Performance and Safety Of Lithium Ion Cells

B. V. Ratnakumar, M. C. Smart, L. Whitcanack and S. Surampudi
Jet propulsion Laboratory, Pasadena, California
and
R. Marsh
Wright-Patterson Air Force Base, Dayton, OH

Supported by Mars Program Office and NASA Code S Battery Programs

NASA Battery Workshop, Nov. 14-16, 2000, Huntsville, AL

Evaluation of Lithium-Ion Cells at JPL

- Cycle life performance at room temperature (25°C)
- Cycle life performance at low temperature (-20°C)
- Cycle life at alternating temperatures (40 and -20°C)
- Discharge rate characterization (at 40, 25, 0, and -20°C)
- Charge rate characterization (at 40, 25, 0, and -20°C)
- Capacity retention tests
- Accelerated LEO Tests
- Storage characterization tests (cruise conditions)
- VT charge characterization tests
- Electrical characterization by a.c. impedance
- Thermal characterization

NASA-DOD Interagency Li Ion Program

Objectives

- **DEVELOP HIGH SPECIFIC ENERGY AND LONG CYCLE LIFE Li -ION BATTERIES**

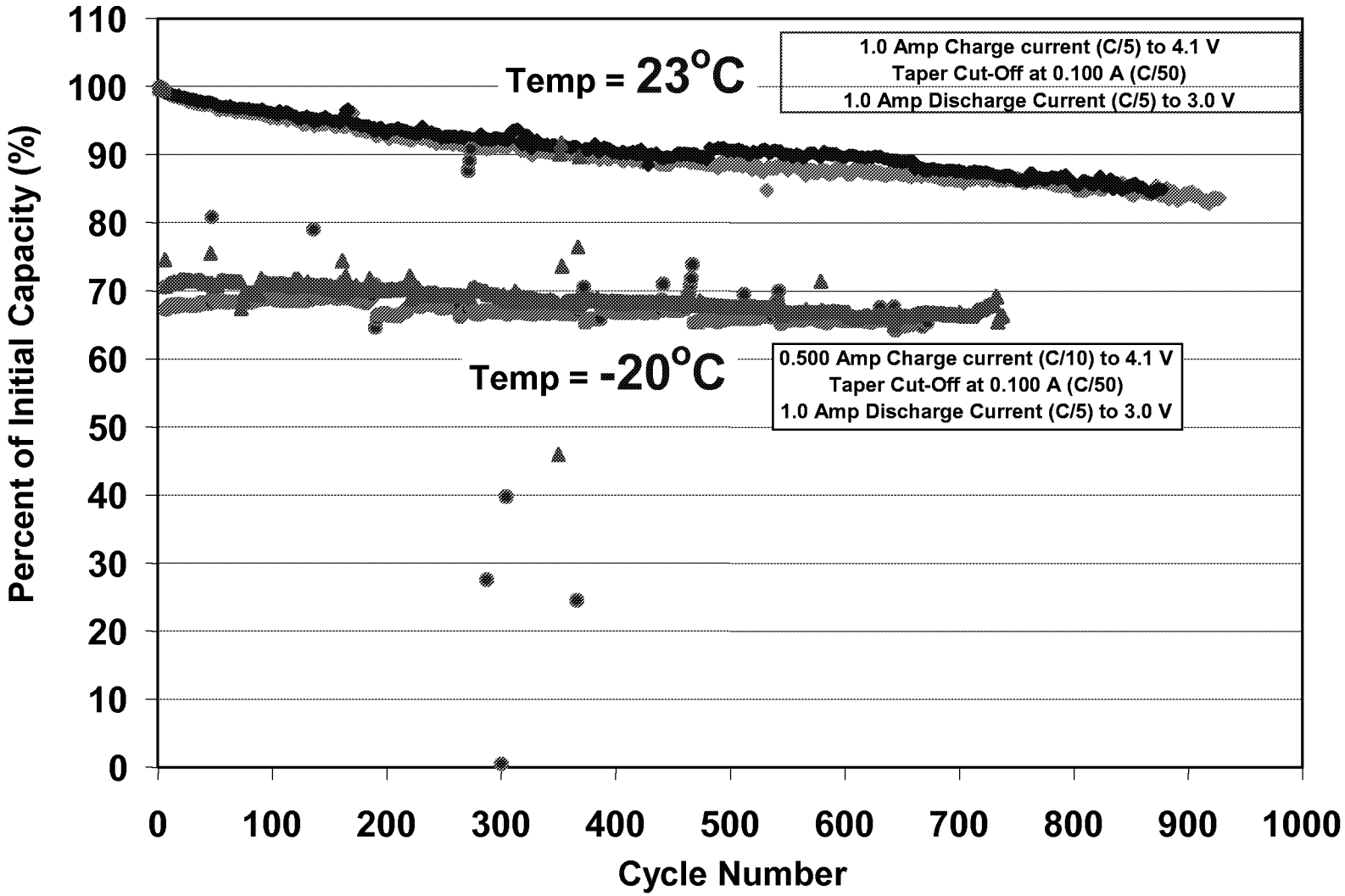
- **ESTABLISH U.S. PRODUCTION SOURCES**

- **DEMONSTRATE TECHNOLOGY READINESS**
  - **LANDERS BY 2001**
  - **ROVERS BY2003**
  - **GEO MISSIONS BY 2003**
  - **AVIATION/UAV's BY 2001**
  - **MILITARY TERRESTRIAL APPLNS's BY 2001**
  - **LEO MISSIONS BY 2003**

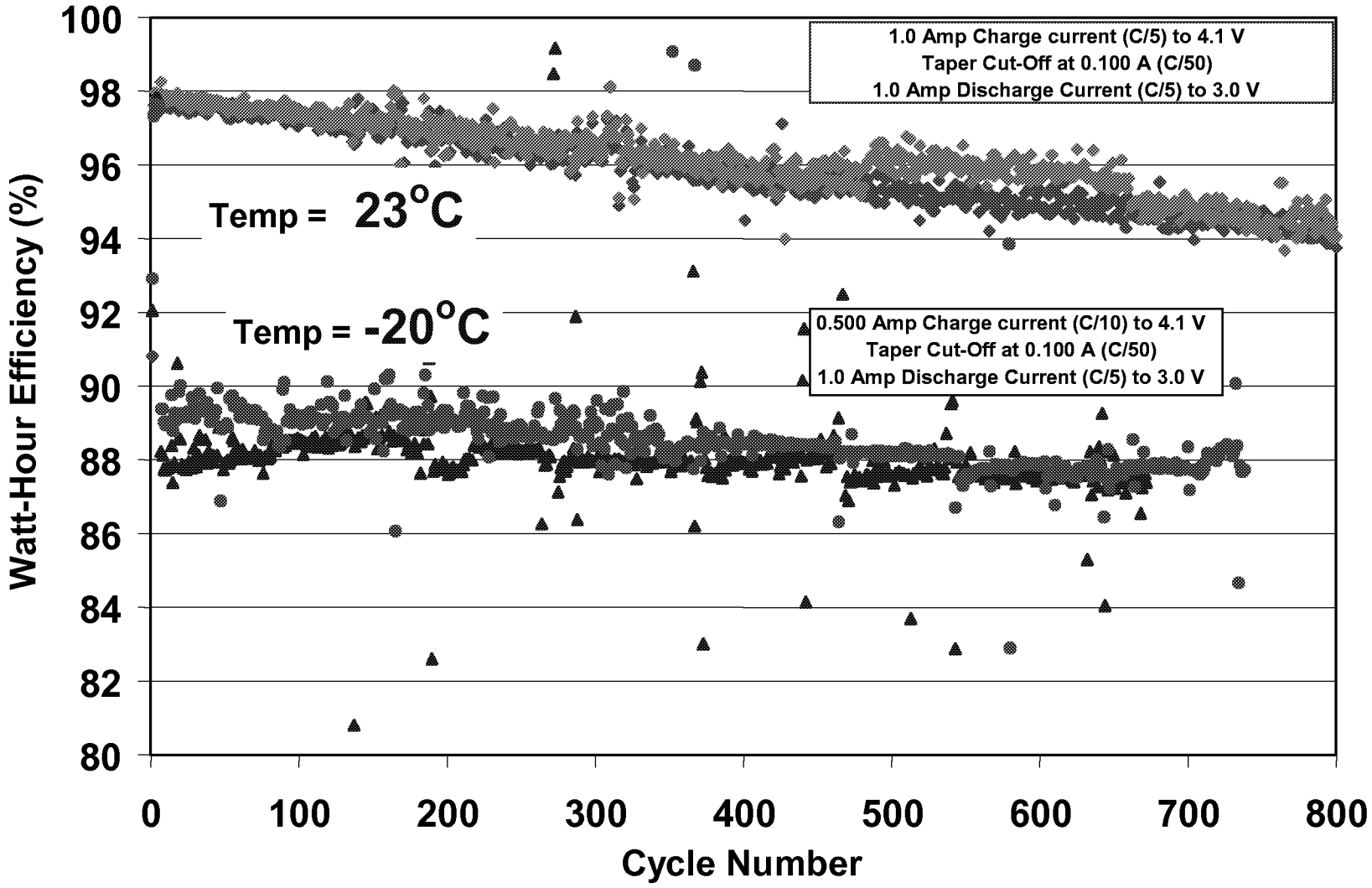
Technology Drivers

Mission	Technology Driver
Lander Rover	Low Temperature Operation High rate Pulse Capability
GEO S/C	10-20 Year Operating life Large Capacity cells (50-200 Ah)
LEO PlanetaryS/C	Long Cycle life(30,000) Medium Capacity Cells (50 Ah)
Aircraft	Low temperature Operation High Voltage Batteries (270 V)
UAV	Large Capacity cells (200 Ah) High Voltage Batteries (100V)

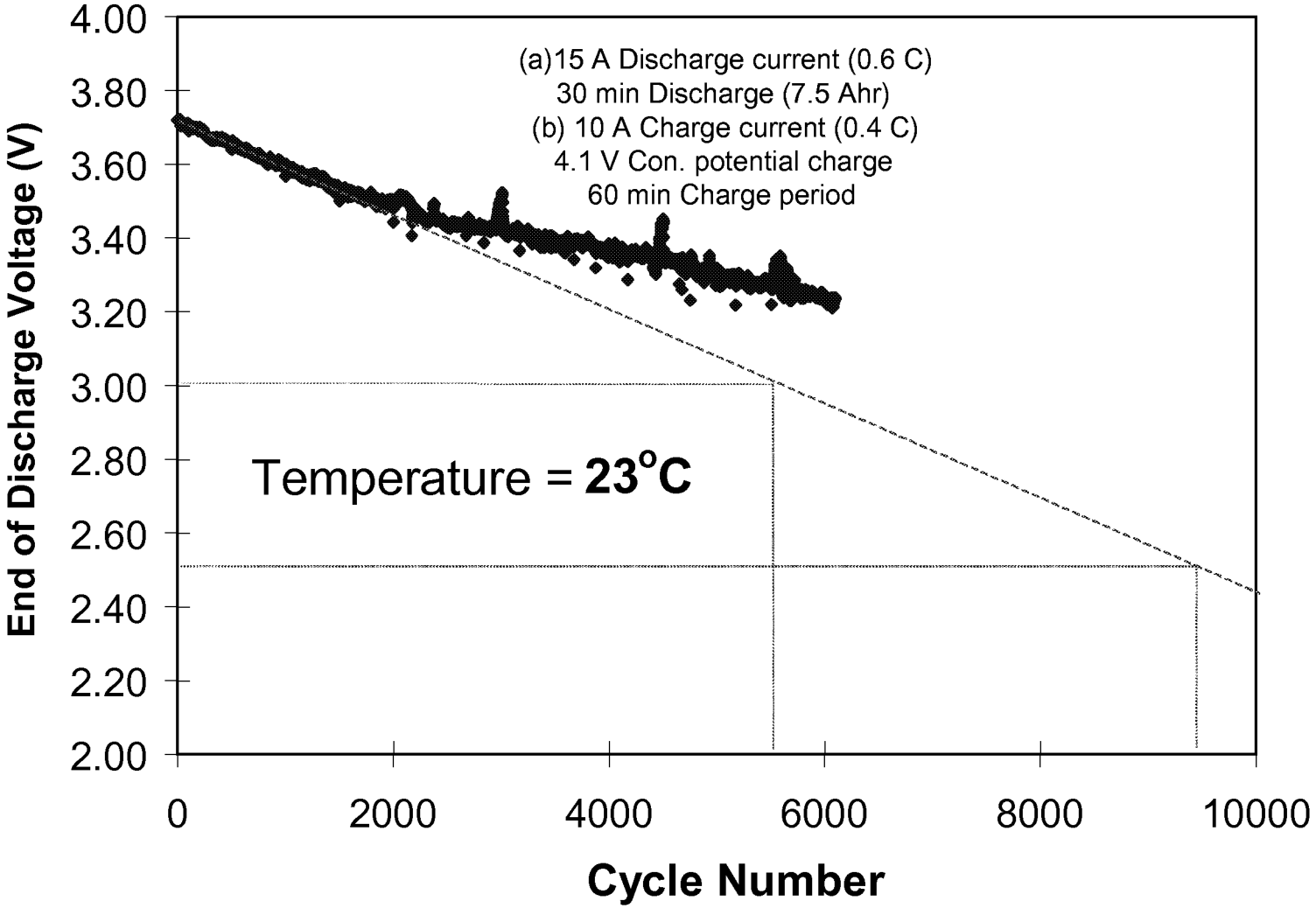
Cycle Life of Li Ion Cells



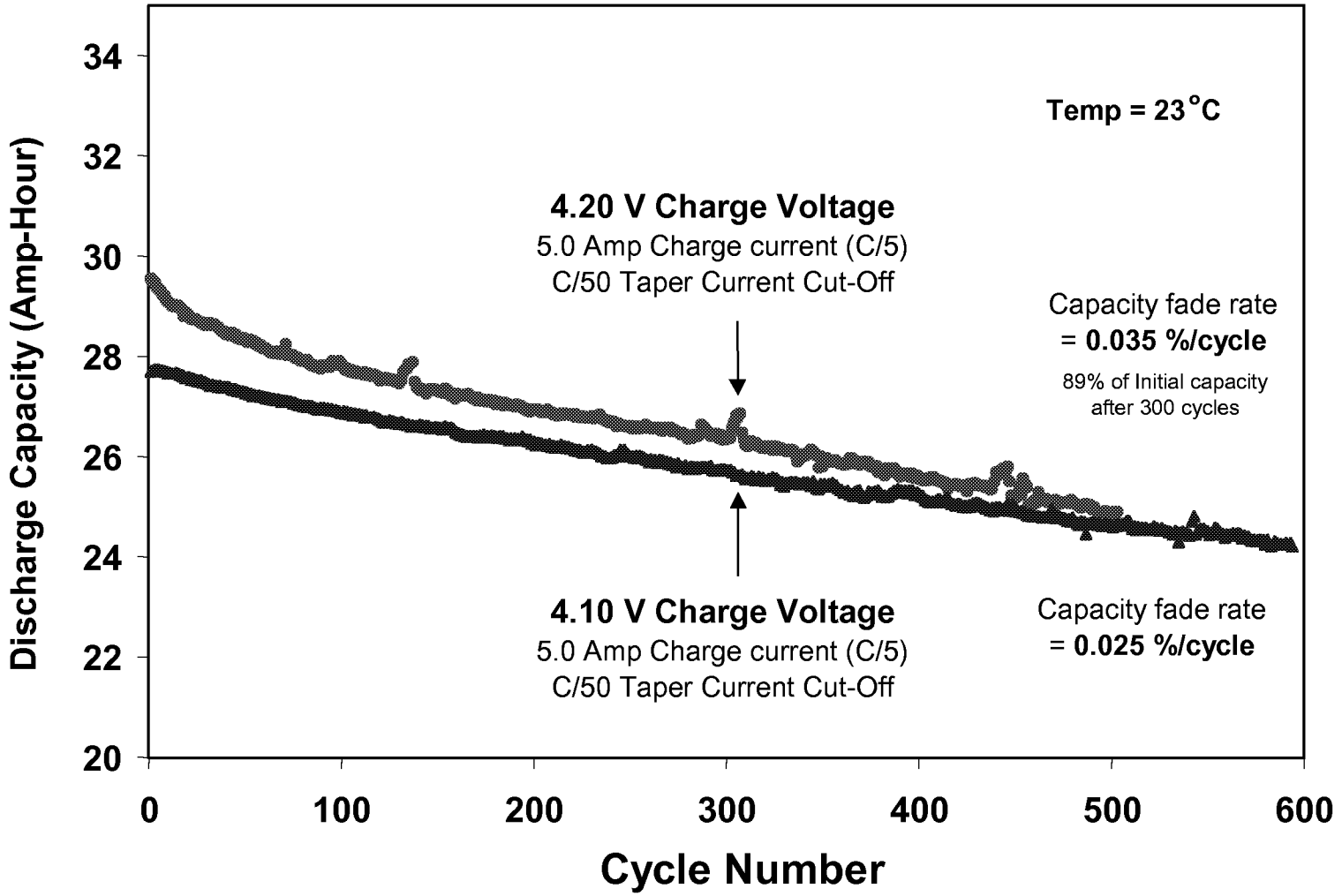
Cycle Life of Li Ion Cells-Energy efficiency



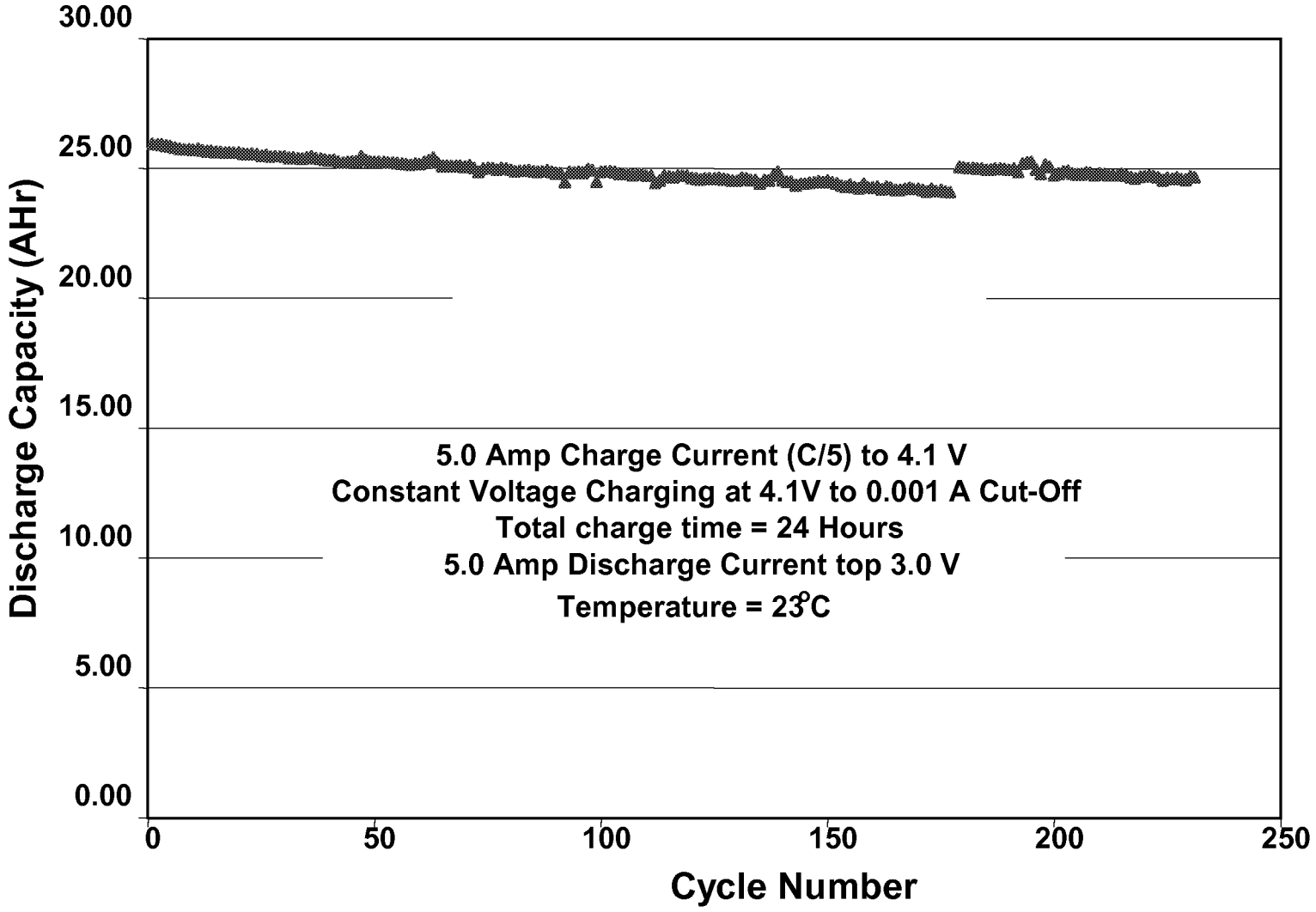
Cycle Life of Li Ion Cells to Partial DOD Accelerated LEO



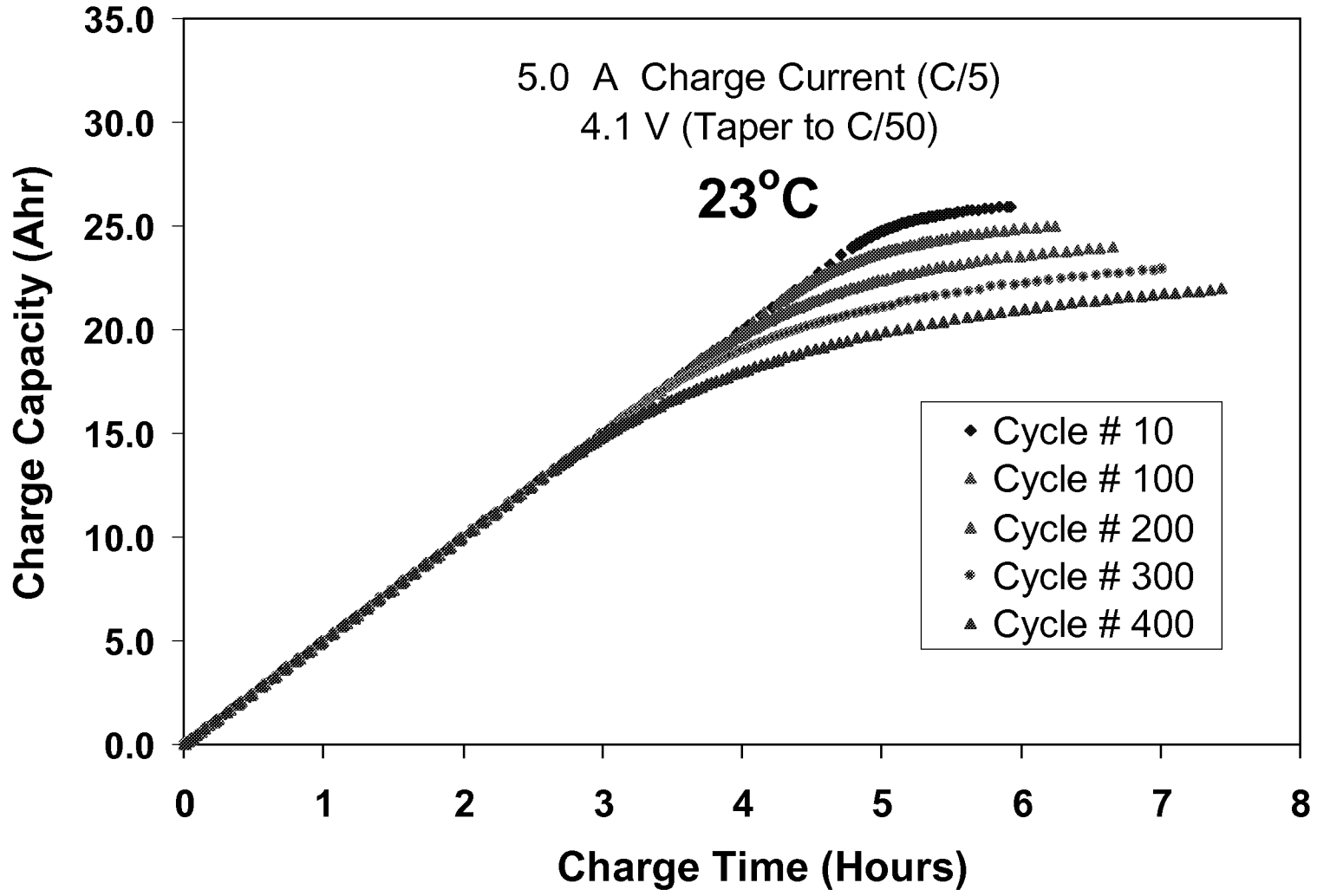
Tolerance to Higher Charge Voltage



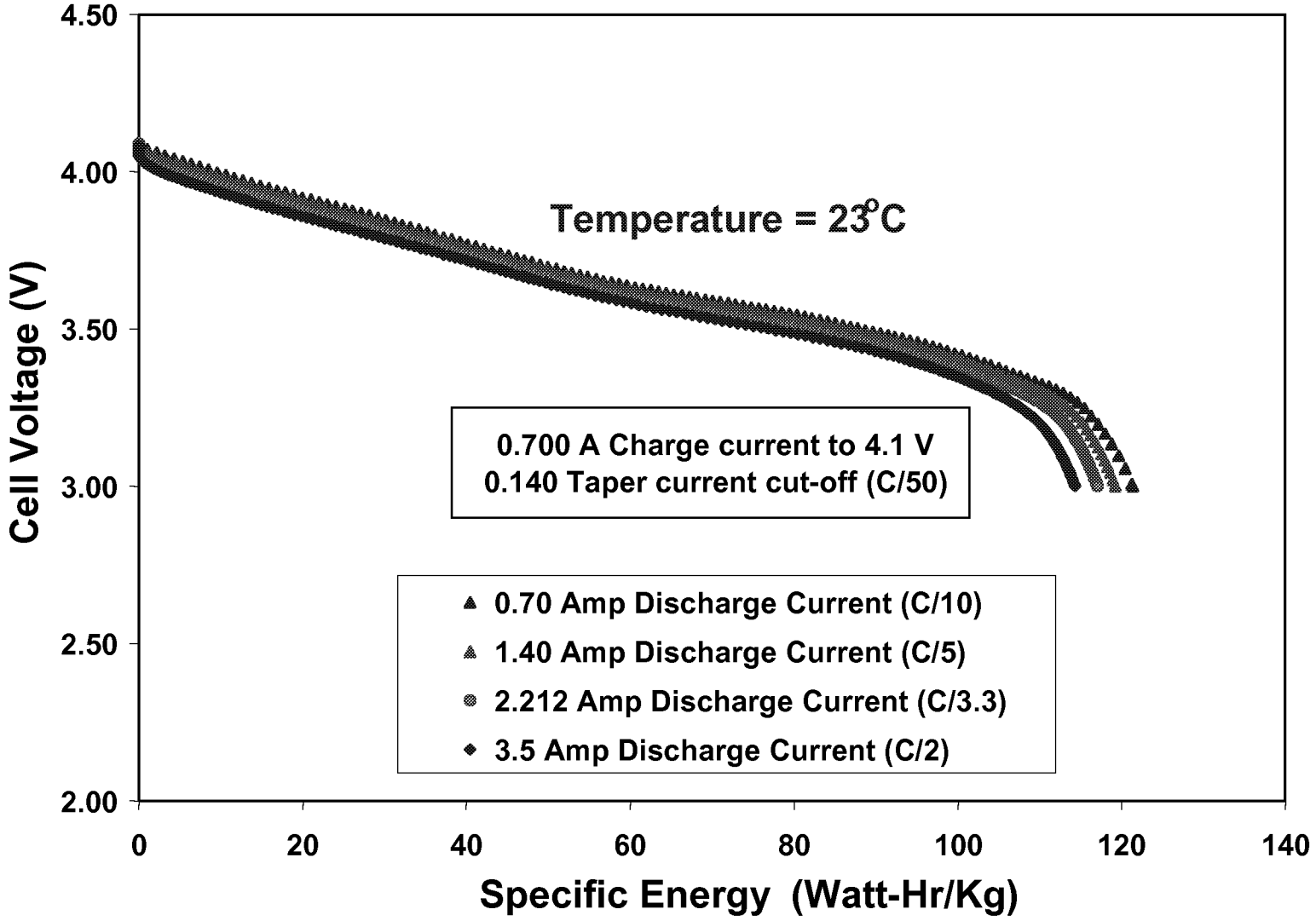
Tolerance to Extended Tapered Charge



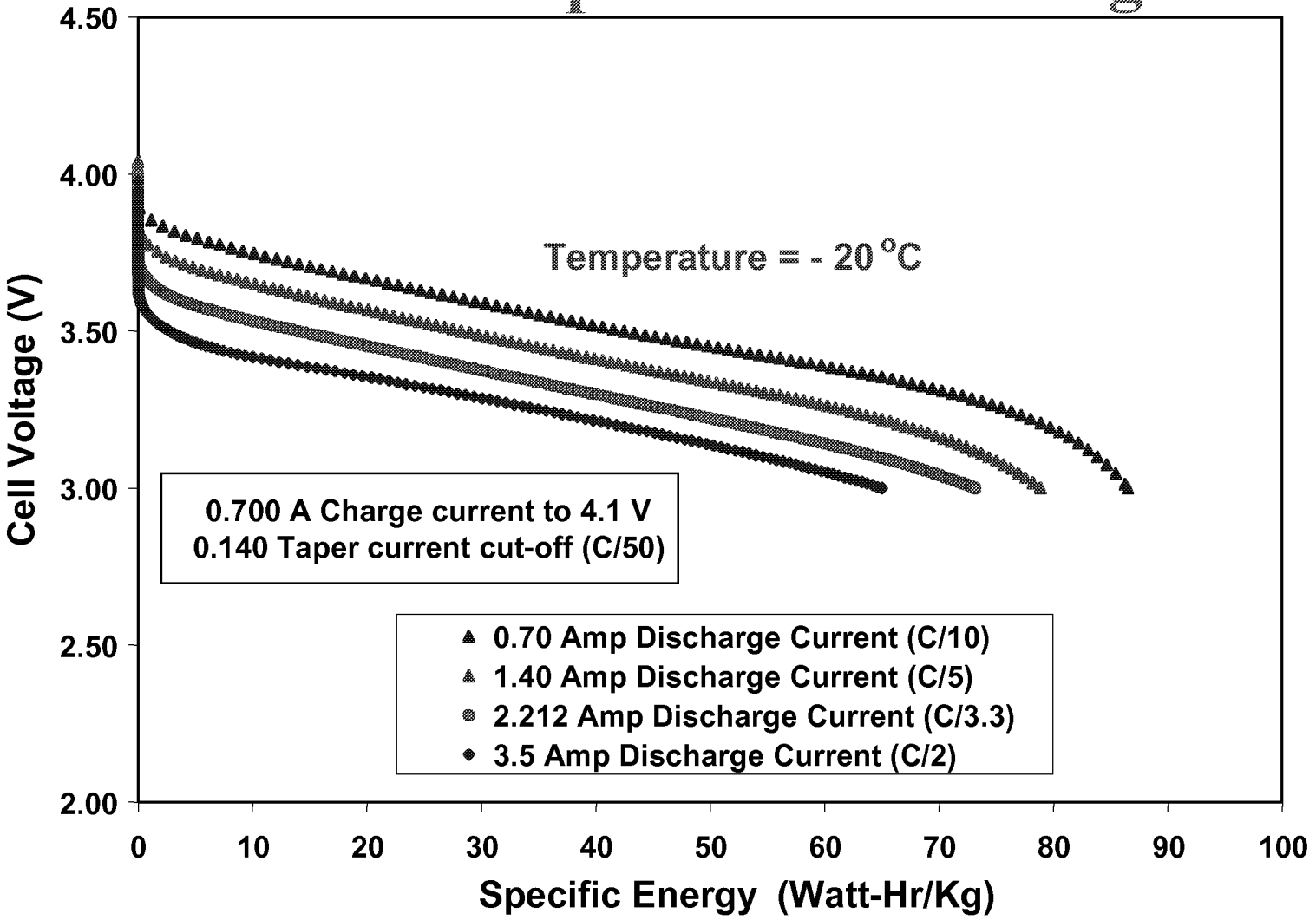
Charge on Cycling



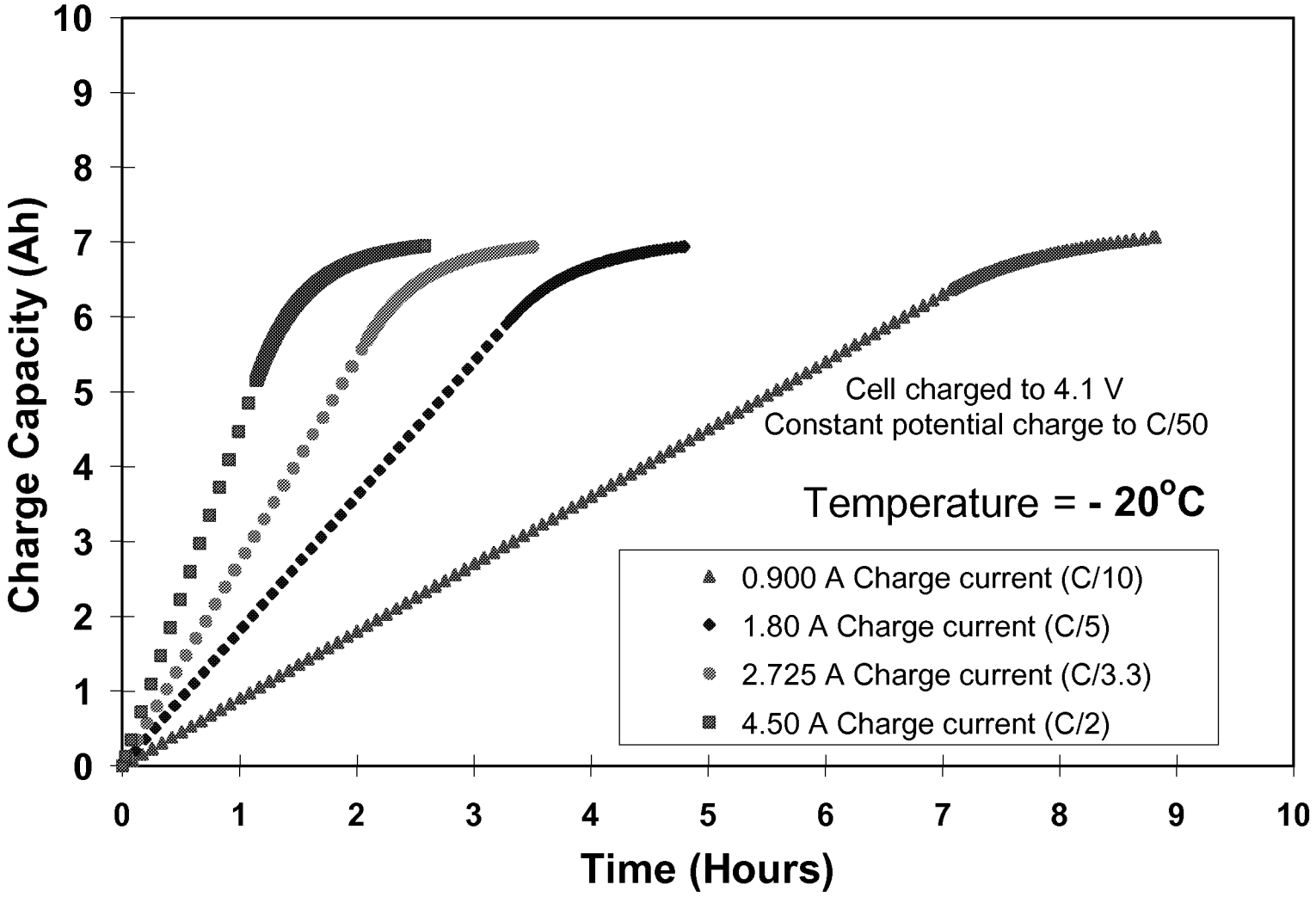
Specific Energy



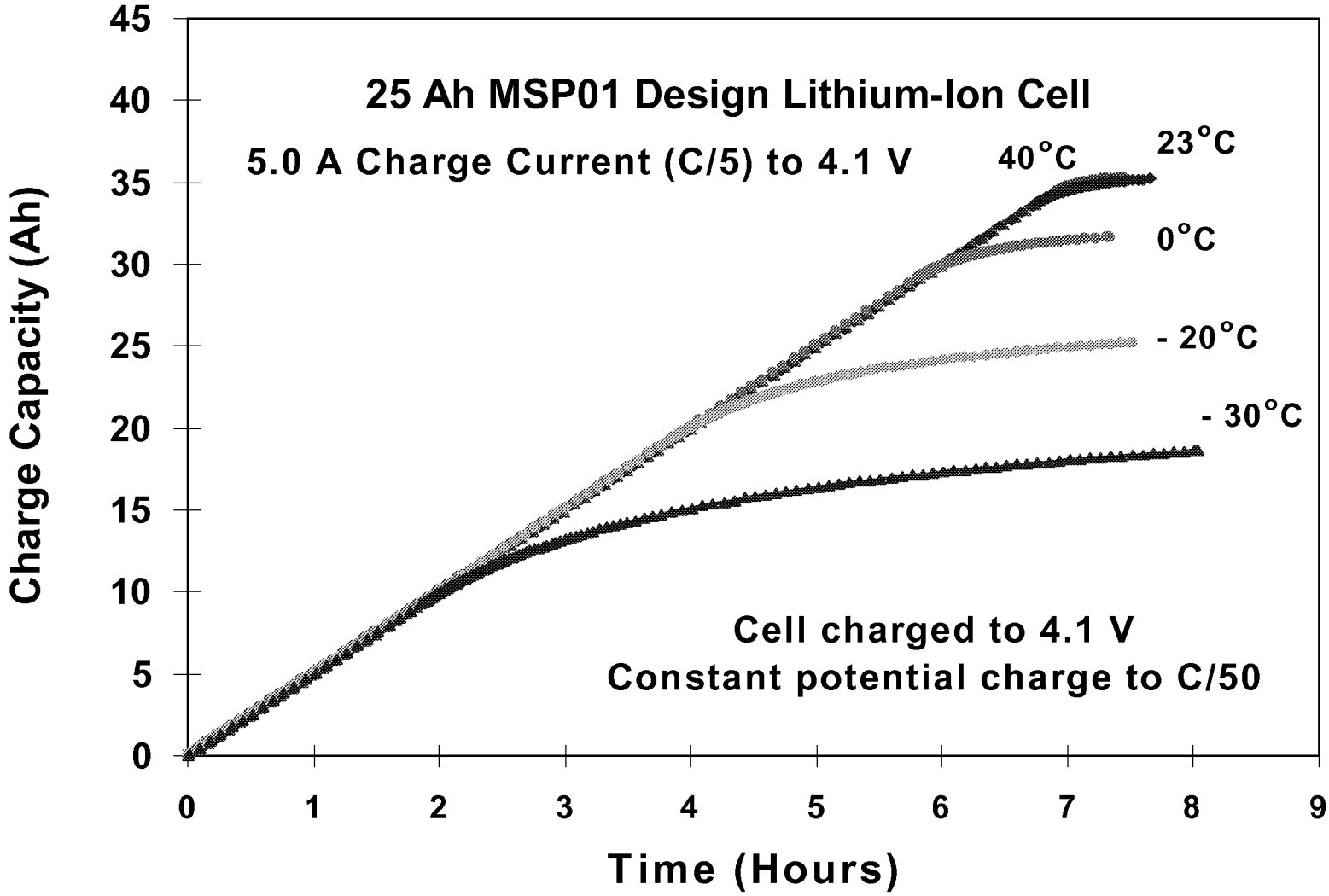
Low Temperature Discharge



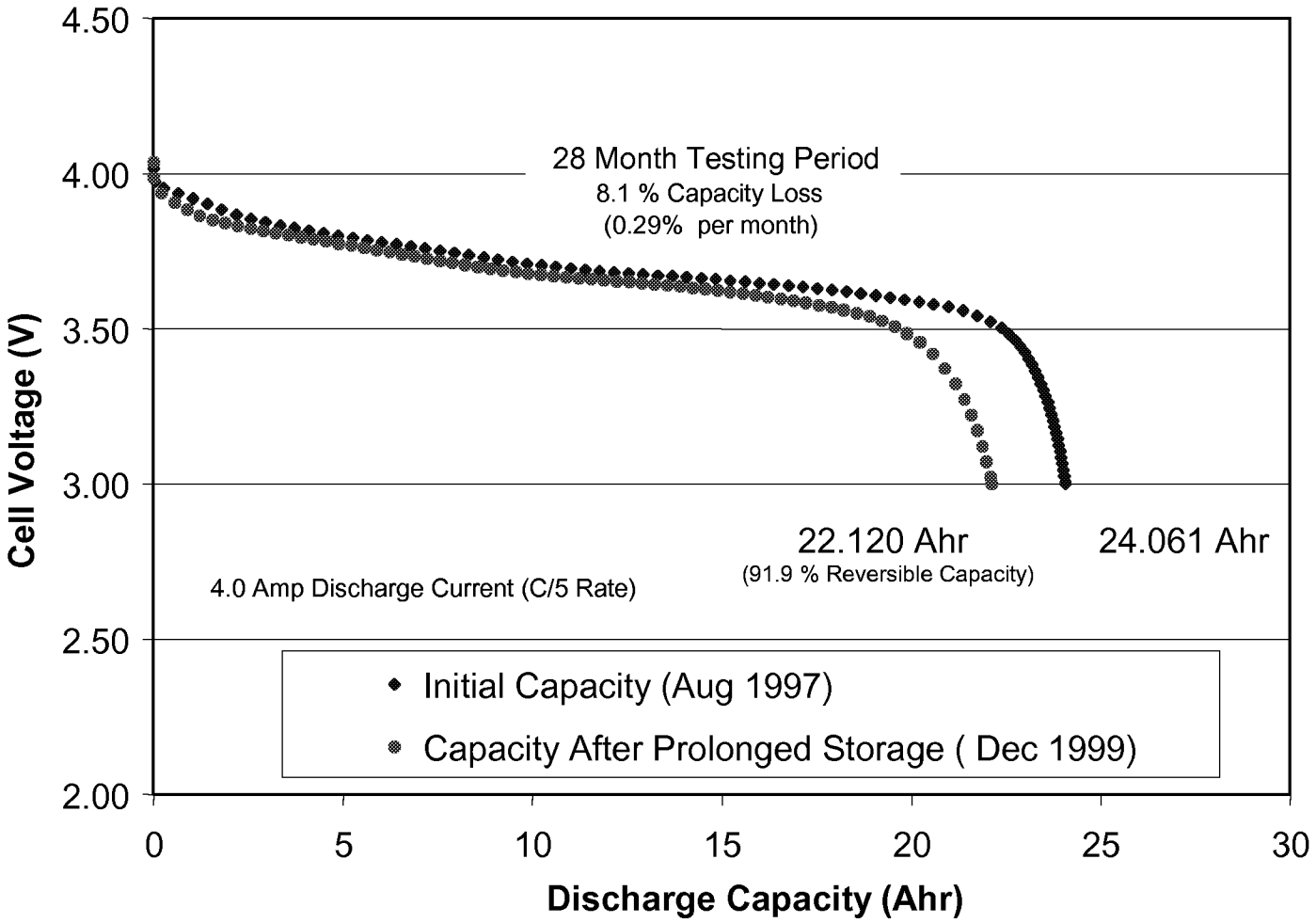
Low Temperature Charge



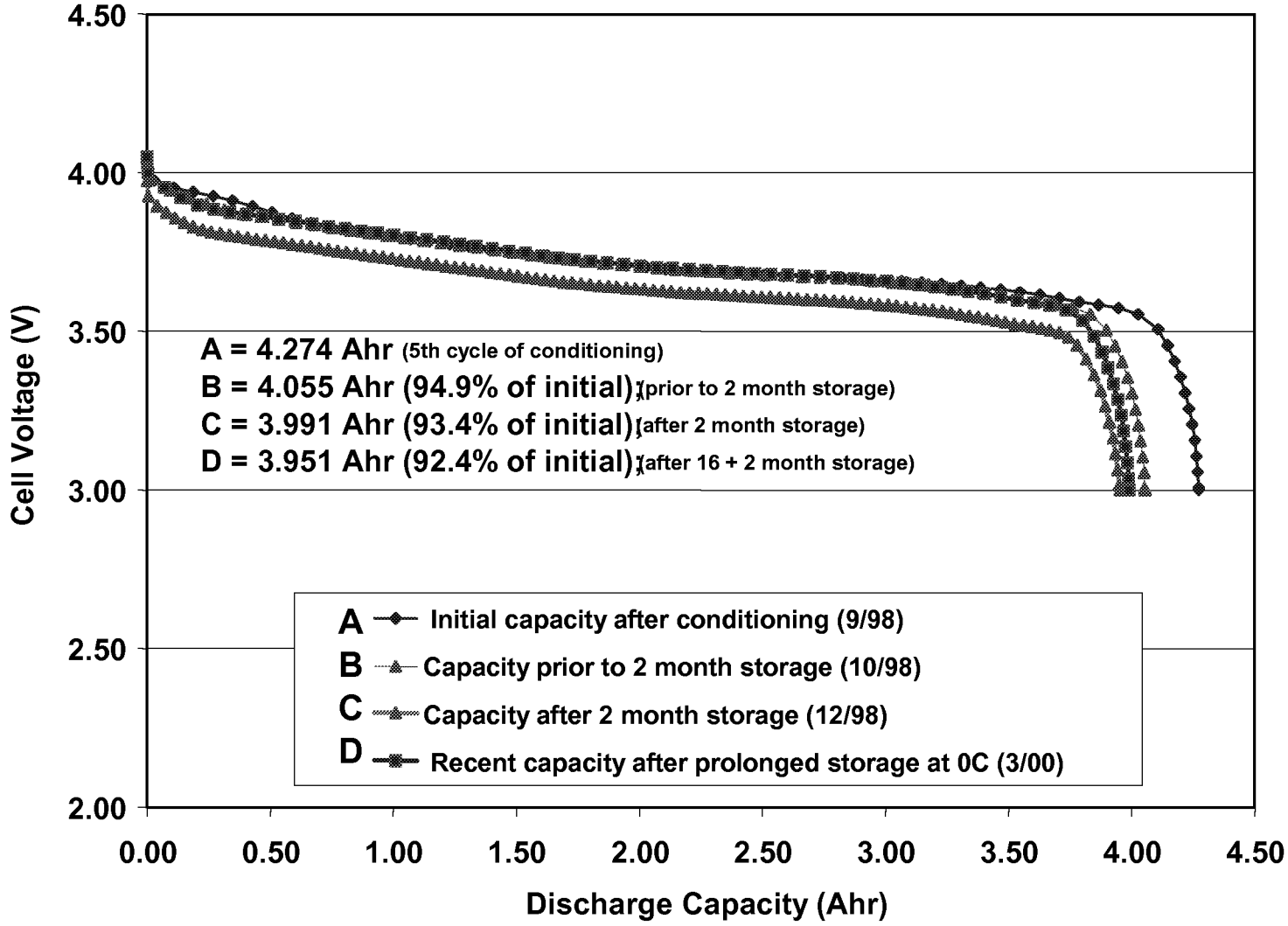
Charge Characteristics of a 25 Ah cell



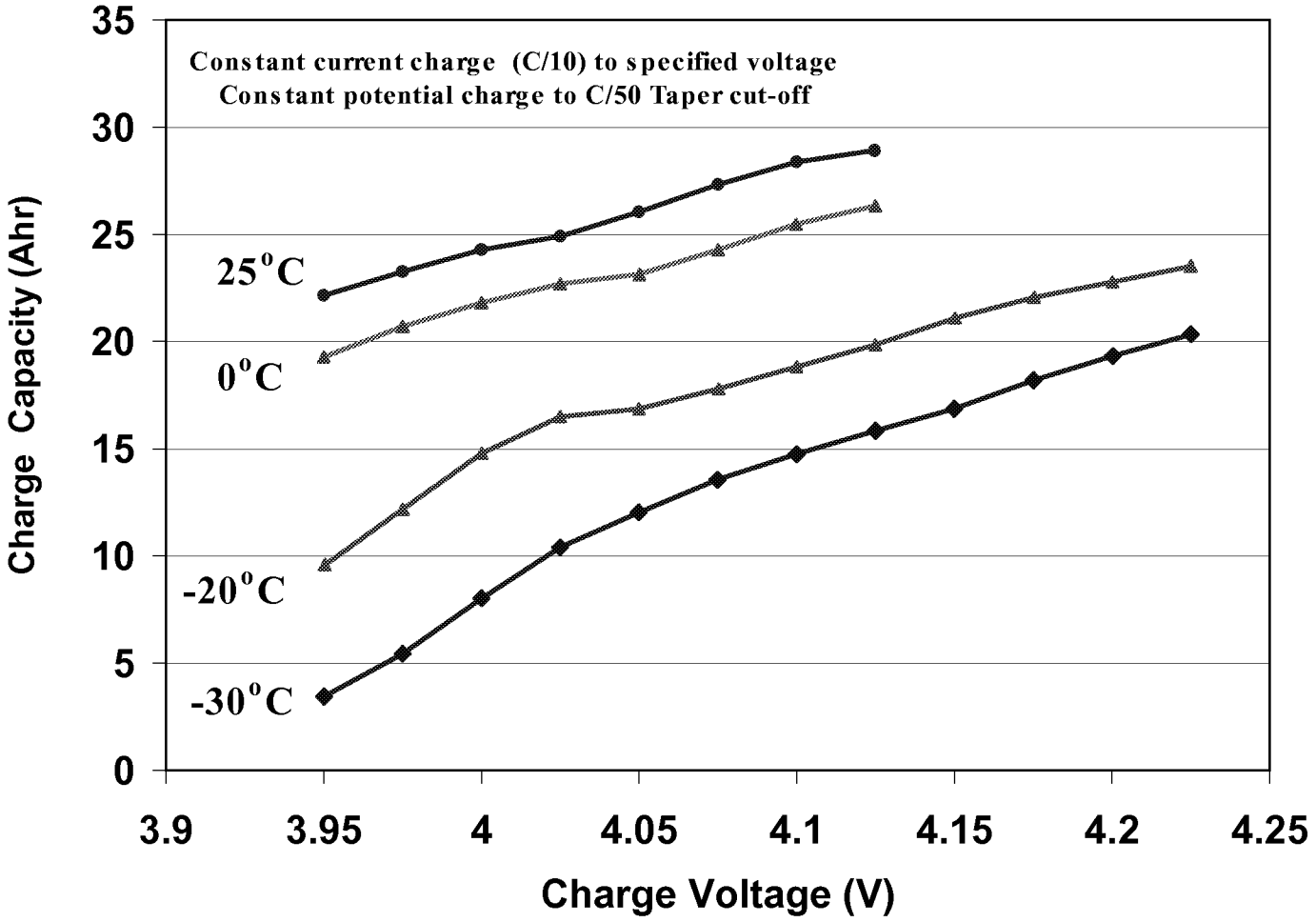
Storage Characteristics



Storage Characteristics



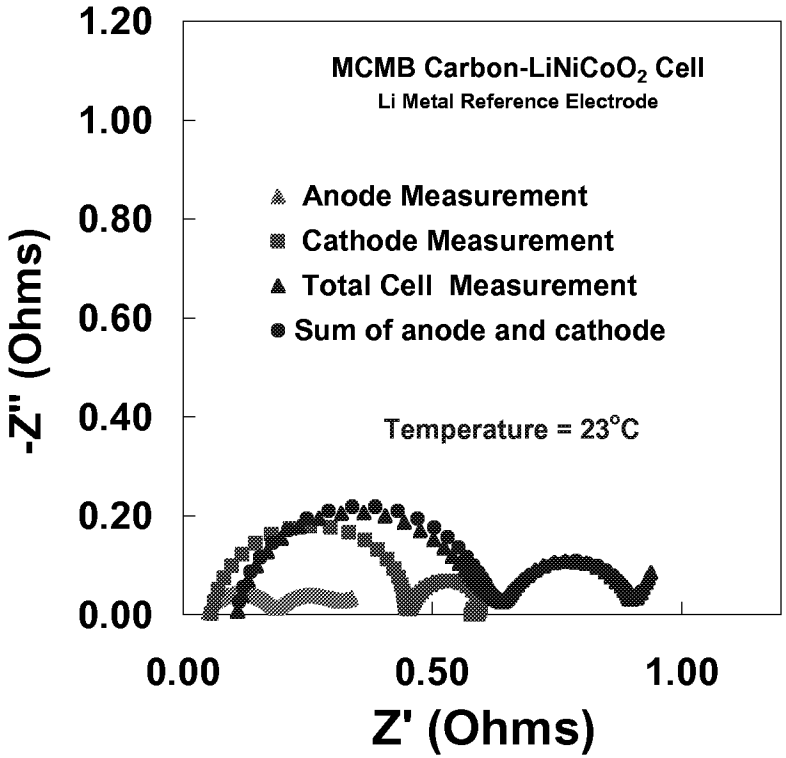
V/T Curves of Li Ion Cells



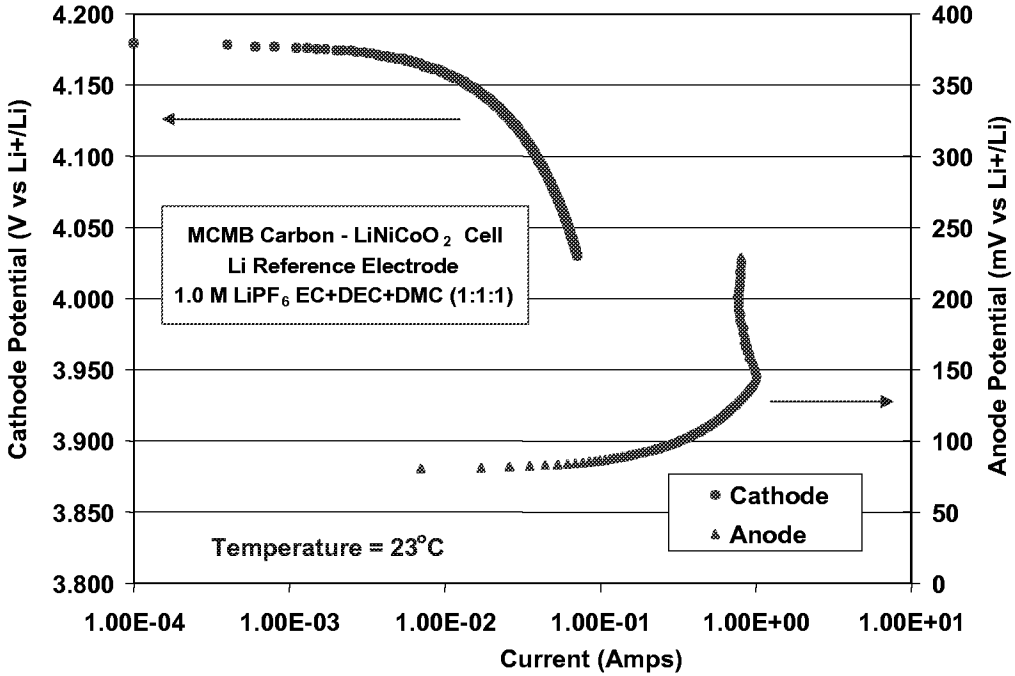
- Are higher charge voltages justified at lower temperature ?
- Need to define specific conditions under which lithium plating can occur (rate and system dependent).

Impedances in a Li Ion Cell

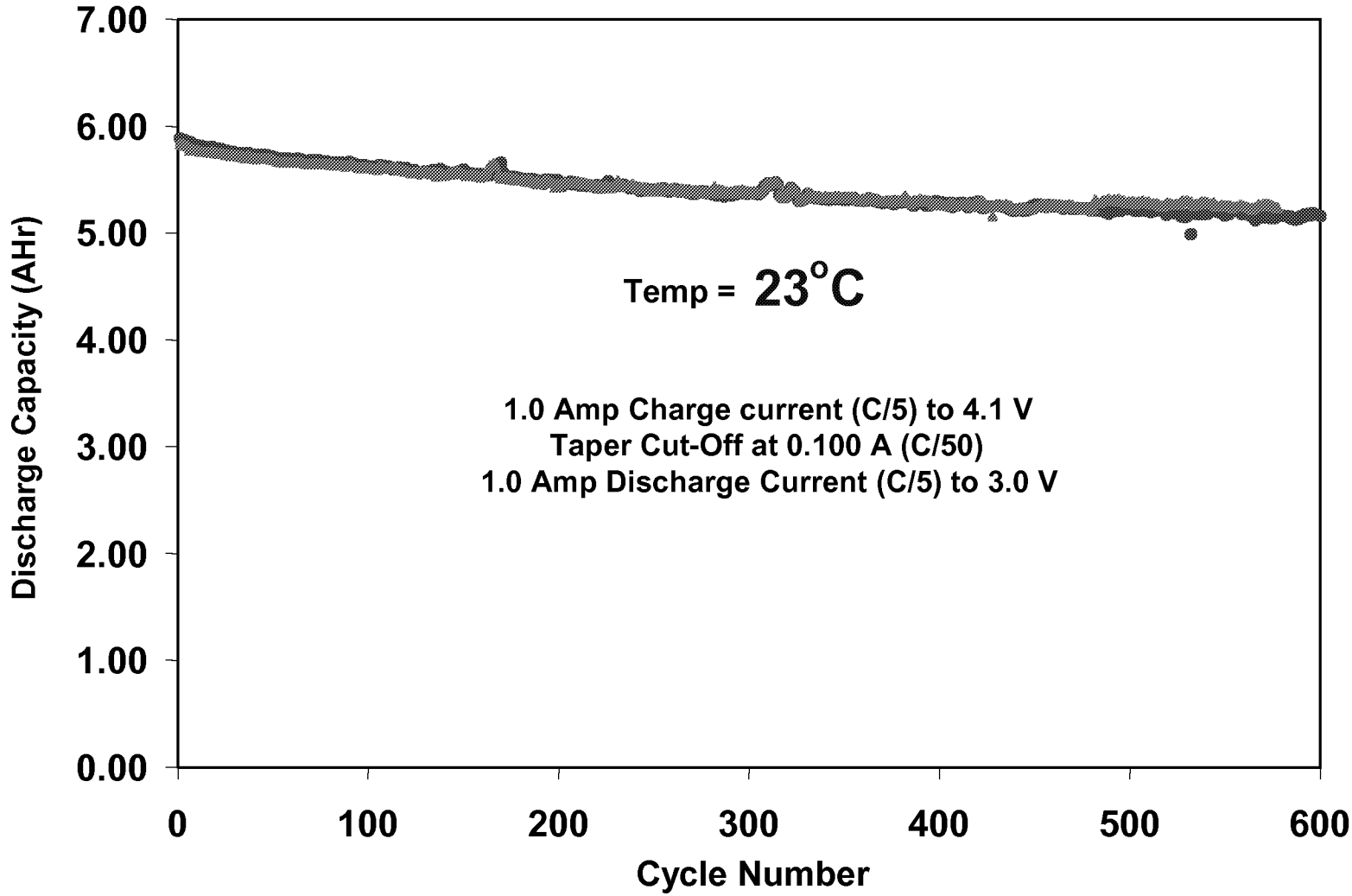
EIS of a Li Ion Cell



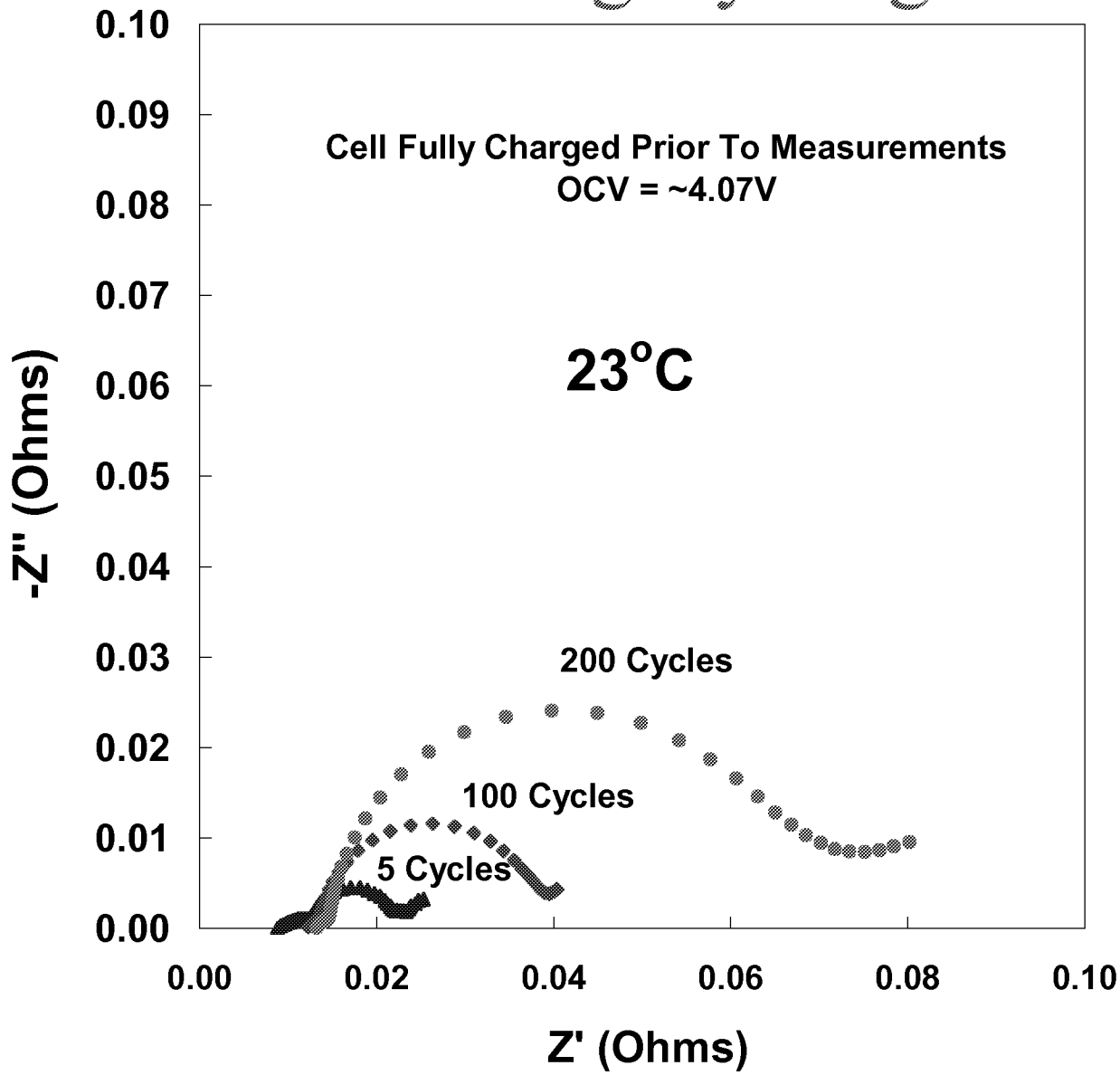
DC Polarizations in Li Ion Cell



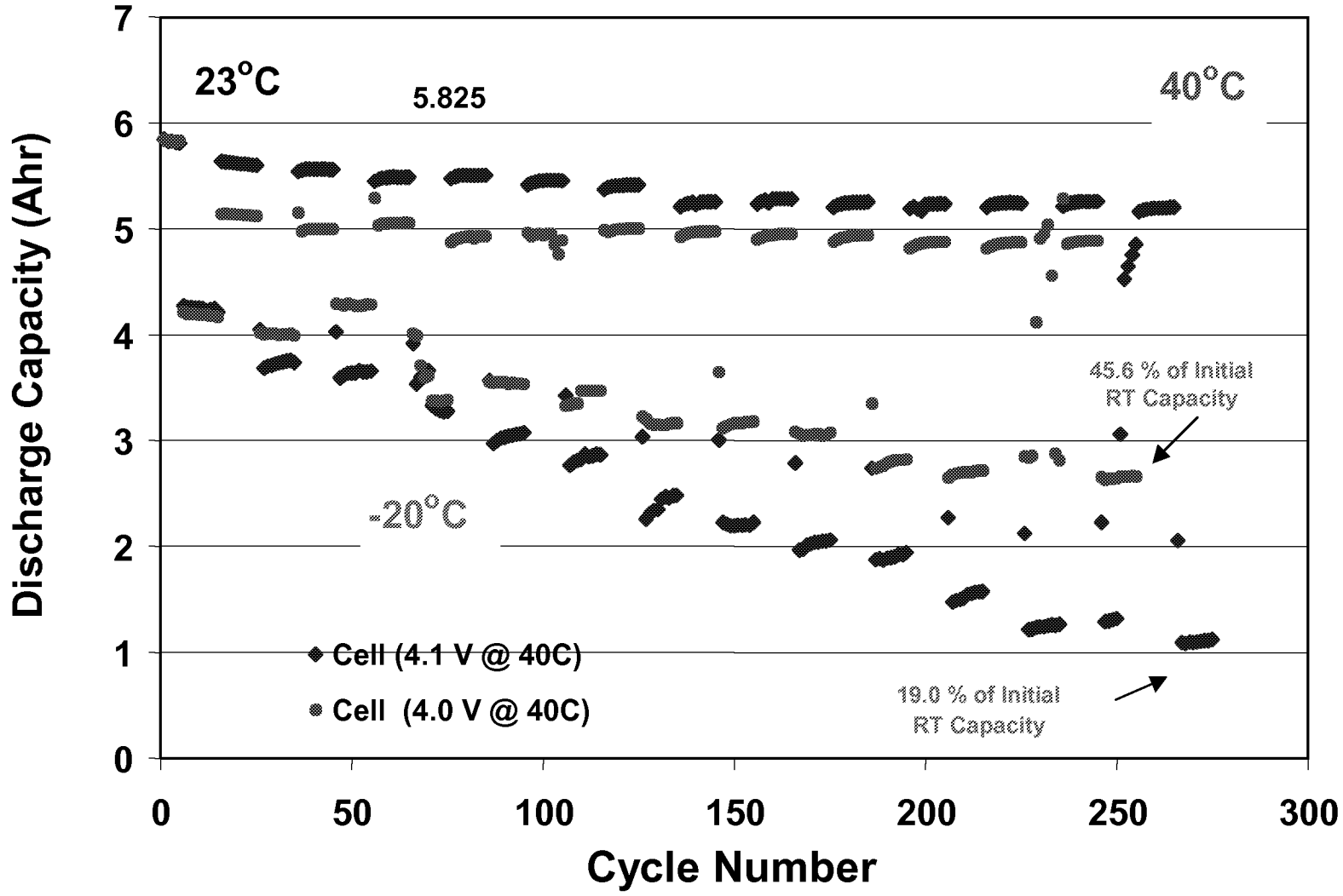
Cycling (100%DOD) at 25°C



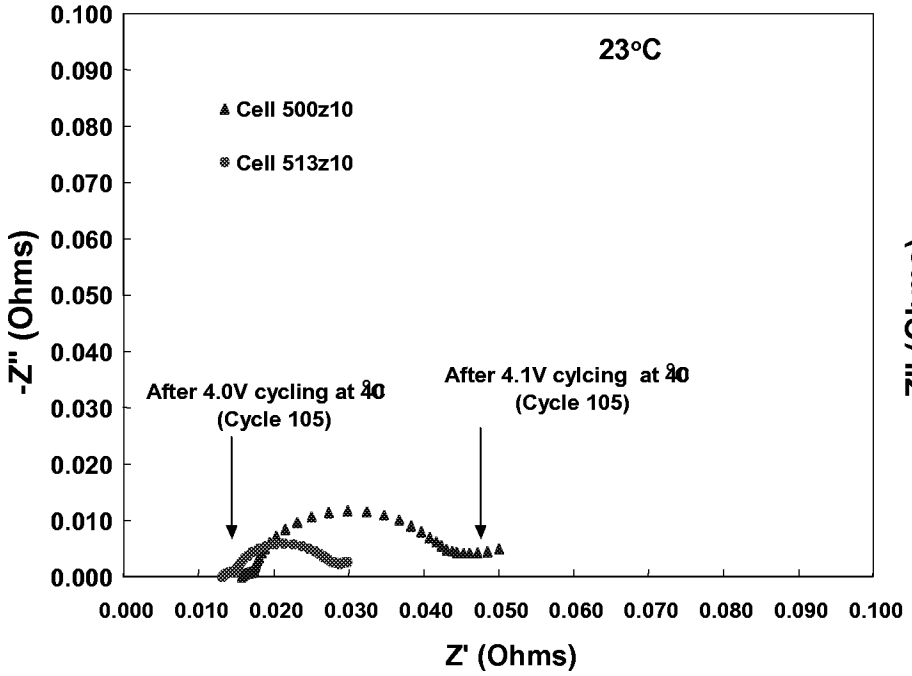
EIS During Cycling

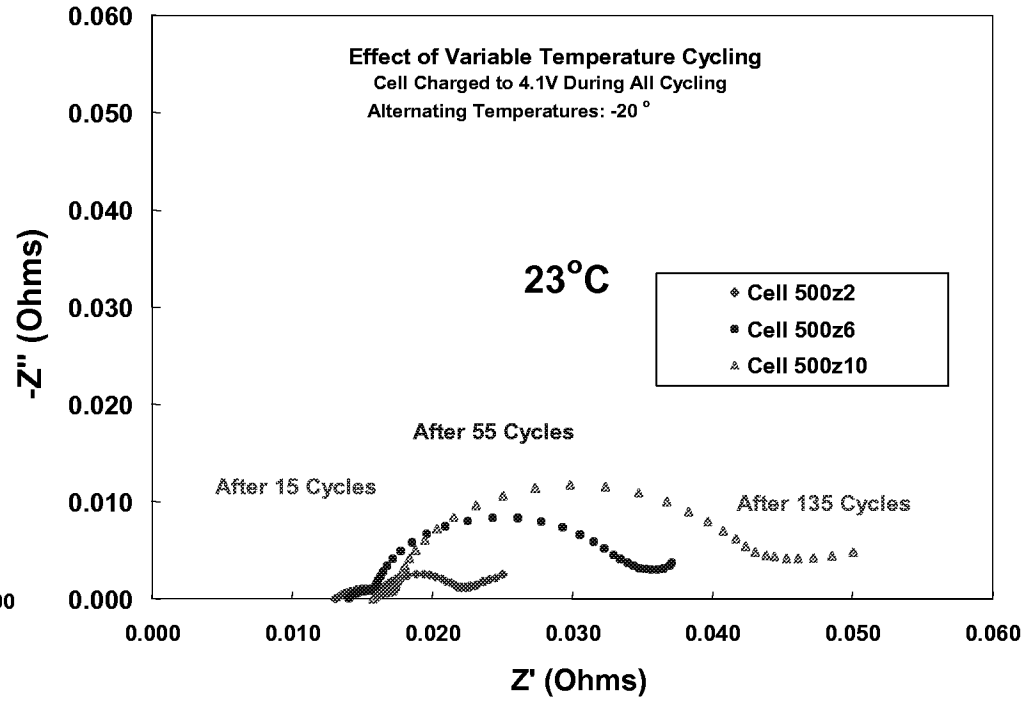


Variable Temperature Cycling

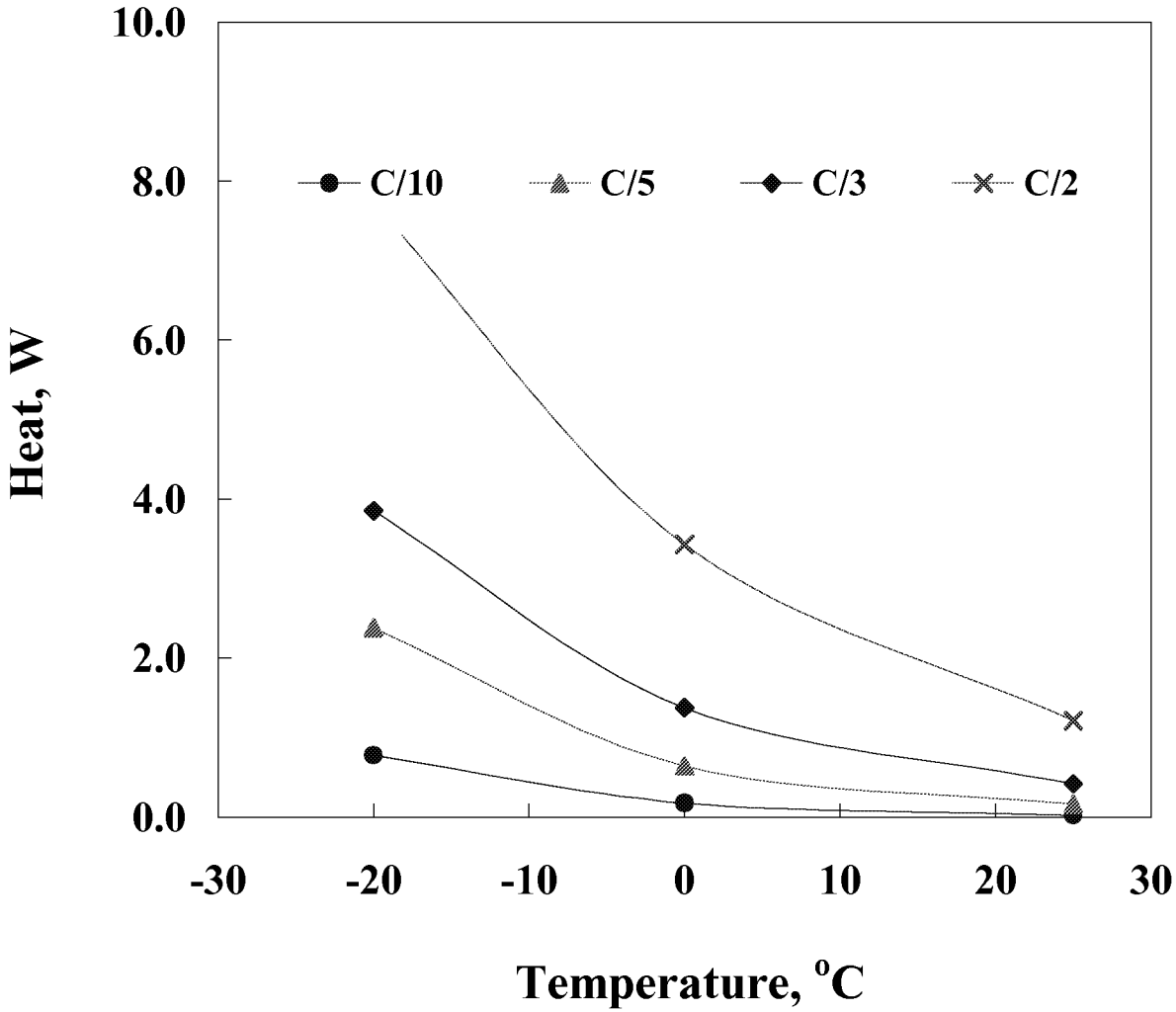


EIS During Variable Temperature Cycling





Heat Generation Rates on Discharge



Safety Events at JPL

- Li Ion Cell Venting upon Inadvertent External short (20-35Ah)
  - No injuries to personnel
  - No damage to equipment
- Li Ion Cell Venting on Extended LT Cycling (5-10 Ah)
  - No injuries to personnel
  - No damage to equipment
- Venting of a pouch (Polymer) cell
  - No damage to equipment

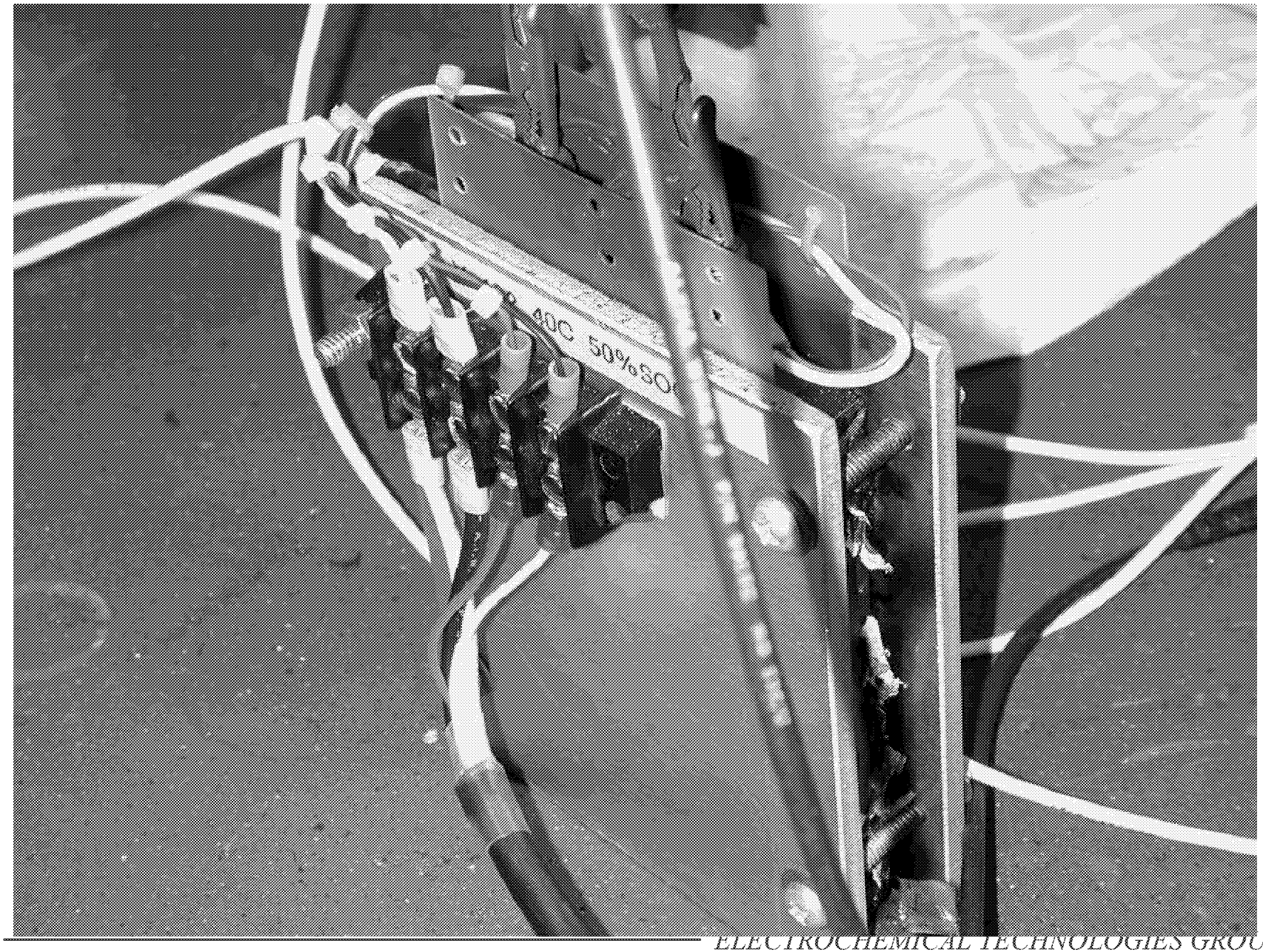
Short Circuit Incident
History of the Cell

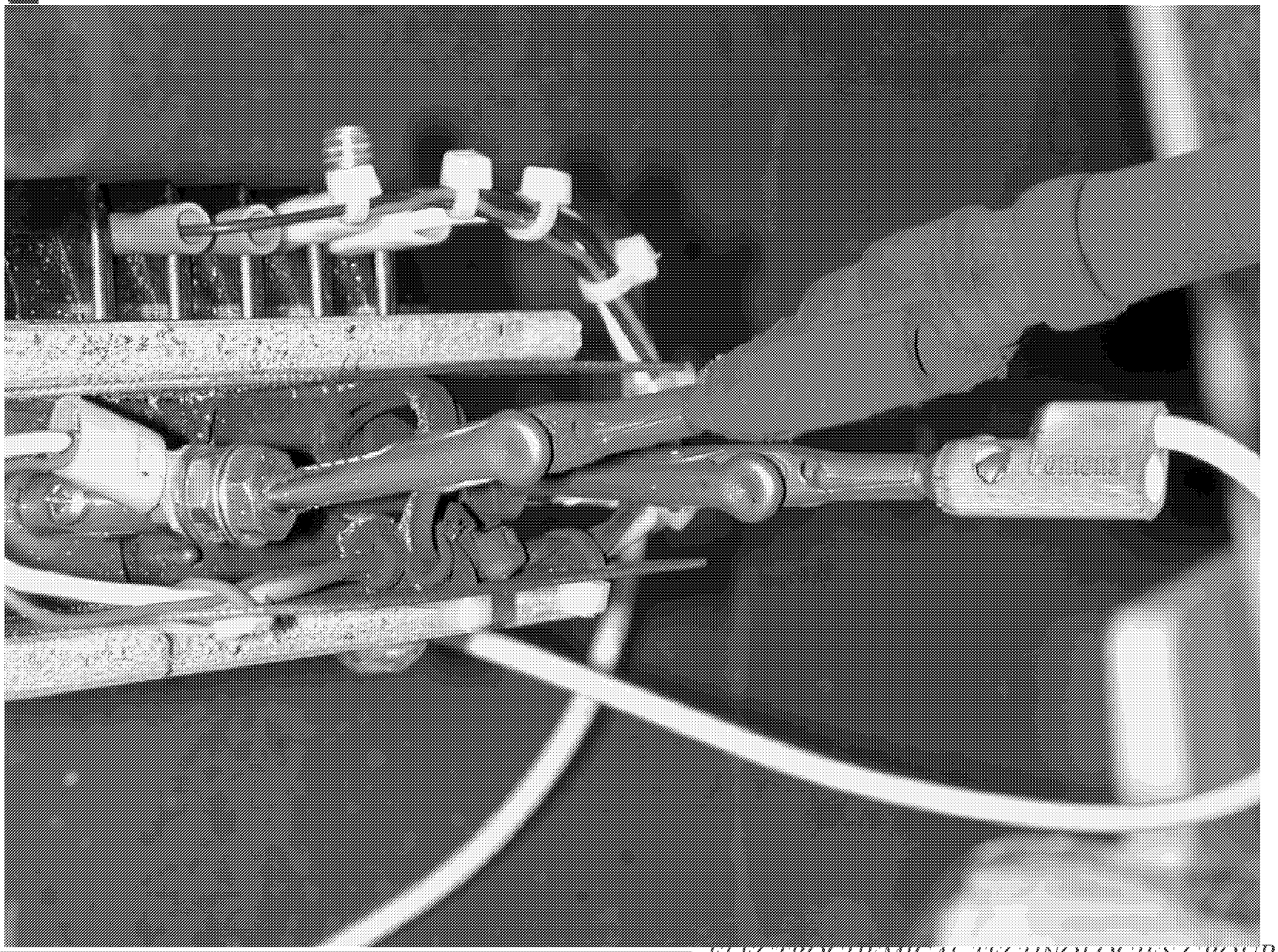
- 2 Month storage in Open Circuit.
- 10 Month on OCV stand.
- Extended storage at 0°C
- Mars Mission Profile
- AC impedance *

Storage

25 Ahr Generation I Lithium-Ion Cells

	Initial	Two Month Storage							Ten Month Storage							
Cell Number and Storage Mode	Initial Capacity (After Cond.)	Capacity Prior To Storage (Ah)	Stored Capacity	Cell Voltage after 10 Month Storage	Capacity After Storage (Ah) 1st Disch.	Capacity After Storage (Ah) 5th Disch.	Capacity Loss (% of stored capacity)	Rever. Capacity (%)	Capacity Prior To Storage (Ah)	Stored Capacity	Cell Voltage after 10 Month Storage	Capacity After Storage (Ah) 1st Disch.	Capacity After Storage (Ah) 5th Disch.	Capacity Loss (% of stored capacity)	Rever. Capacity (%)	Total Reversible Capacity After 12 Months (% from Initial)
151 (0°C and 50 % SOC)	27.879	27.609	14.000	2.565 V	0.000	27.327	100	98.976	26.972	14.000	0.578 V	0.000	27.602	100	102.337	99.006
152 (40°C and 50 % SOC)	28.749	28.021	14.000	3.308 V	1.968	27.479	85.943	98.065	27.918	14.000	0.482 V	0.000	27.675	100	99.129	96.263
178 (0°C and 100 % SOC)	25.475	25.471	25.487	3.982 V	23.114	24.781	9.310	97.289	24.607	24.623	3.762 V	16.996	25.279	30.975	102.731	99.227
201 (40°C and 100 % SOC)	25.674	25.670	25.584	3.834 V	19.611	25.156	23.349	97.998	23.912	23.807	3.608 V	10.309	23.789	56.699	99.486	92.659


40C 50%SO



Summary

- Lithium ion cells developed under the DOD/NASA consortium were found to exhibit:
  - High specific energy (>120 Wh/kg) and High energy density (300 Wh/l)
  - Long cycle life (over 1000 Cycles)
  - Excellent low temperature performance(-20 C Operation)
  - Good storage characteristics
- Three minor safety incidents occurred over a period of three years of testing more than five hundred lithium ion cells of 1-35 Ah sizes.
- Further improvements in cell design will minimize such safety events.