000 Cycles for Cells Cold Stored for additional 5 Years
    - Higher Dome Temperatures Observed

- **Projected HST Battery Life**
  - 56,700 Cycles or 10.3 Year On-Orbit Life at 14% DOD

Acknowledgement

- **This Work Was Supported by NASA Contract Mod 593 Dated 2 June 1987**
  - Directed LMSC to Design, Develop and Deliver Nickel-hydrogen Battery Modules
  - For the Hubble Space Telescope Low Earth Orbit Mission
    - Per NAS 8-32697 and NAS 5-5000.