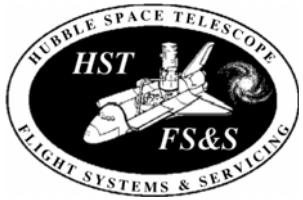
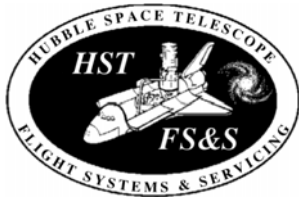


LOCKHEED MARTIN

NiH_2 LEO Cycle Life Study

Roger P. Hollandsworth
Jon D. Armantrout
Lockheed Martin Space Systems Operations
Sunnyvale, CA

Gopalakrishna M. Rao
NASA/Goddard Space Flight Center
Greenbelt, MD



LOCKHEED MARTIN

Mantech Cell Cycle Test History

- **Mantech Cells on Duty Cycle Test at 41 °F at Various Load Levels Since 1996**
  - **Generic LEO Load Profile with Peak Load Test for Minimum Voltage Test**
  - **Concern With Spacecraft is Low Bus Voltage Trip into Safe-Mode**
  - **Reconditioning Scheduled Annually During Cycling**
  - **Also Perform Reconditioning to Maintain Voltages Above Minimum Requirement**
    - **19 - 22 Cells in Series Configuration**

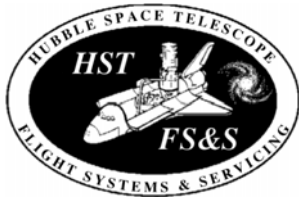
- **Lot 1 Slurry Process Cells Added 3/96 - Completed 35.2K Cycles**

- **Lot 2, 3 Slurry Process Cells Added 9/97 - Completed 26.7K Cycles**

- **HST Dry Sinter Cells (3) added 9/97**
  - **Previously Cycled 6 Years at MSFC (~33K Cycles) - Unknown Storage History**
  - **Removed From Test 10/00 (16K + ~33K Cycles) - Cold Storage @ EPT**

- **Lot 5 Slurry Process Cells Added 10/98 - Completed 21.0K Cycles**

- **Lot 6 Slurry Process Cells Added 10/00 - Completed 10.5K Cycles**

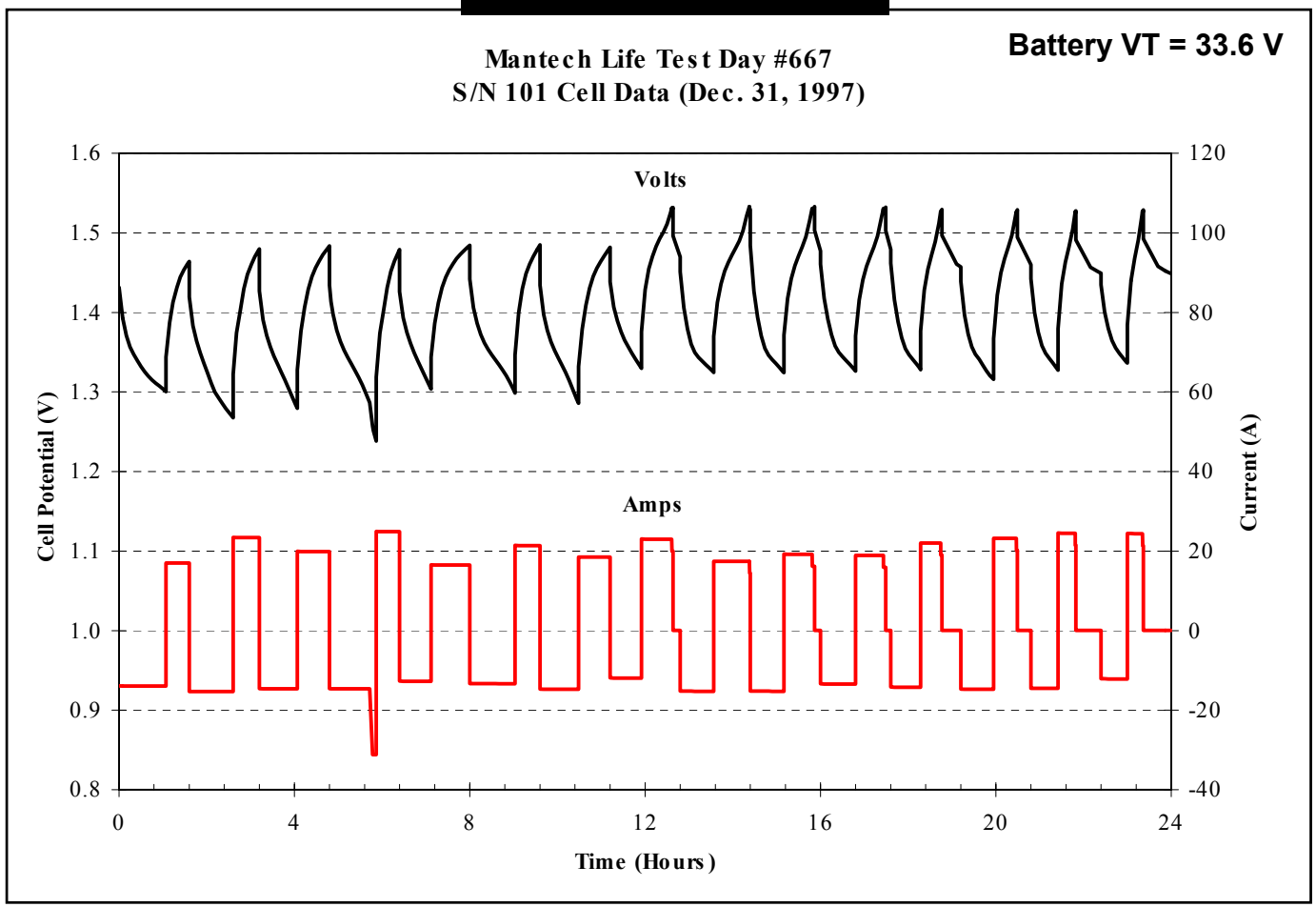


LOCKHEED MARTIN

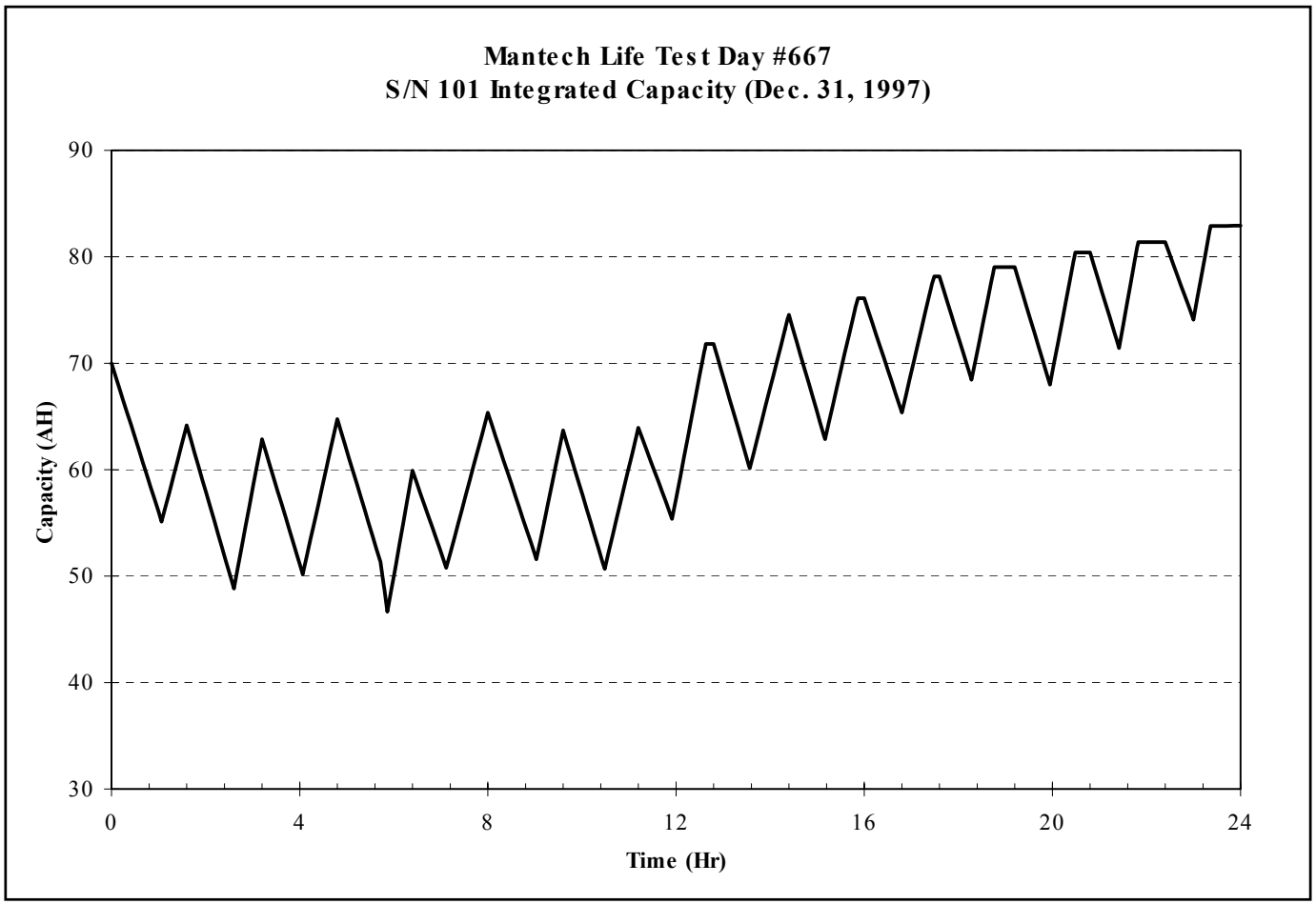
Eagle Picher Cell Life Test Load Profiles

Test Profile	Ave. Dischg. Amps	Ave. Dischg. Minutes	Ave. Batt. Load Ahout/rev	Max. DOD AH	Peak Load Amps	Battery Max V	Profile Dates	Comments
ML1	12.8	52.3	11.2	28.8	15.2	33.1	3/14/96 -	Lot 1 Cells (3/96)
ML2	12.8	52.3	11.2	33.0	25.0	33.1	- 4/26/97	
HL1	16.2	49.3	13.3	32.4	32.4	33.1/33.6	4/26/97 - 8/18/97	
HL7	14.8	49.3	12.2	25.1	31.2	33.6	8/18/97 - 9/13/97	
HL8	14.2	49.3	11.7	22.0	31.2	33.6	9/13/97 - 1/28/98	Lot 2, 3, HST Cells Added (9/97)
UHL	11.7	47.3	9.2	40.8	27.3	33.2	1/28/98 - 5/23/98	
HL8	14.2	49.3	11.7	22.0	31.2	33.2	5/23/98 - 10/9/98	
HL10M	15.0	49.3	12.4	30.0	32.3	33.2/33.6	10/9/98 - 8/9/99	Lot 5 Cells Added (10/98)
HL12M	13.9	49.3	11.4	25.7	29.4	32.8/33.0	8/9/99 - 6/22/01	HST Cells Removed Lot 6 Added (10/00)
HL14R	10.8	47.4	8.6	14.1	30.0	32.8	6/22/01 - 3/21/02	
HL15R	10.8	47.4	8.6	17.1	30.0	32.8/33.0	3/21/02 -	

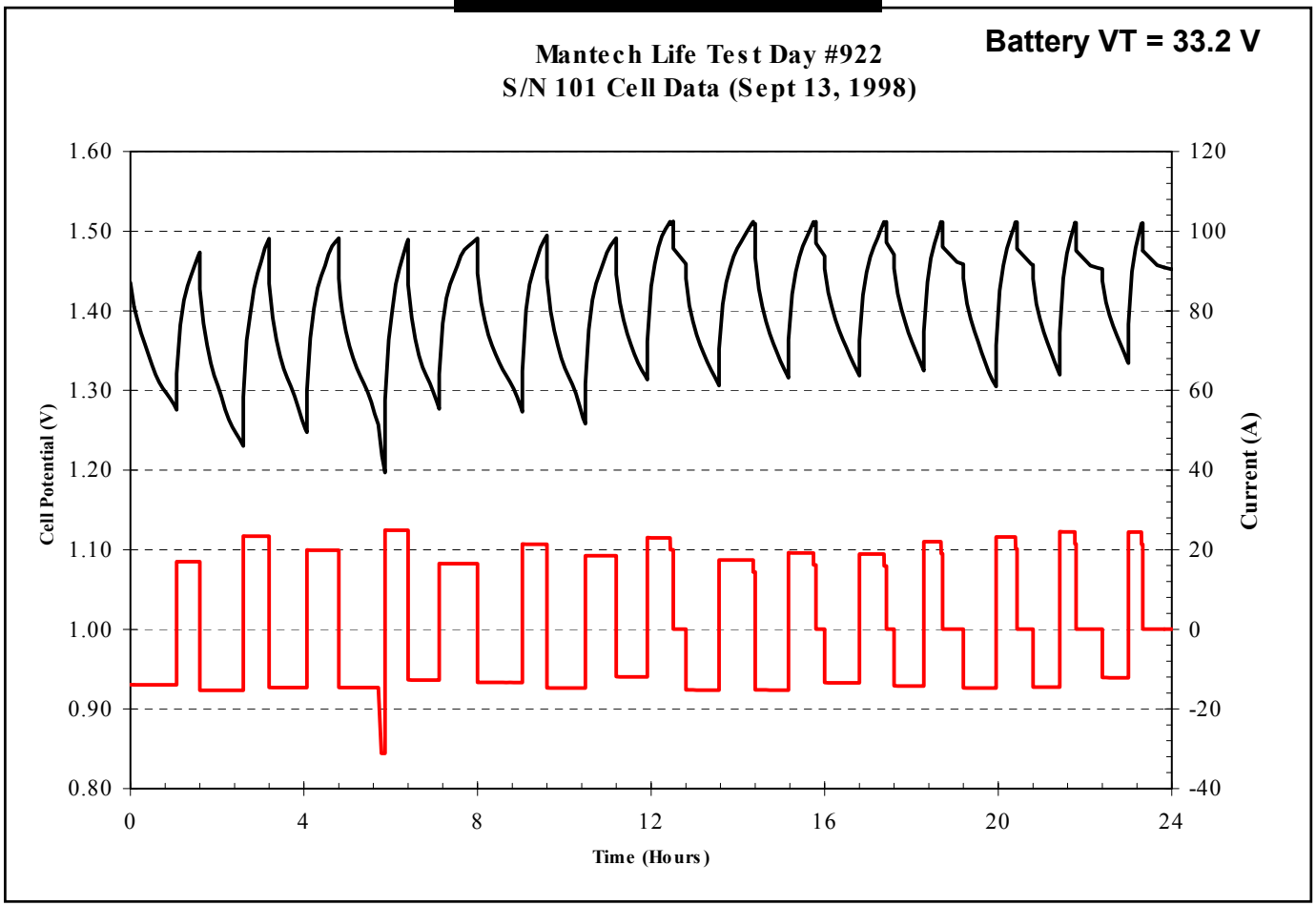
Cell Life Study
HL8 Test Profile



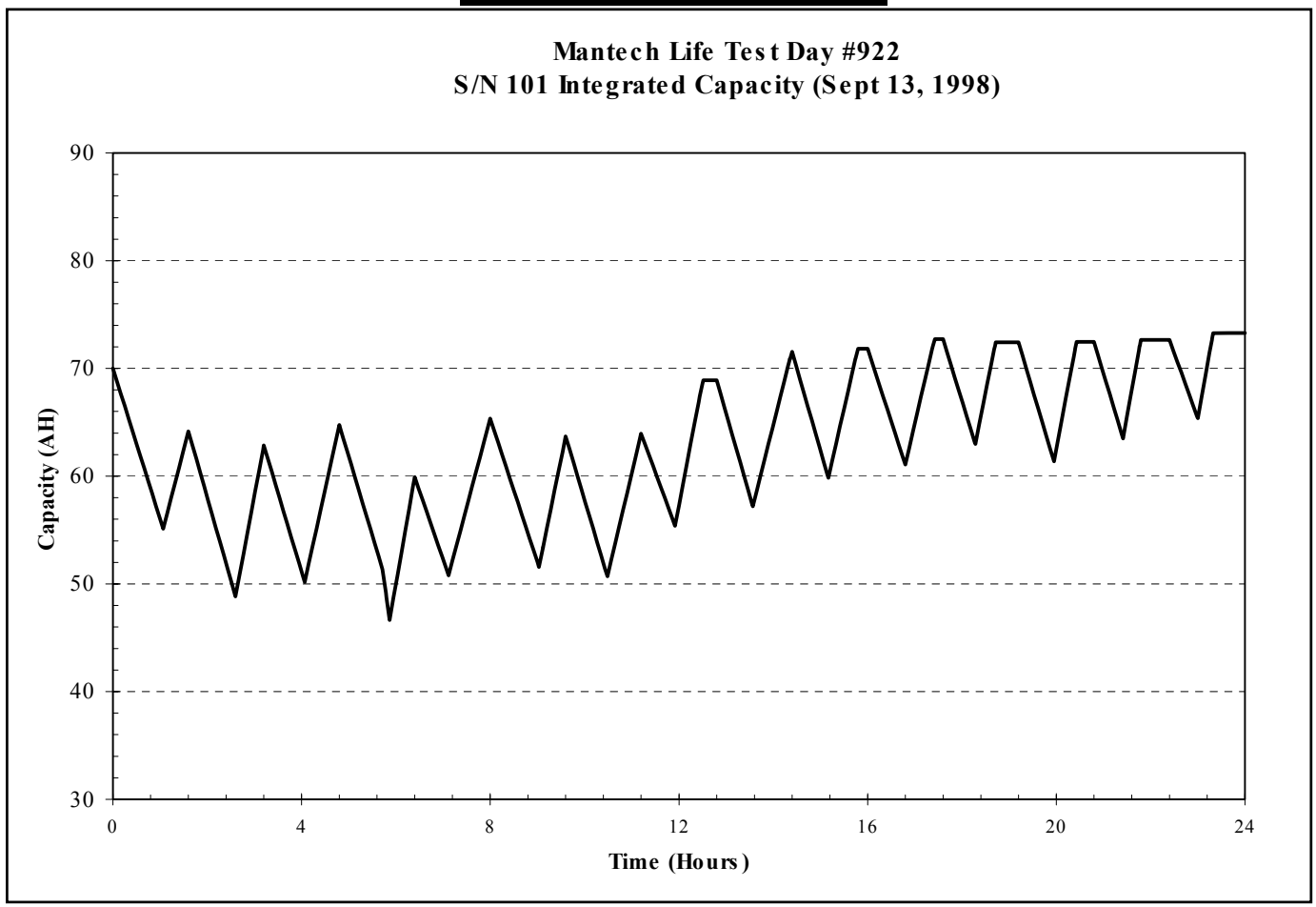
Cell Life Study
HL8 Test Profile



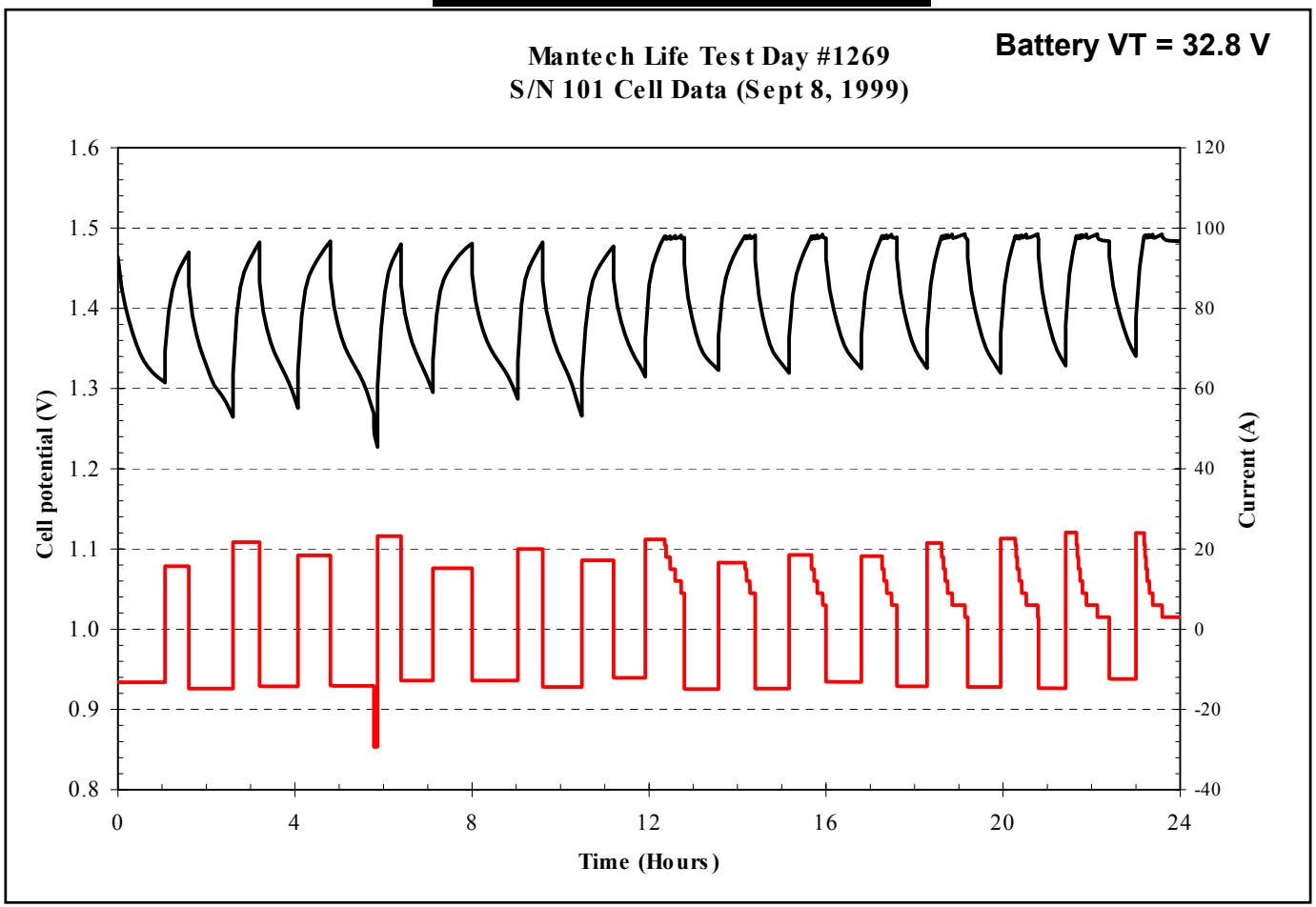
Cell Life Study
HL8 Test Profile



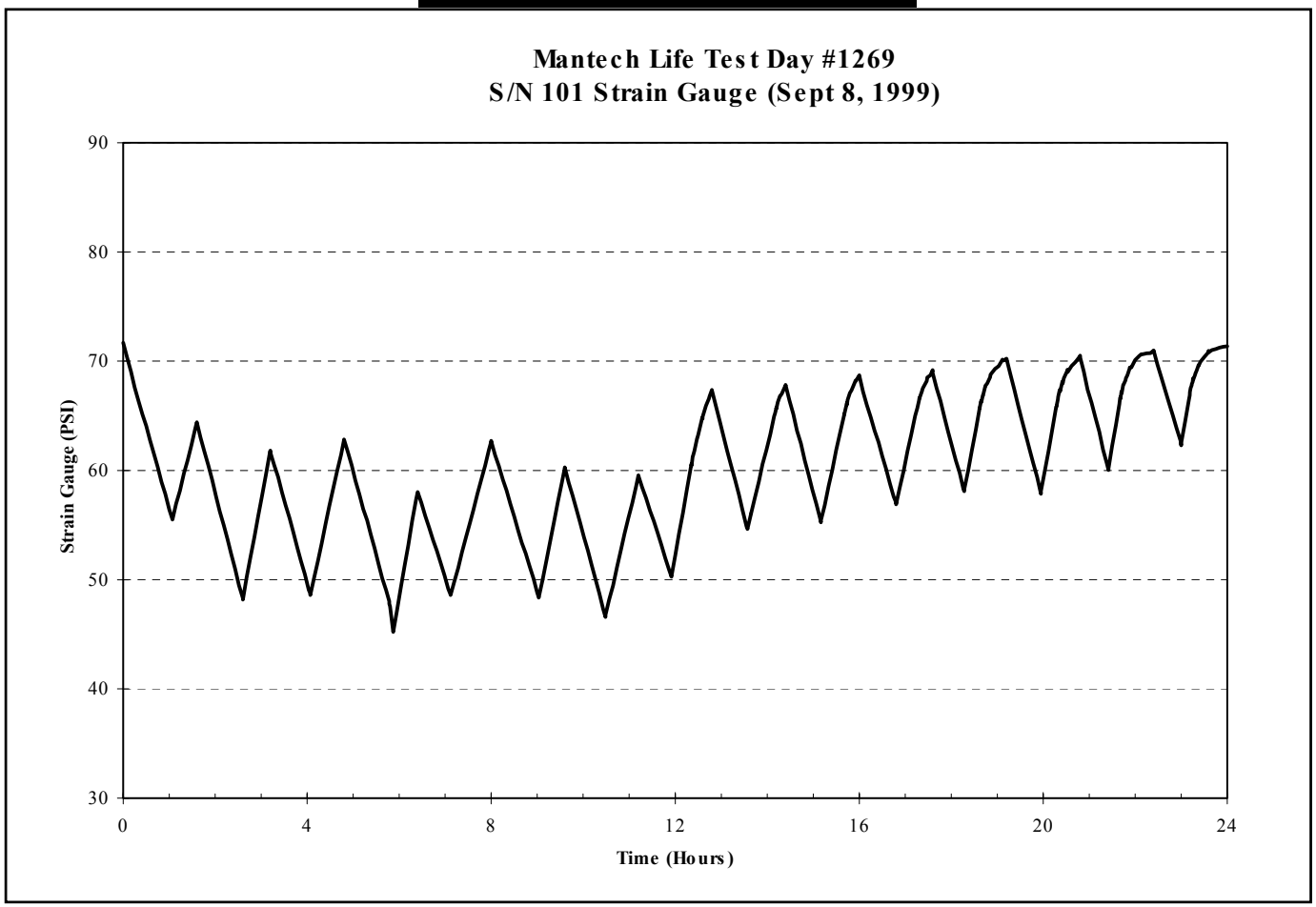
Cell Life Study
HL8 Test Profile



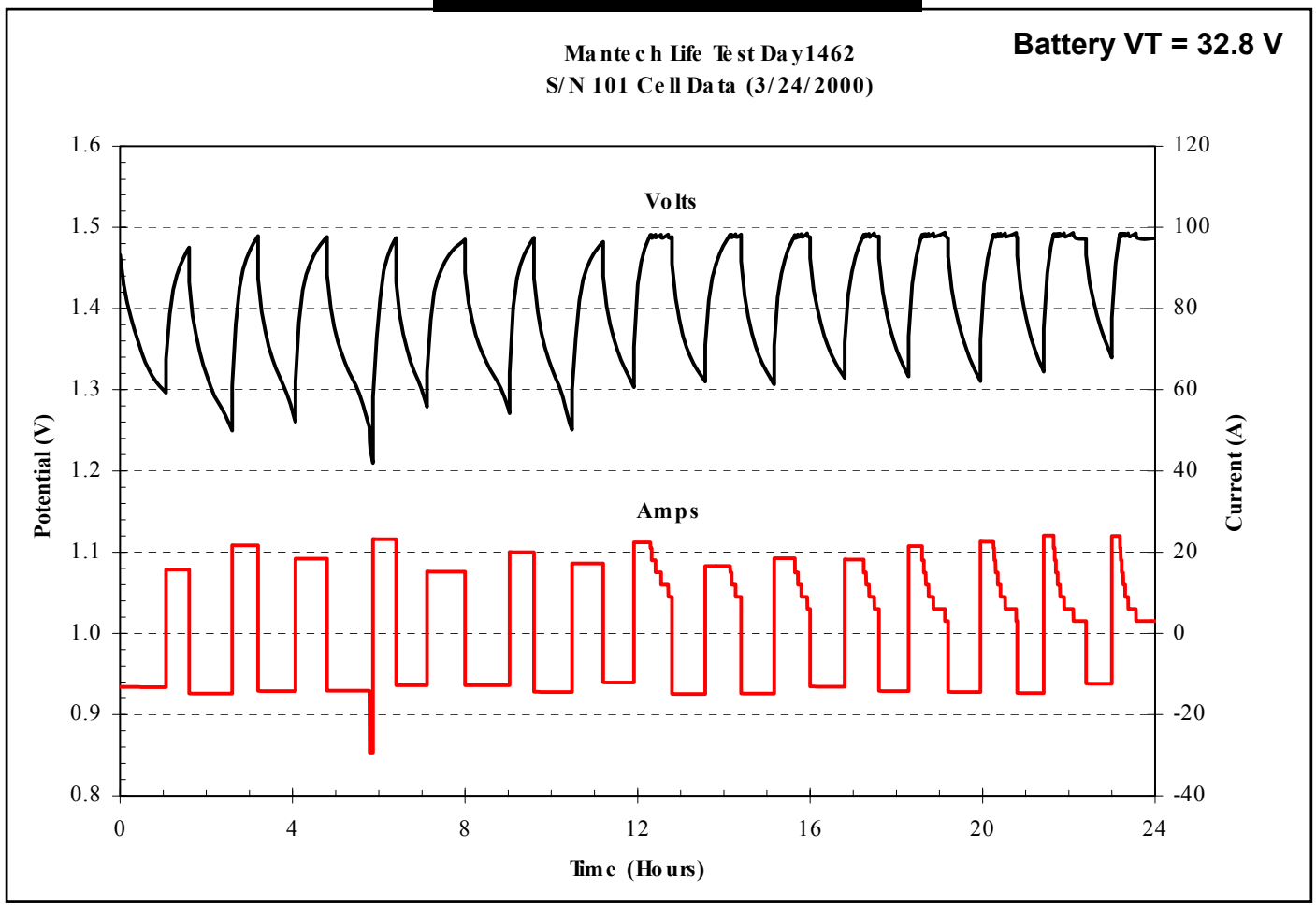
Cell Life Study
HL10M Test Profile



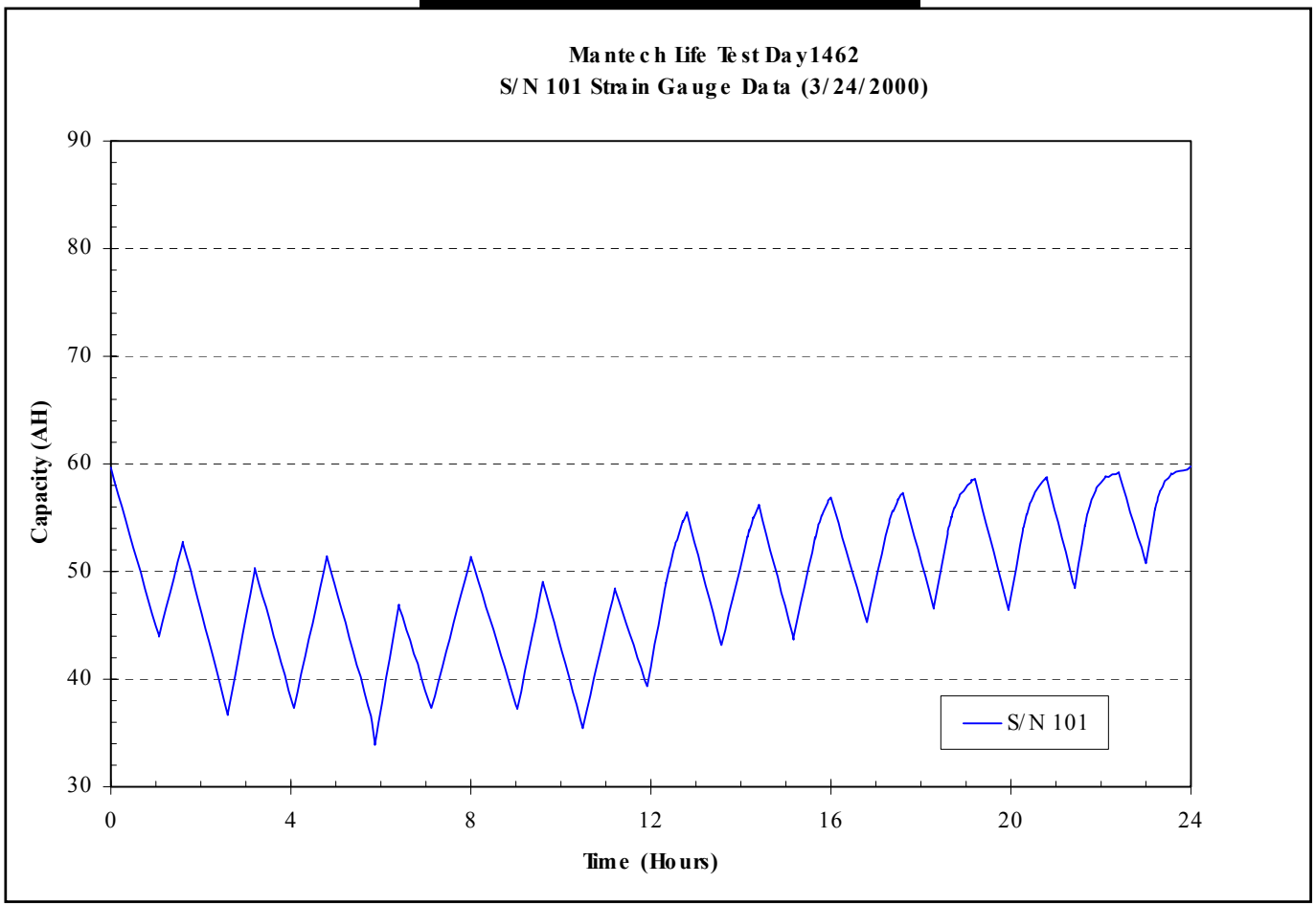
Cell Life Study
HL10M Test Profile



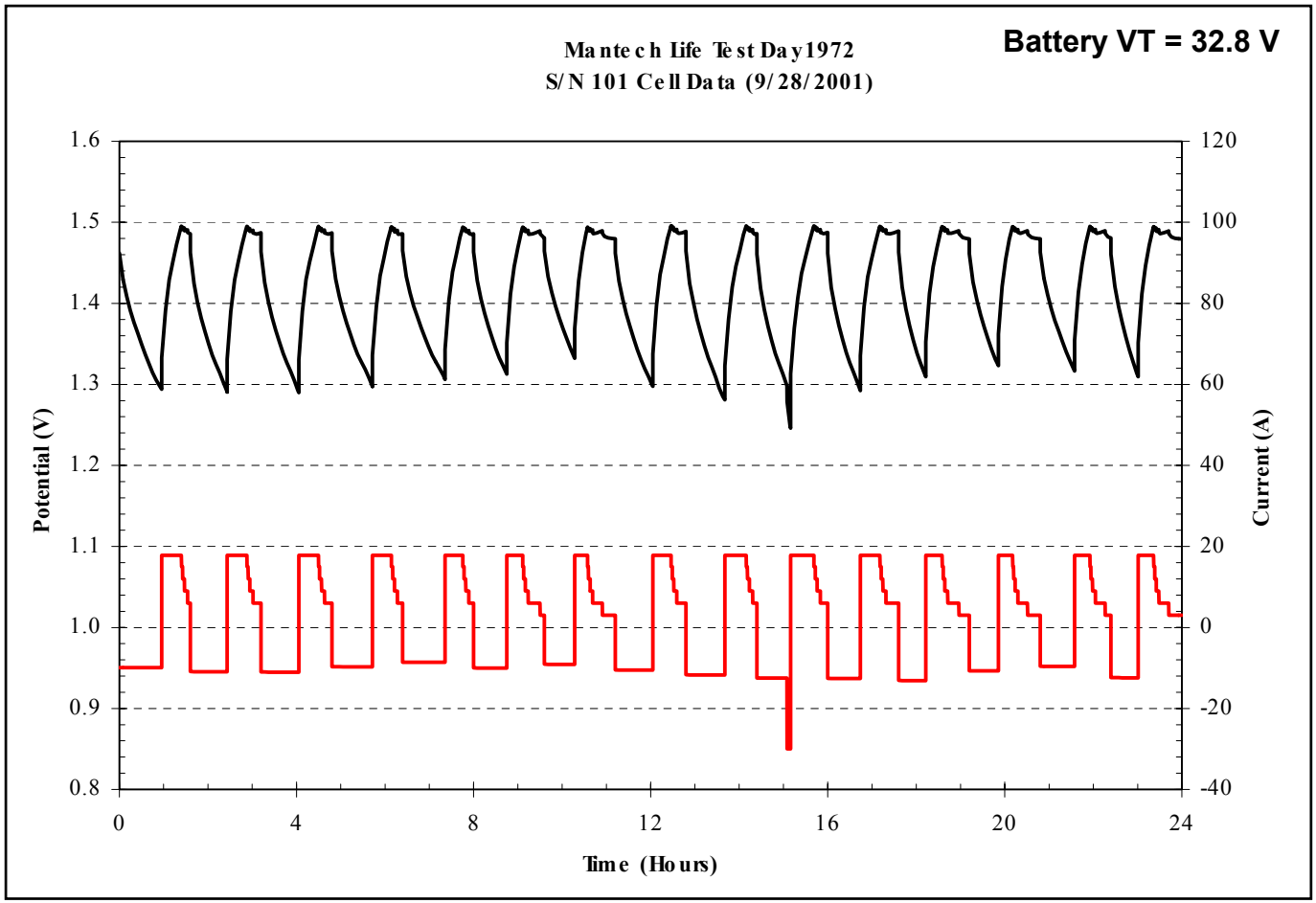
Cell Life Study
HL12M Test Profile



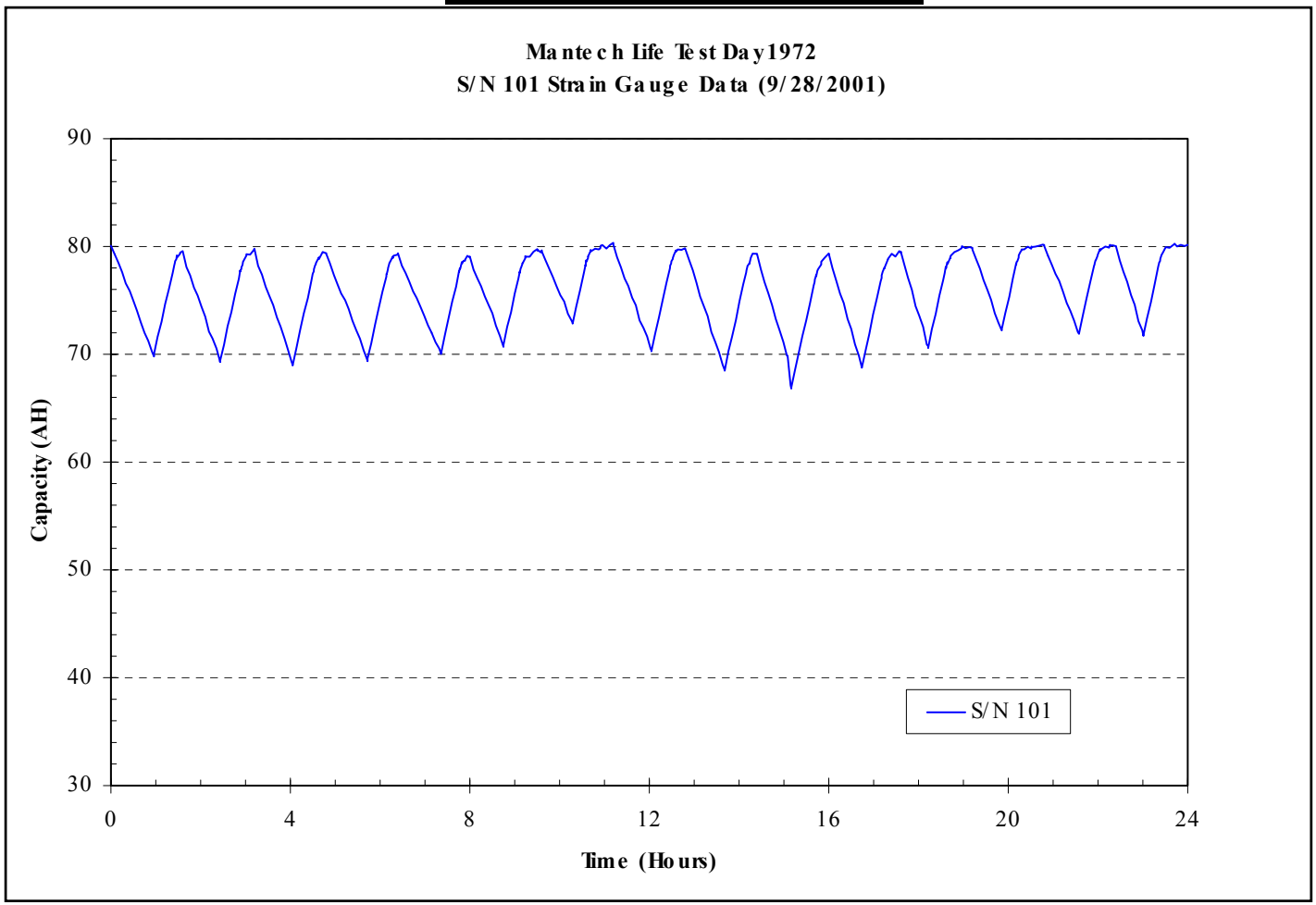
Cell Life Study
HL12M Test Profile



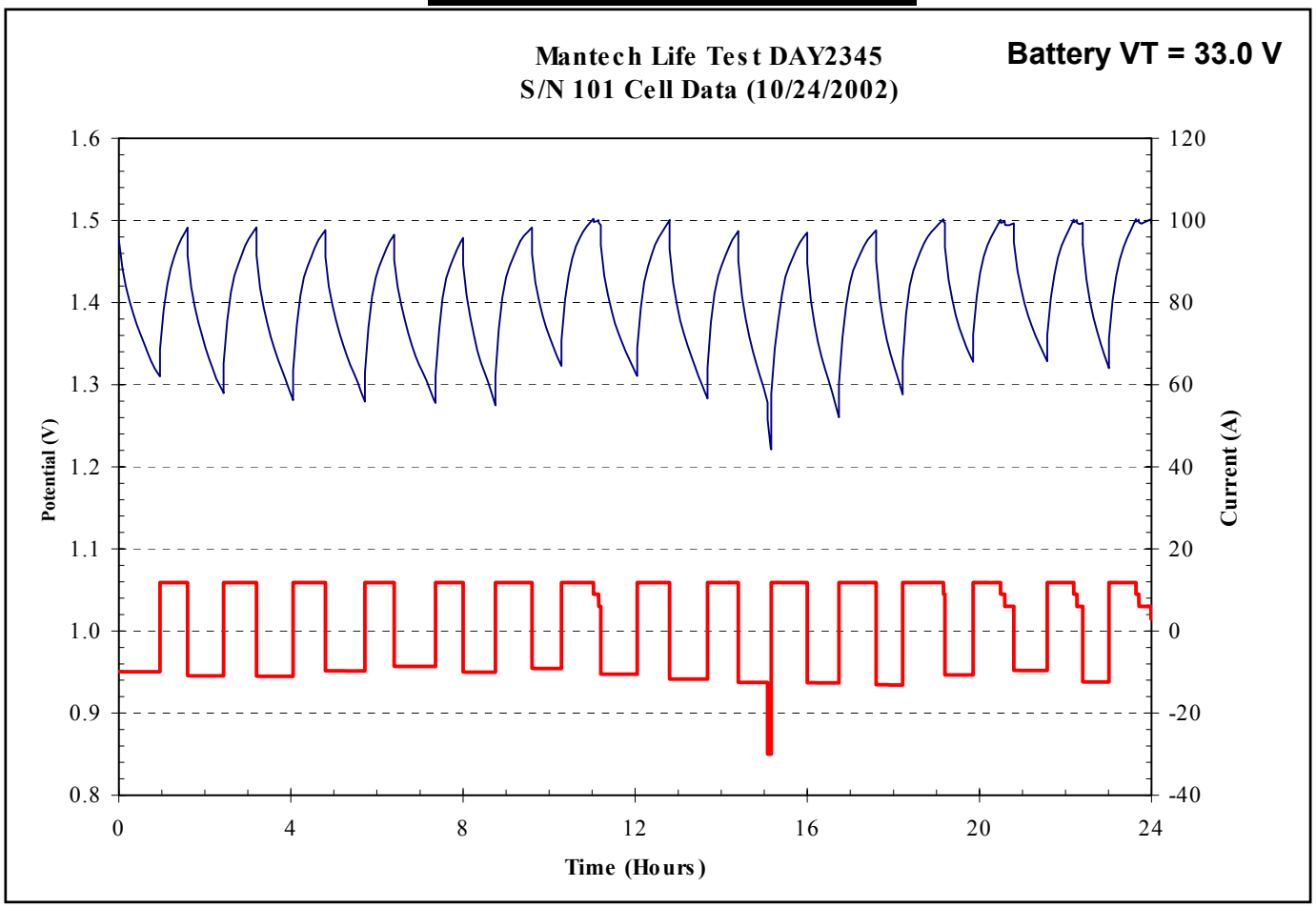
Cell Life Study
HL14R Test Profile



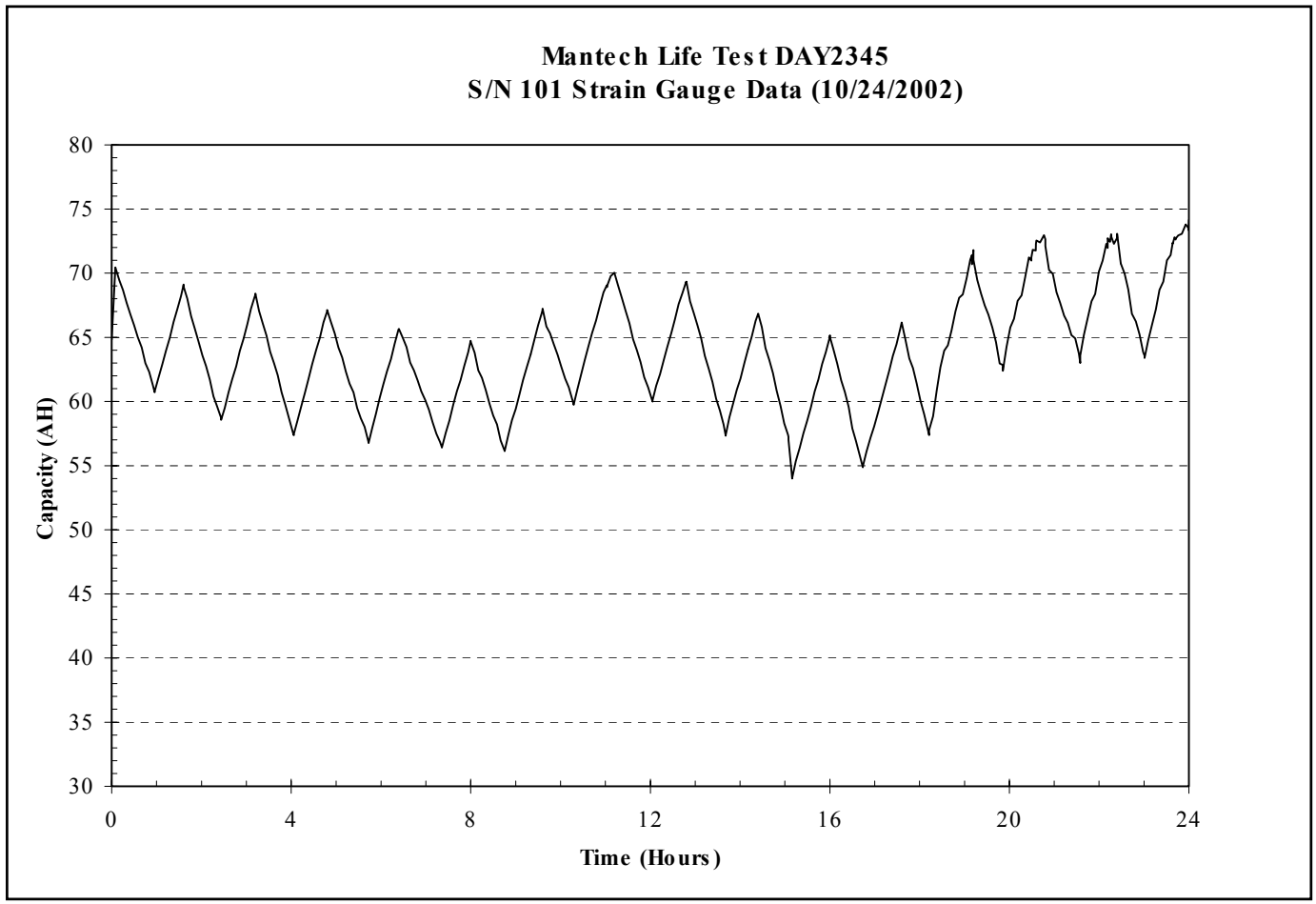
Cell Life Study
HL14R Test Profile



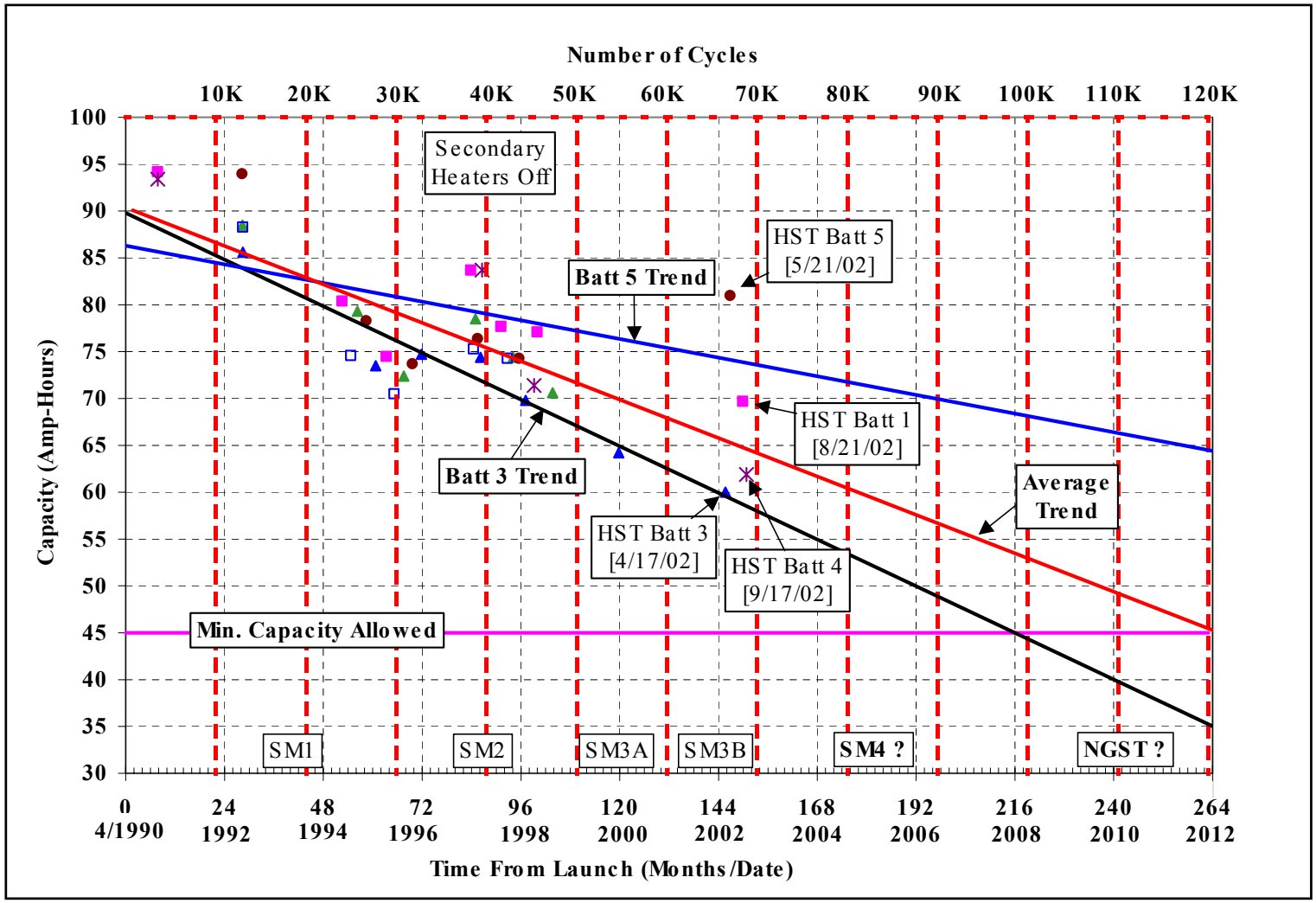
Cell Life Study
HL15R Test Profile



Cell Life Study
HL15R Test Profile

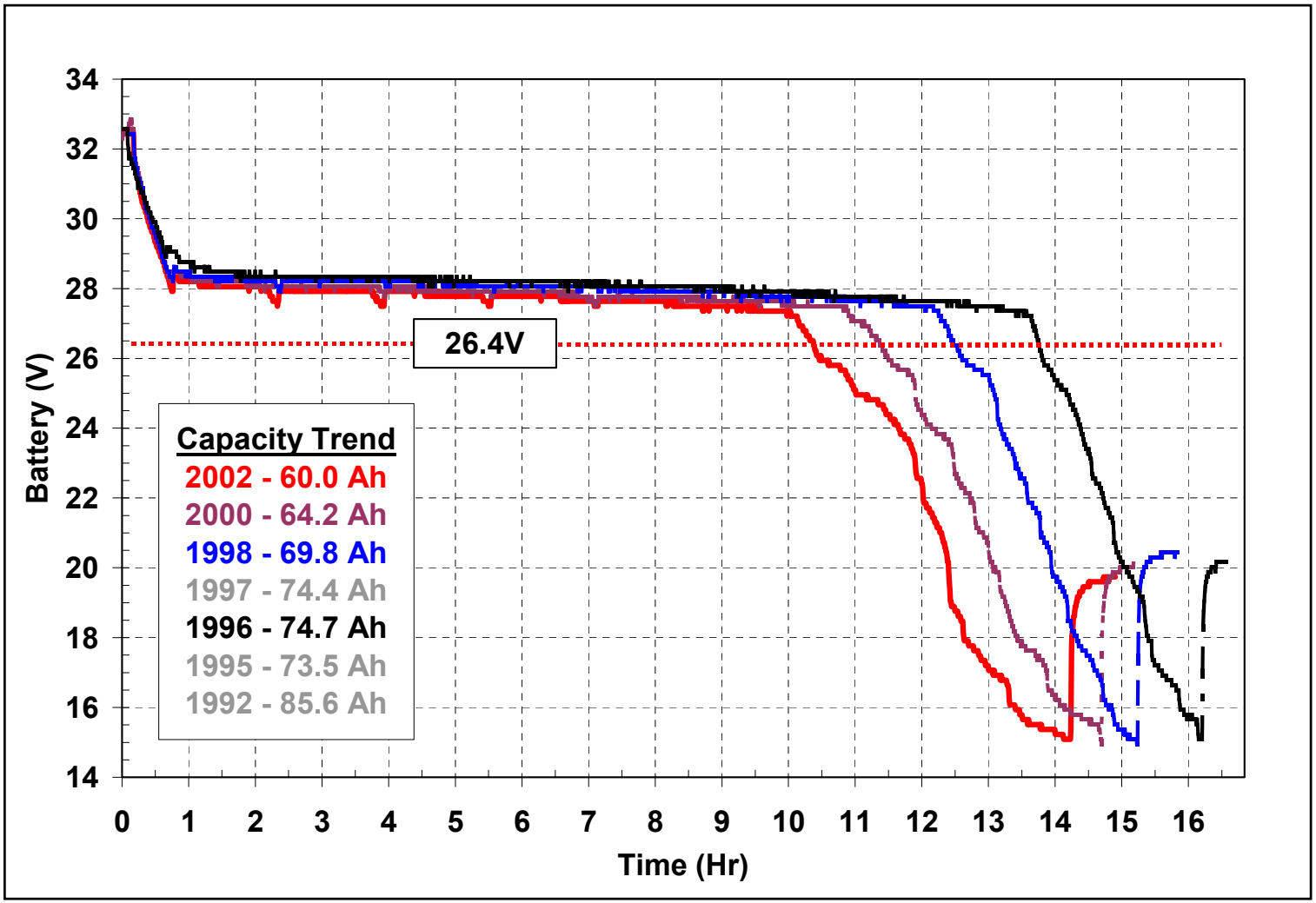


HST Orbital Capacity Trend



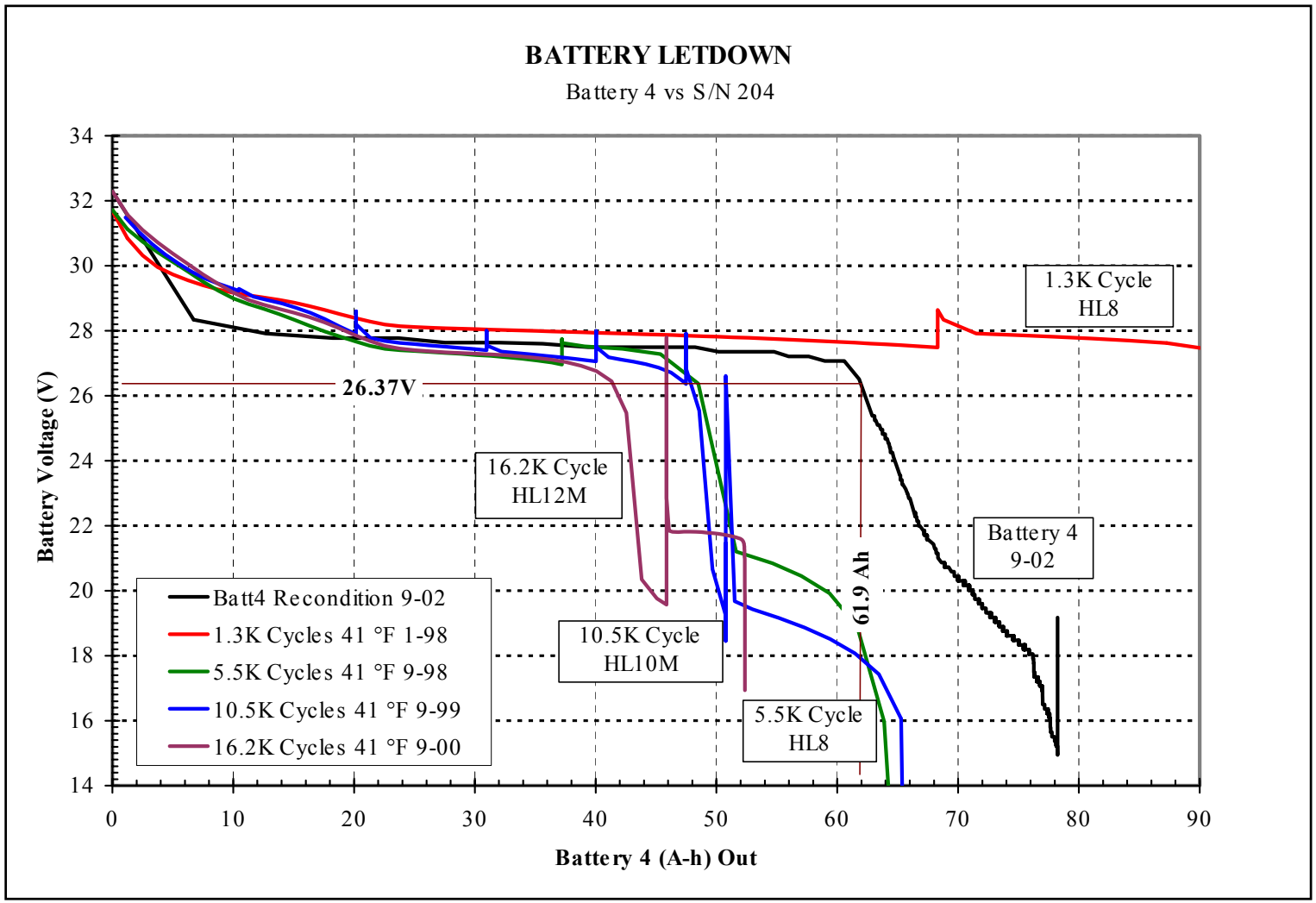
IECEC-2002

HST Orbital Recondition Capacity Trend Battery 3

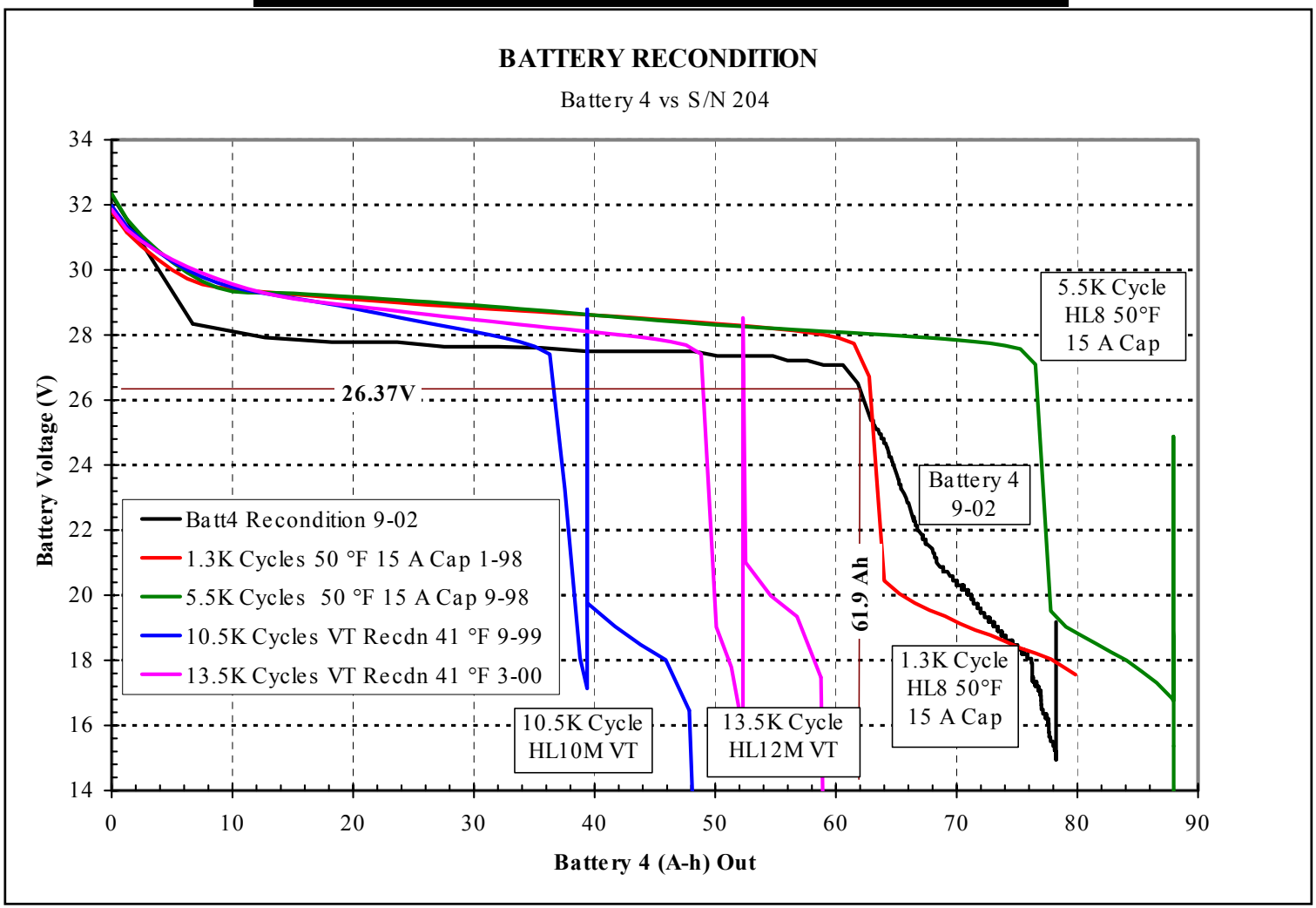


IECEC-2002

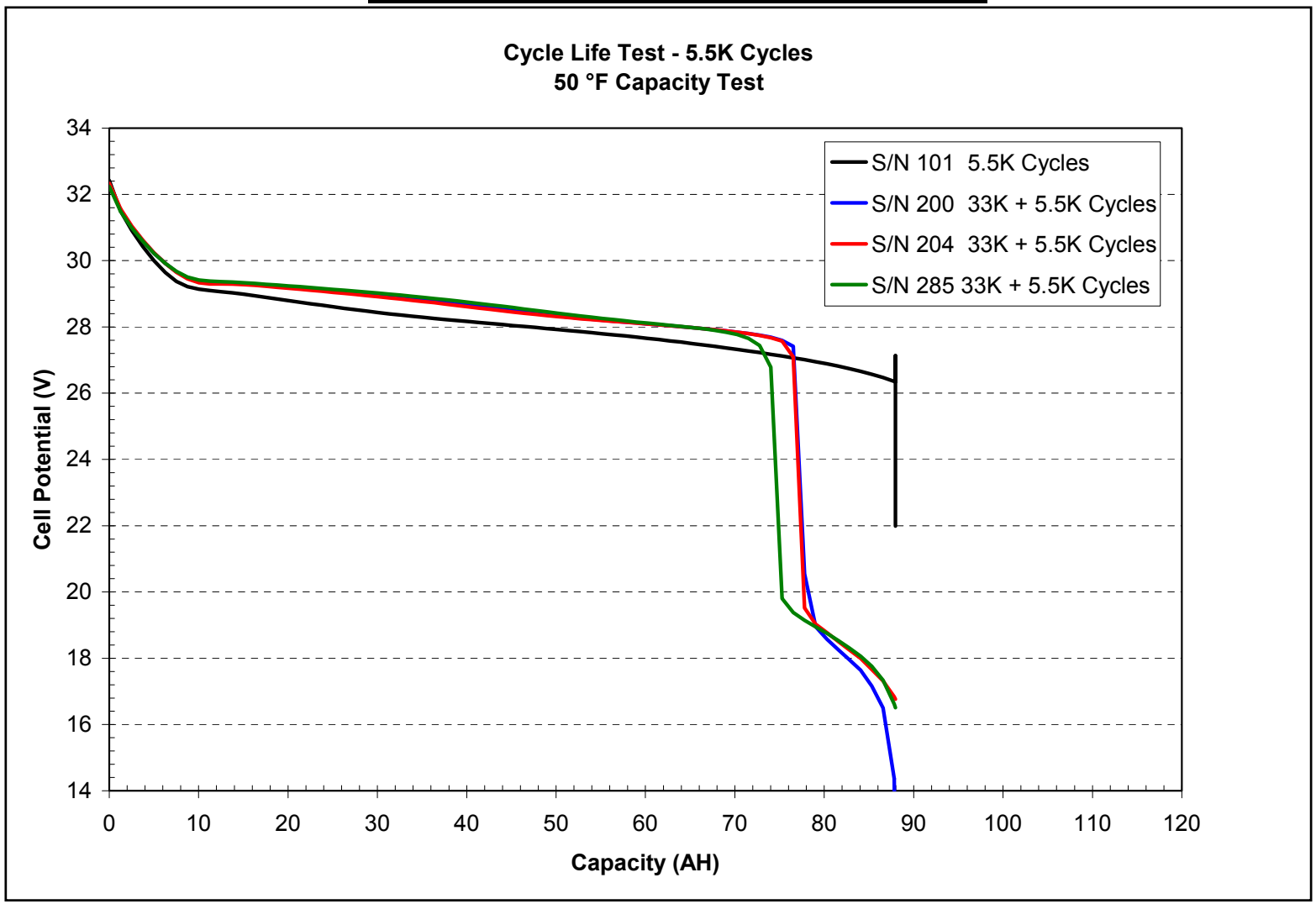
HST Recondition Capacity Comparison
Battery 4 Orbital vs S/N 204 Ground



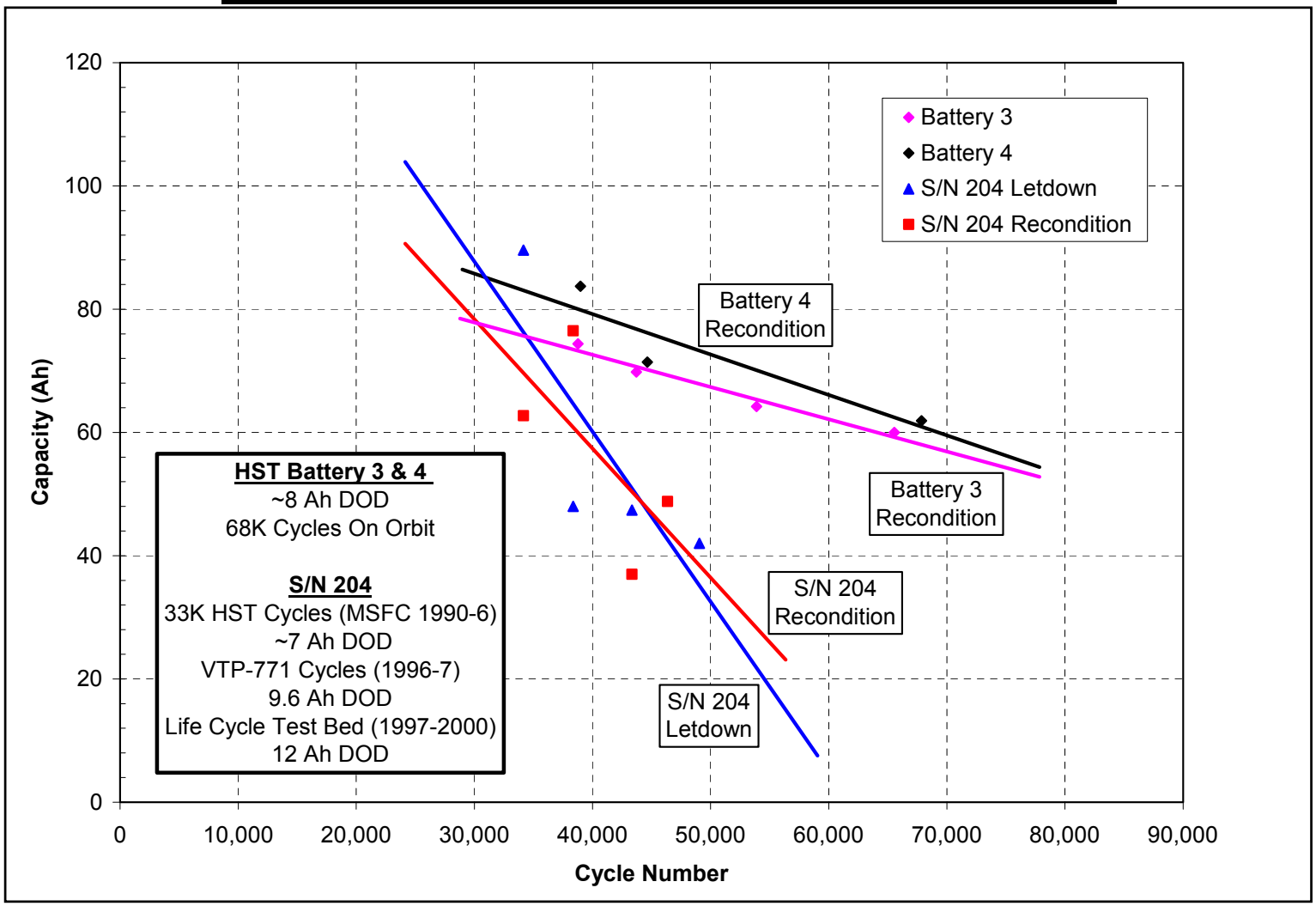
HST Recondition Capacity Comparison
Battery 4 Orbital vs S/N 204 Ground



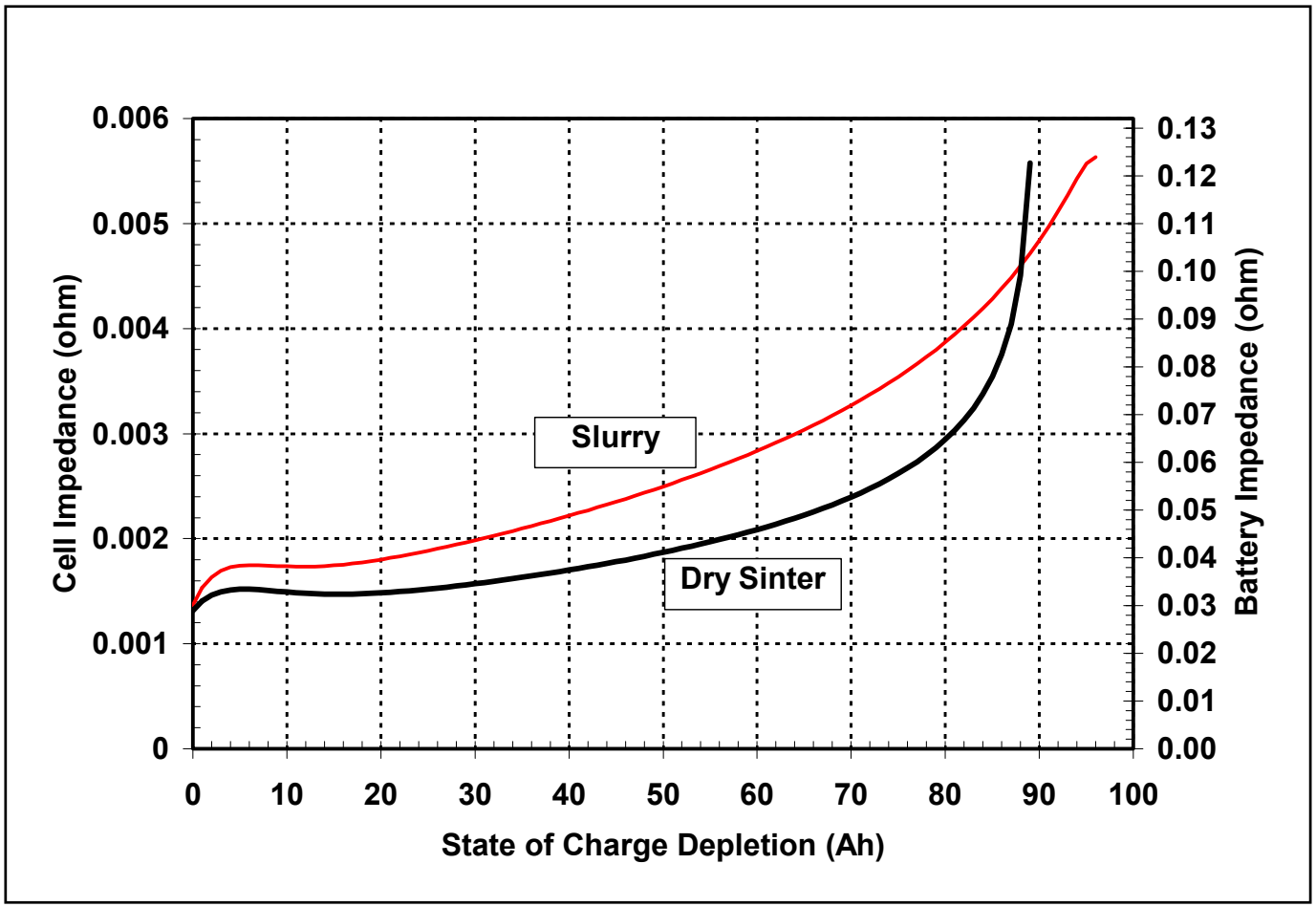
50 °F Capacity Test Comparison
Cycle Life Test



HST Recondition Capacity Comparison
Battery 3 & 4 Orbital vs S/N 204 Ground

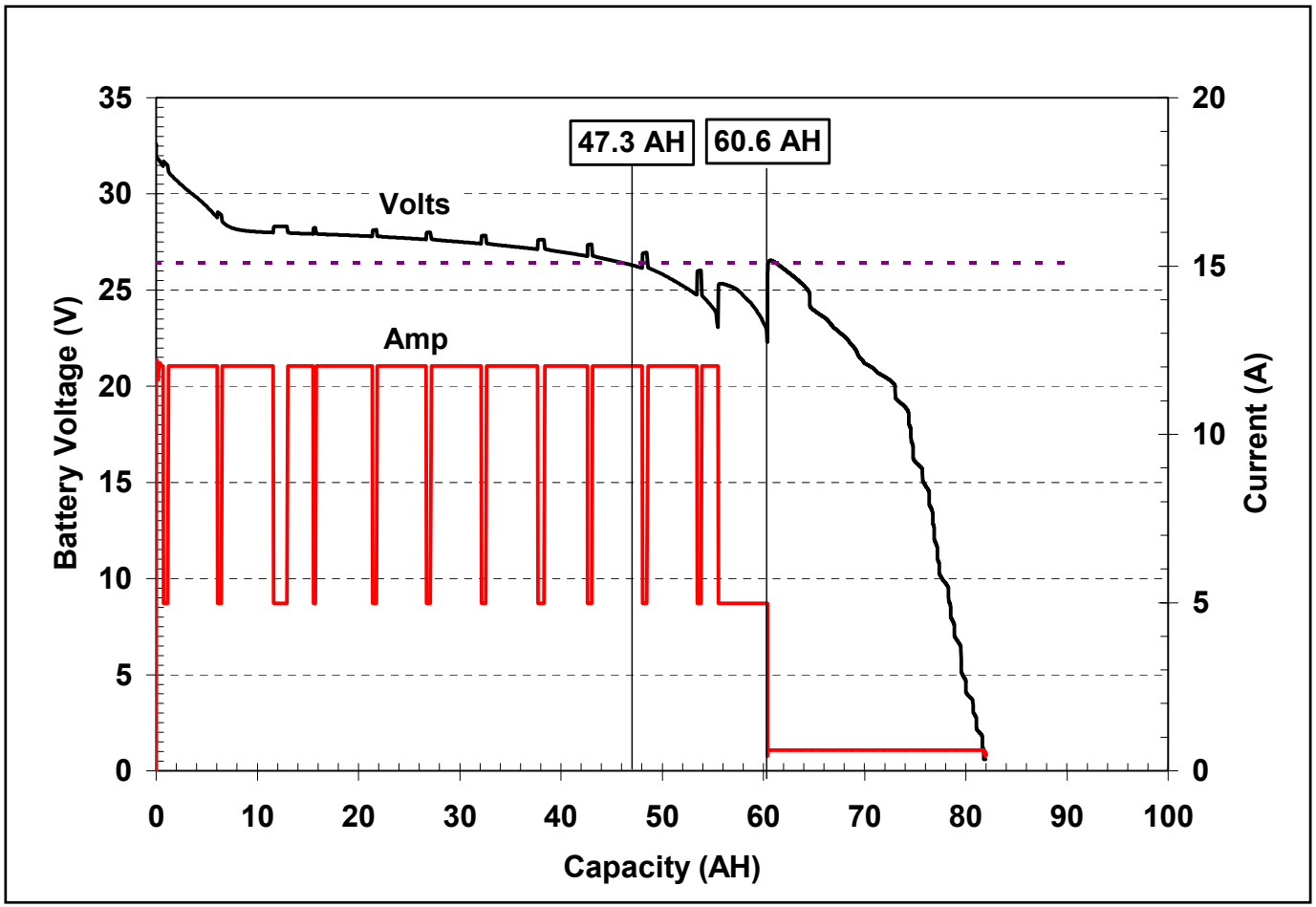


Battery Model Impedance Prediction



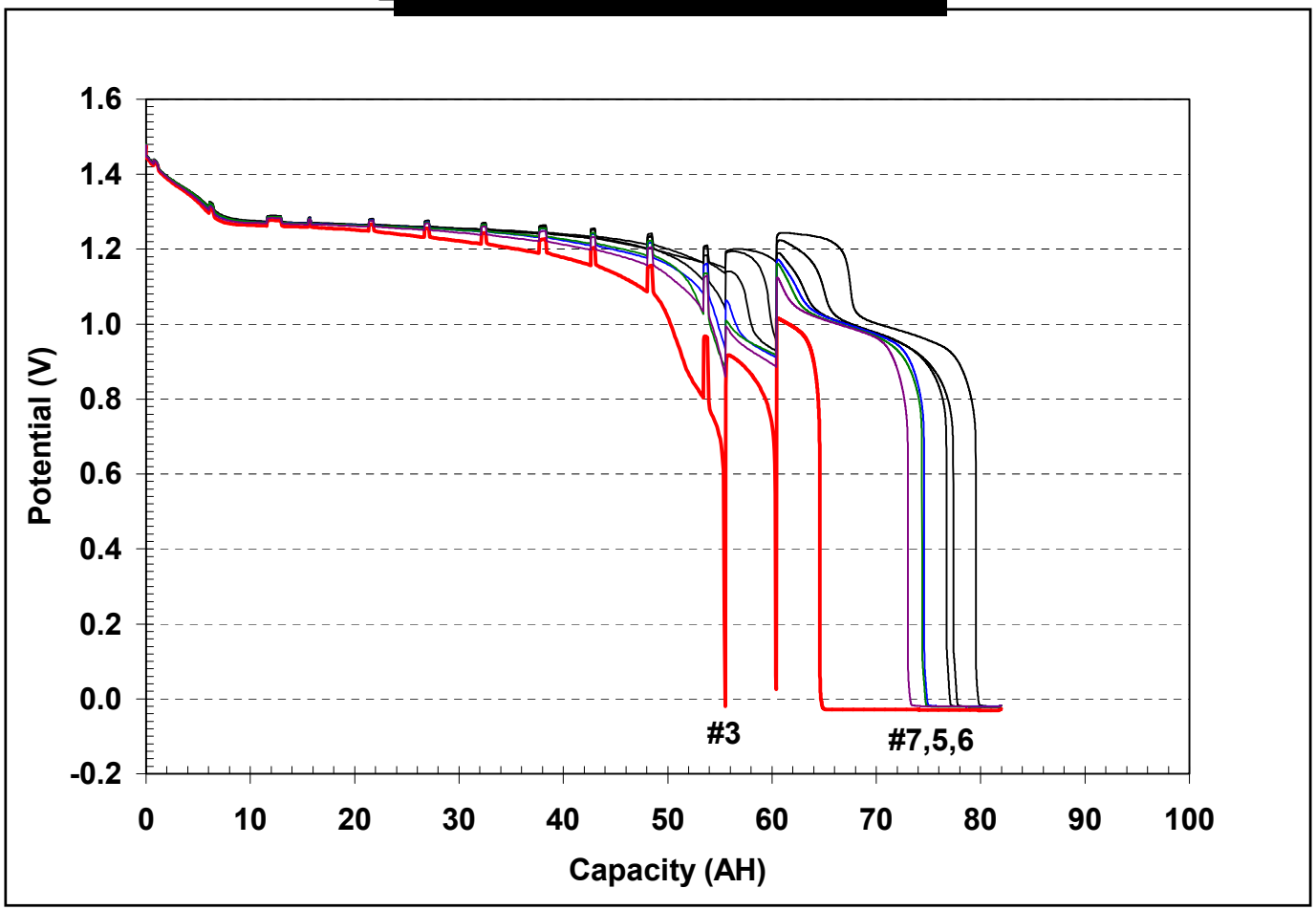
IECEC-2002

Flight Spare Battery Pulse Discharge



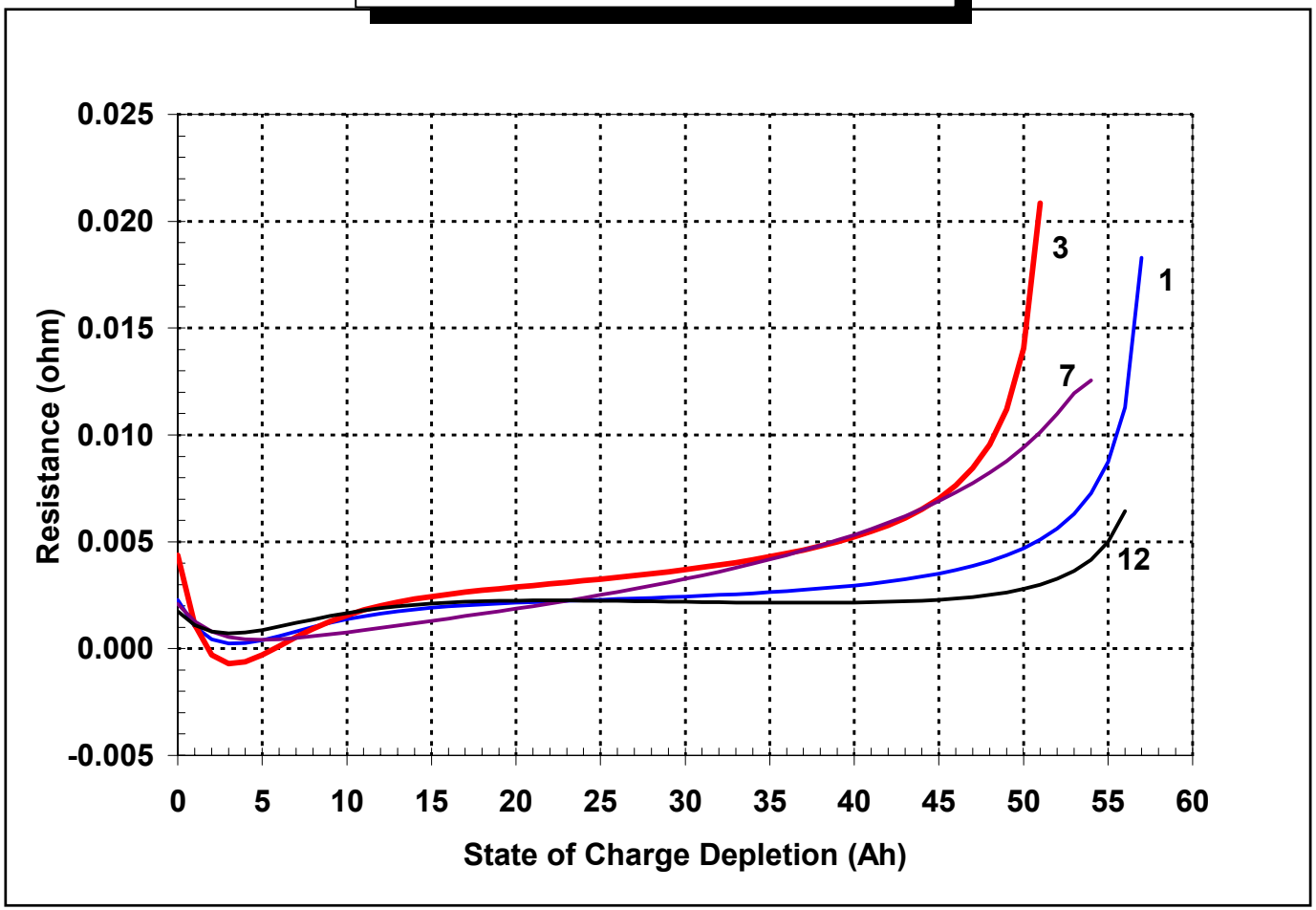
IECEC-2002

Flight Spare Battery Cell Potential Distribution



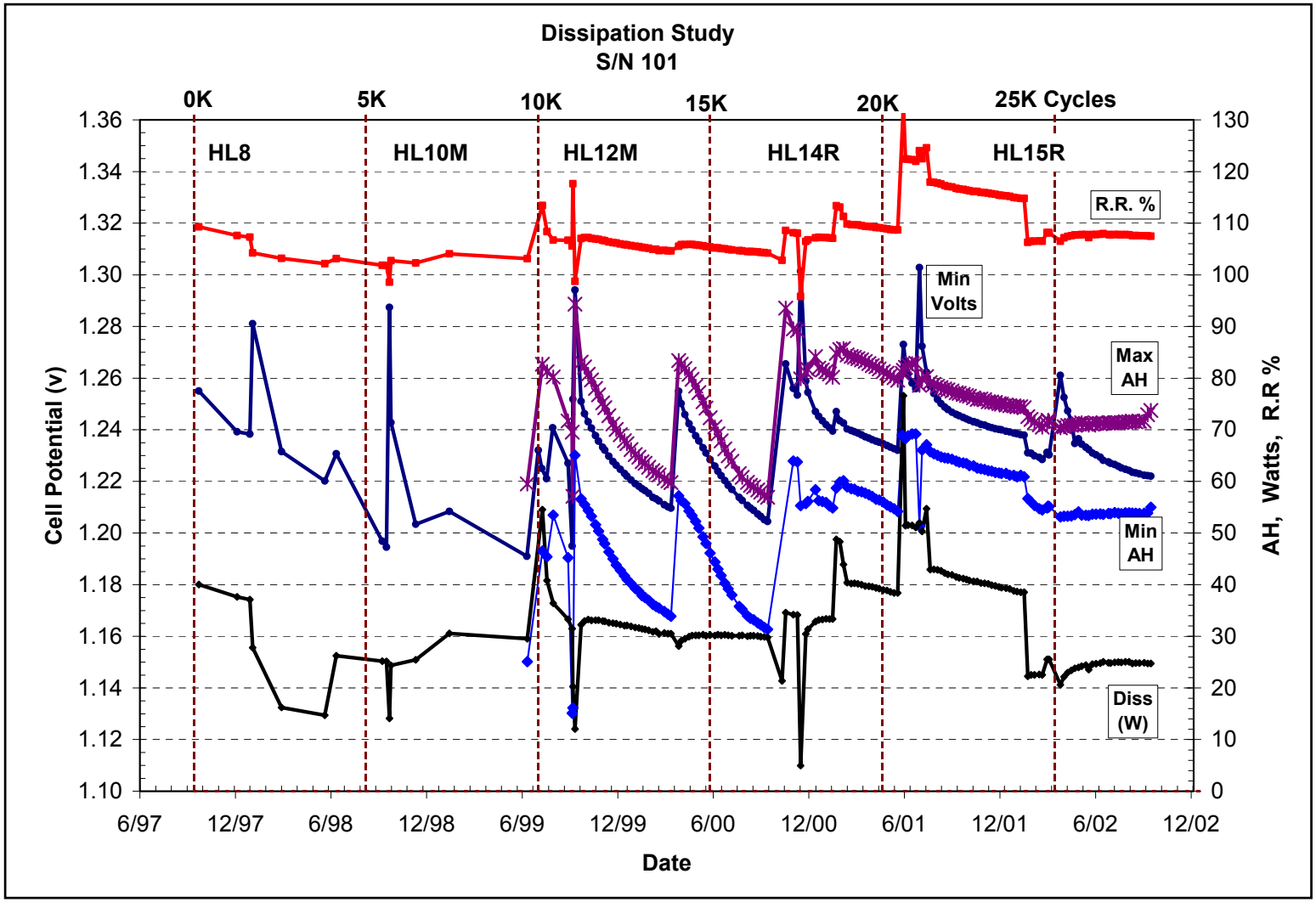
IECEC-2002

Flight Spare Battery Cell Impedance Distribution

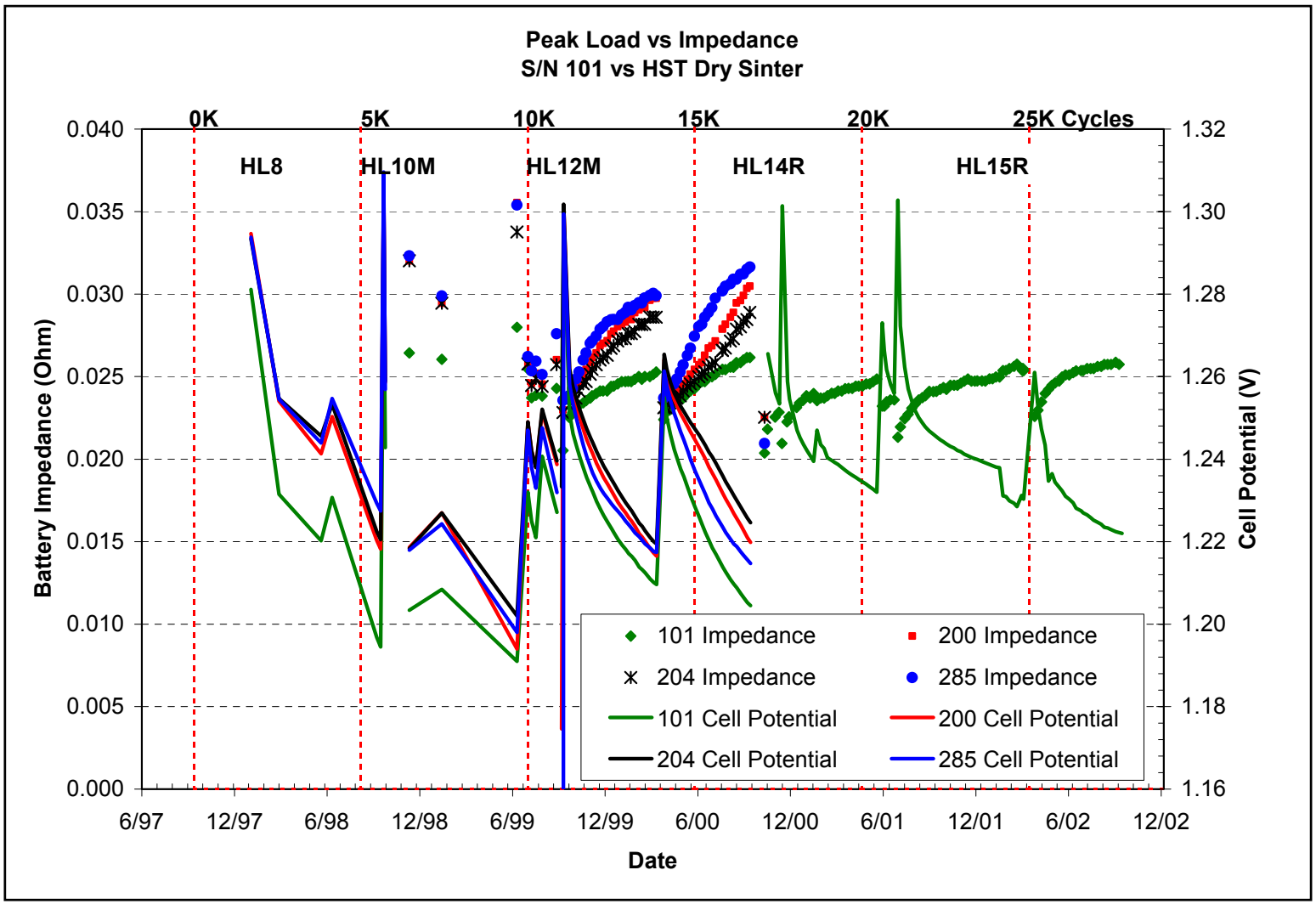


IECEC-2002

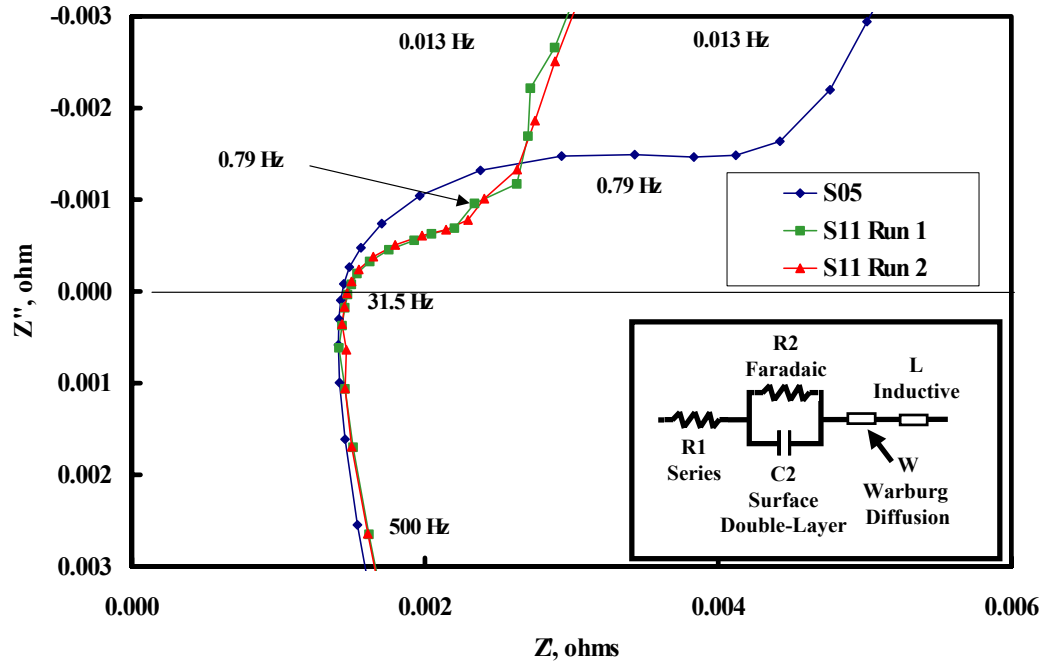
Cell Life Study
9/1/97 - 11/1/02



Cell Life Study
9/1/97 - 11/1/02



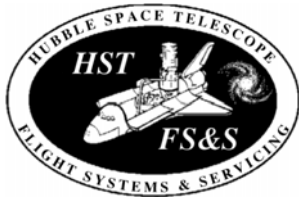
AC Impedance - GEO Ground Cycling (RNH 76-11 Dry Sinter)



	S/N 11	S/N 05
Seasons	15 (Real)	58 (Accel.)
R1, milliohms	1.4	1.4
R2, milliohms	0.8	2.4
C2, farads	44	26

Interpretation of Results

- Decrease in Active Surface (R2, C2)
- Electrode Surface Effect (R2, C2)
- No Difference at High-Frequency (R1 - No Separator Difference)
- Inductive Effects Ignored



REFERENCES

- Larry Thaller & H. S. Lim, Aug. 10, 1987, "A Predictive Model of the Depth-of-Discharge Effect on the Cycle Life of a Storage Cell," *Proceedings of the 22nd IECEC*, Vol.2, pp 751-757

- Thomas Whitt & Jeffrey Brewer, "Hubble Space Telescope Nickel-Hydrogen Battery Testing, An Update," 1994, *Proceedings 1994 NASA Aerospace Battery Workshop*

- Jon Armantrout & Doug Hafen, 1996, "NiH2 Battery Reconditioning for LEO Applications," *Proceedings 1996 NASA Aerospace Battery Workshop*

- Douglas P. Hafen, 1998, "NiH_2 Battery Reliability Update," *Proceedings 1998 NASA Aerospace Battery Workshop*

- Jon Armantrout & Dale Gordon, 2000, "Effects of Dry Storage on NiH_2 Slurry Electrode Cells," *Proceedings 2000 NASA Aerospace Battery Workshop*

- Roger P. Hollandsworth, Jon D. Armantrout & Gopalakrishna M. Rao, July, 2002, "NiH_2 Reliability Impact Upon Hubble Space Telescope Battery Replacement", *Proceedings of the 37th IECEC*, Paper # 20034

ACKNOWLEDGEMENTS

- **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.

- **LMMSO Wishes to Acknowledge the Technical Support From**
  - HST Program Office for Orbital Data
  - NASA/MSFC for Ground Test Data.