Performance Characteristics of Lithium-Ion Prototype Batteries for Mars Surveyor Program 2001 Lander

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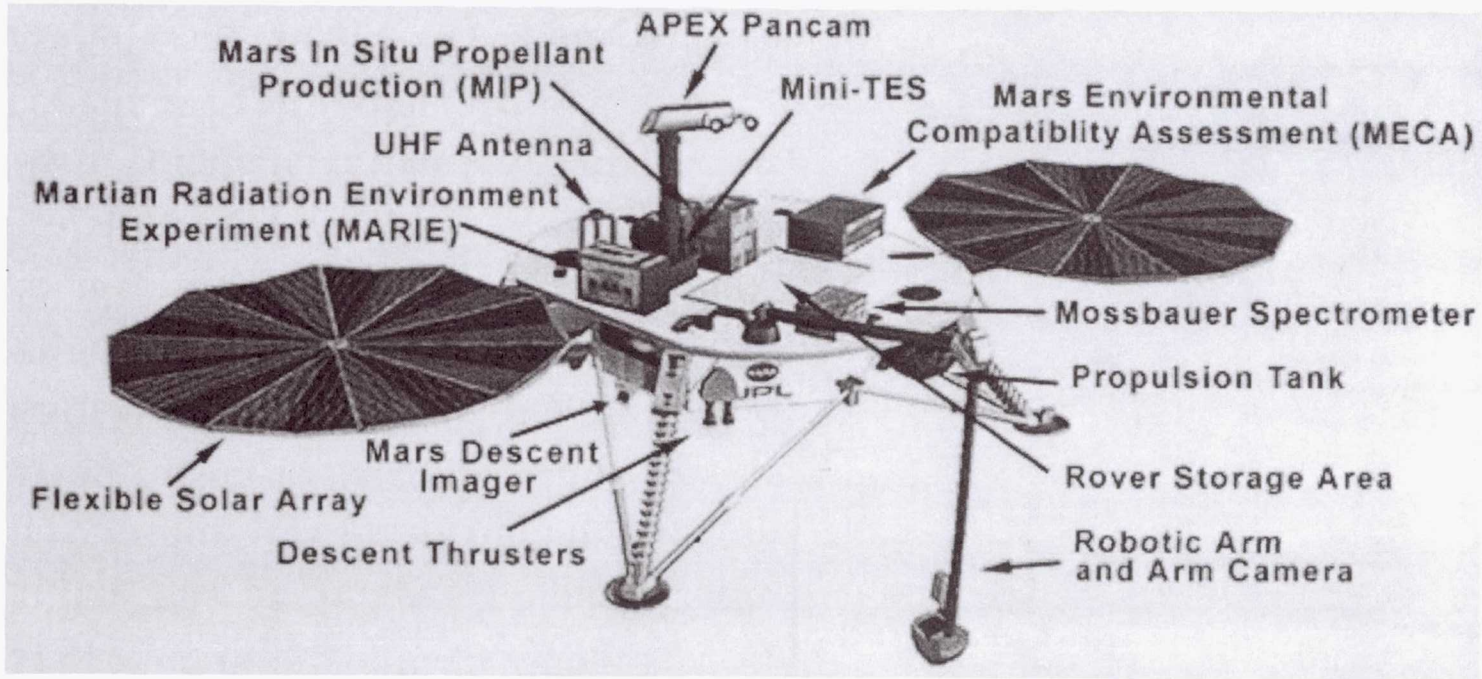
Lithium-Ion Cells for Mars Surveyor 2001 Lander

Outline

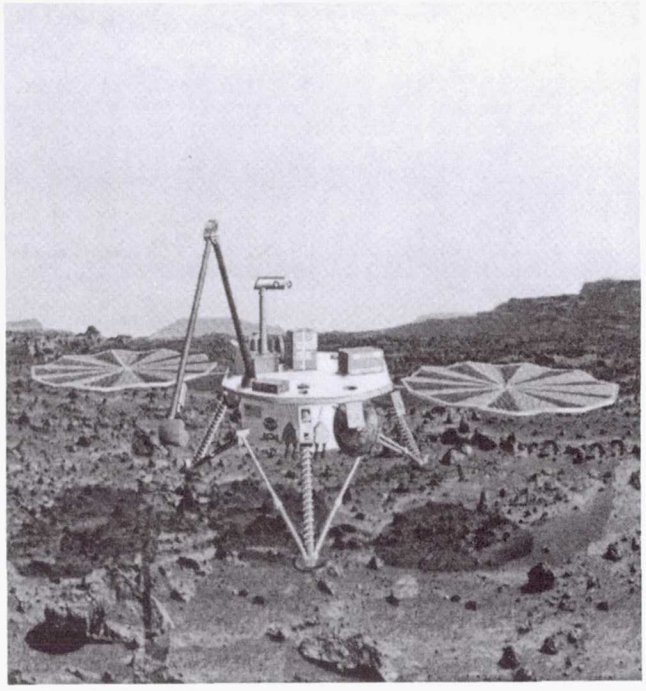
- Introduction
- Cell Performance and Battery Requirements
- Overview of Performance Evaluation Tests
- Cycle Life Performance Tests
- Low Temperature Performance Tests
- Cell Charge Characteristics
- Cell Storage Characteristics
- Summary and Conclusions

Mars Surveyor 2001 Lander- Scientific Payload

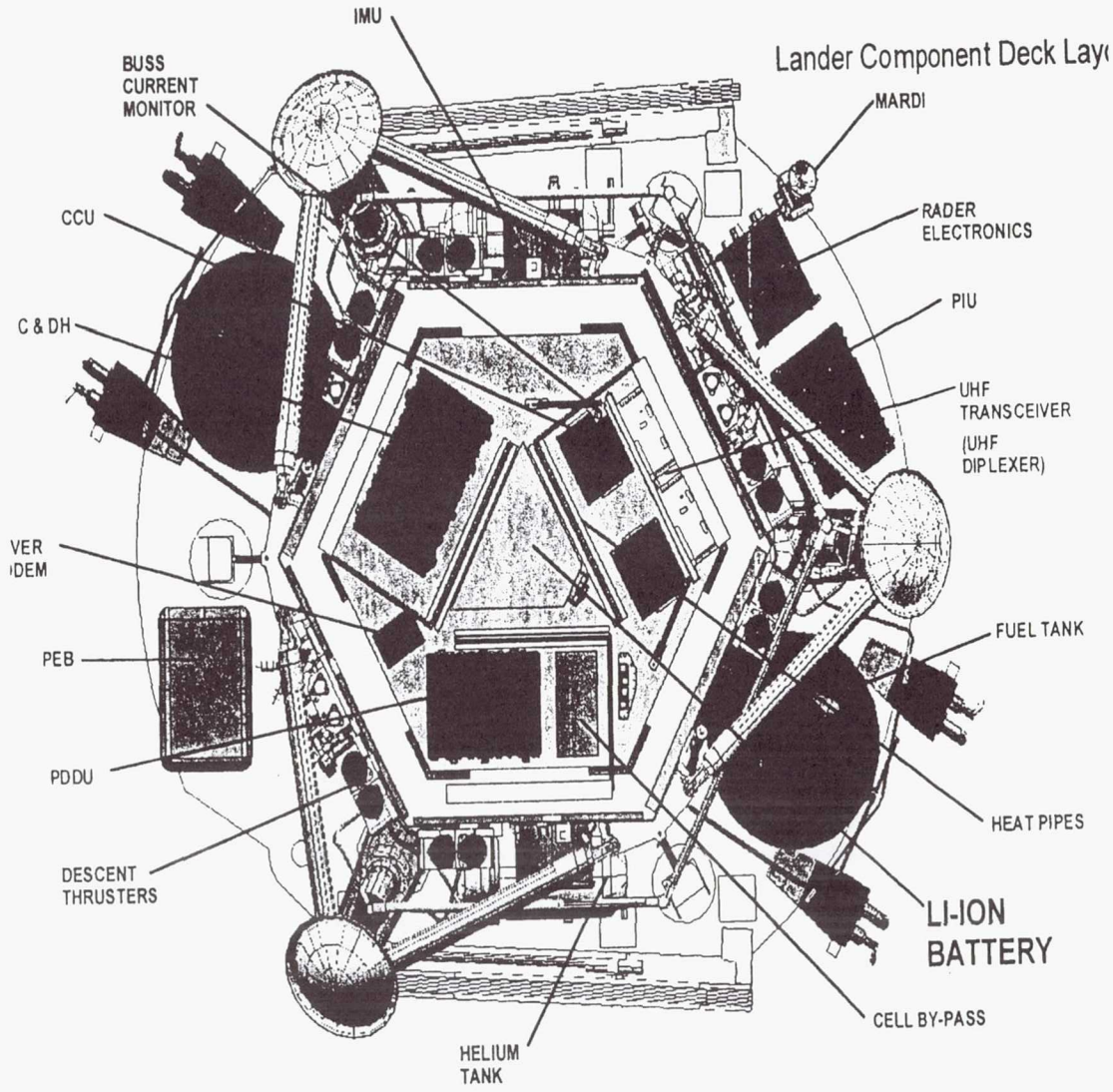


Mars Surveyor 2001 Lander

- Scheduled launch date April 10, 2001; Expected landing Jan 22, 2002.
- Lander has an imager to picture the surrounding terrain of the landing site during rocket-assisted descent.
- Platform for instruments and technology experiments designed to provide key insights to decisions regarding human missions to Mars.
- In-situ demonstration test of rocket propellant production.
- Martial soil properties and surface radiation environment



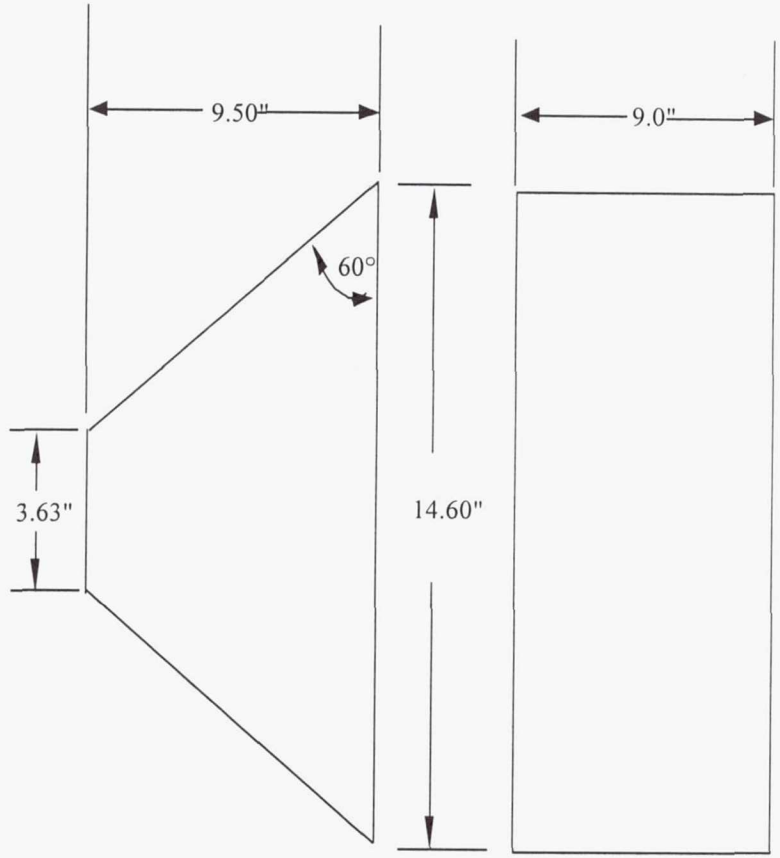
Mars Surveyor 2001 Lander- Components



MSP 2001 Lander Battery

- Two 25 Ah, 8-Cell Li Ion Batteries (N+1)
- Individual Cell Monitoring and control via Cell Bypass Unit (CBU) to prevent overcharge
- Individual Charge Control Unit (CCU)
- Constant Voltage Charging at - 32.8 Vdc
- 16 Selectable V/T curves.
- Amp Hour Integration.

Battery Envelope



MSP 2001 Lander Power System Battery Challenges

- *High specific Energy*
  - 800 Wh in 7.94 Kg (100 Wh/kg)
- *Low Temperature Performance*
  - Op. Temperature : -20 to +40°C
  - Capacity of 25 Ah -20°C at C/5
- *Good Cycle Life*
  - 200 Cycles @ 70%
- *Long Calendar Life*
  - Two years of storage (1 year cruise) before battery operation
  - Low temperature performance after storage (final phase of the mission)

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)

Lithium-Ion Cells for Mars Surveyor 2001 Lander Program Objectives

- Assess viability of using lithium-ion technology for future Aerospace applications.

- Demonstrate applicability of using lithium-ion technology for the MSP 2001 Lander application.

Lithium-Ion Cells for Mars Surveyor 2001 Lander

Performance Evaluation Tests

- **Cycle Life Performance**
  - Room temperature cycle life (23° +/- 2°C)
  - Low temperature cycle life (-20°C)
  - High temperature cycling (40°C)
  - Variable temperature cycling
- **Electrical Performance Characterization**
  - Range of charge and discharge rates (C/2, C/3.3, C/5 and C/10)
  - Range of temperatures (-30, -20, 0, 23, 40°C)
  - Pulse capability (40 and 60A)
  - Impedance measurements
- **Storage Characteristics**
  - * 2 Month storage test (0 and 40°C, 50 and 100% SOC)
  - * Accelerated storage test: at different SOC (50, 70,100% SOC), temperatures (25, 40, 55°C), and storage conditions.
- **Quality Control**
  - Reproducibility of cell results
  - Cell to cell performance performance variations

Cycle Life Performance Tests

Requirement **: Deliver > 200 cycles on surface of Mars**

- **100% DOD cycling (3.0-4.1V, C/5-C/10)**
- **Wide temperature range (-20°C to 40°C)**
- **At end of life should deliver 25 Ah**

Approach**:**

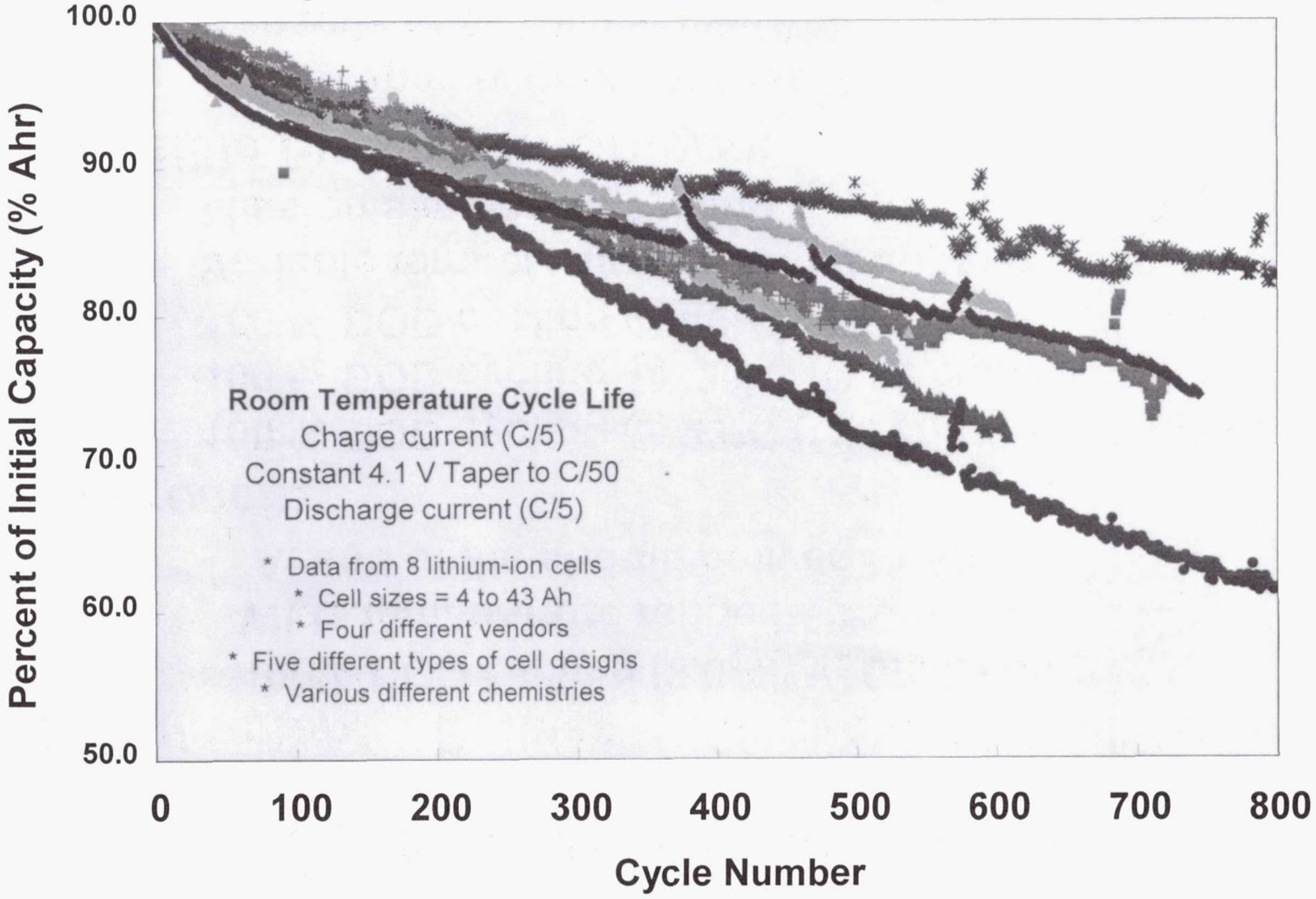
100 % DOD cycling @ 23°C (C/5 charge, C/5 discharge)
100 % DOD cycling @ -20°C (C/10 charge, C/5 discharge)
100 % DOD cycling @ 40°C (C/5 charge, C/5 discharge)
Variable temperature cycling (temperature extremes)
Mission simulation cycling

Possible Evaluation Criteria**:**

Initial capacity (must exceed 25 Ah)
Capacity after 200 cycles (Ah)
Capacity fade rates
Capacity delivered over range of temperatures

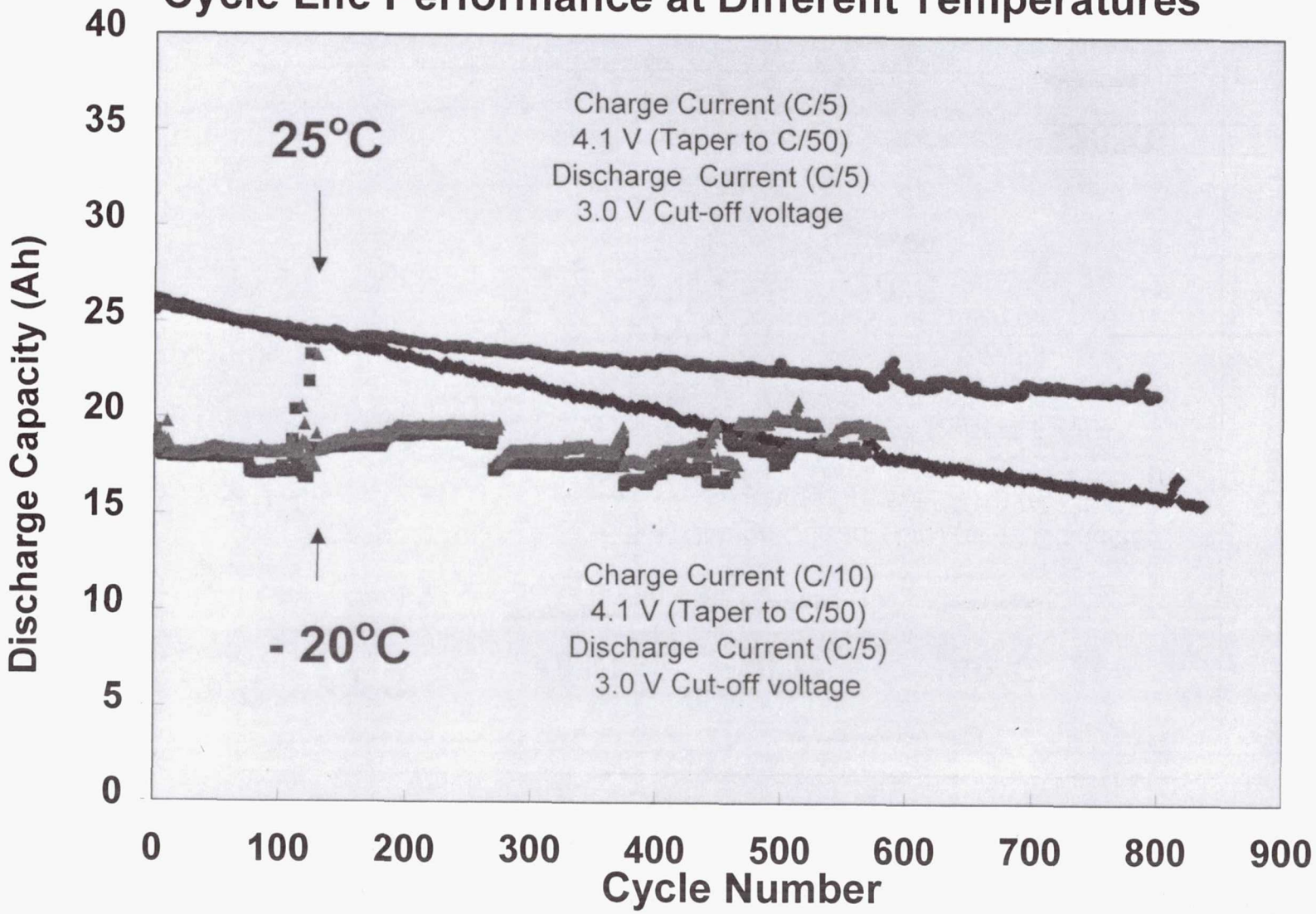
Lithium-Ion Cells for Mars Surveyor 2001 Lander

Room Temperature Cycle Life Performance
Comparison of Different Cell Designs and Sizes



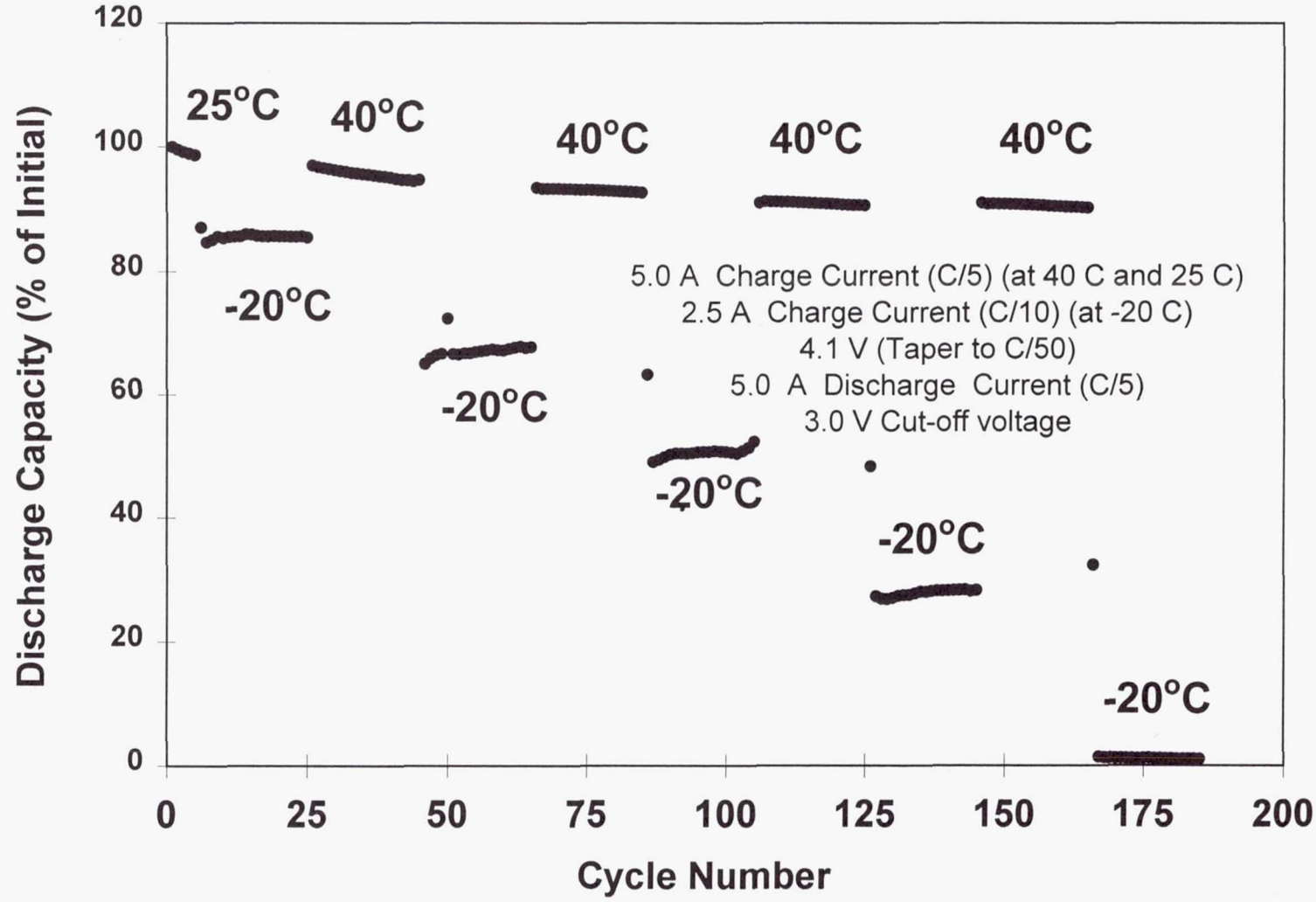
Lithium-Ion Cells for Mars Surveyor 2001 Lander

Cycle Life Performance at Different Temperatures



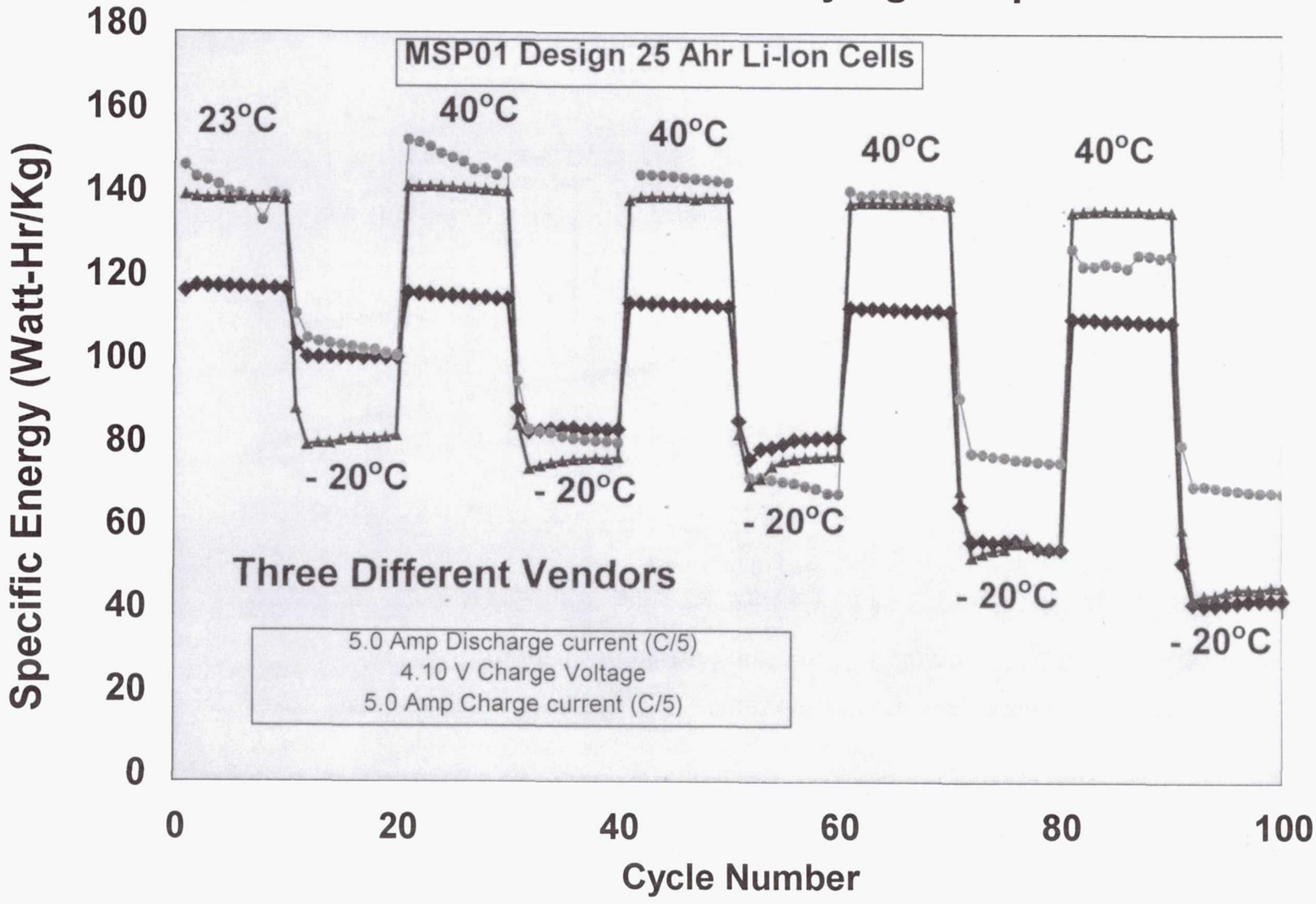
Lithium-Ion Cells for Mars Surveyor 2001 Lander

Cycle Life Performance at Varying Temperatures



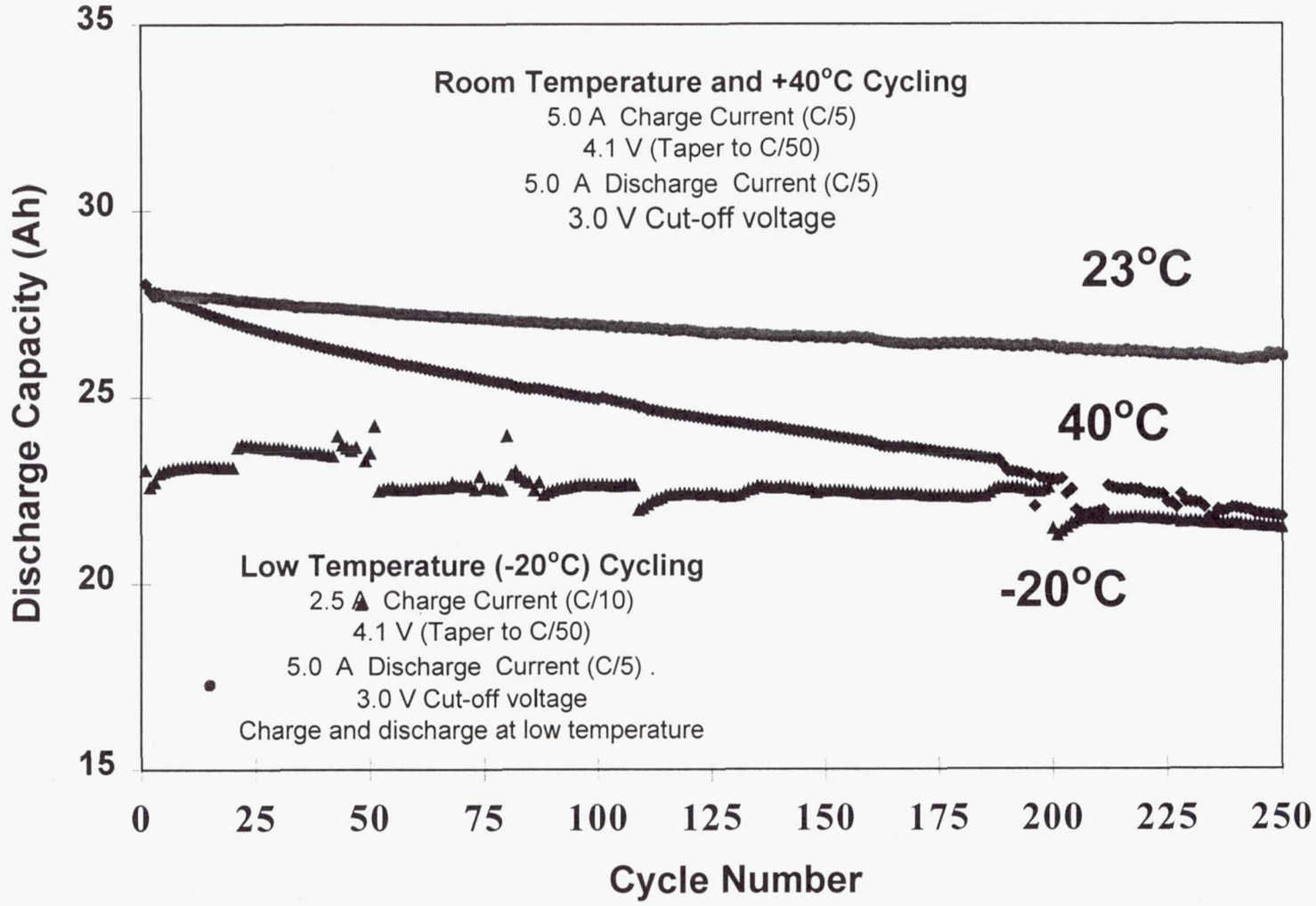
Lithium-Ion Cells for Mars Surveyor 2001 Lander

Cycle Life Performance at Varying Temperatures



Lithium-Ion Cells for Mars Surveyor 2001 Lander

Cycle Life Performance at Different Temperatures



Lithium-Ion Cells for Mars Surveyor 2001 Lander

Low Temperature Performance Evaluation

Requirement :

- Provide 25 Ah over wide range of temperatures (-20°C to 40°C)
- Provide 25 Ah at C/2 rate - C/10 rate
- Should be capable of meeting mission profile

Approach:

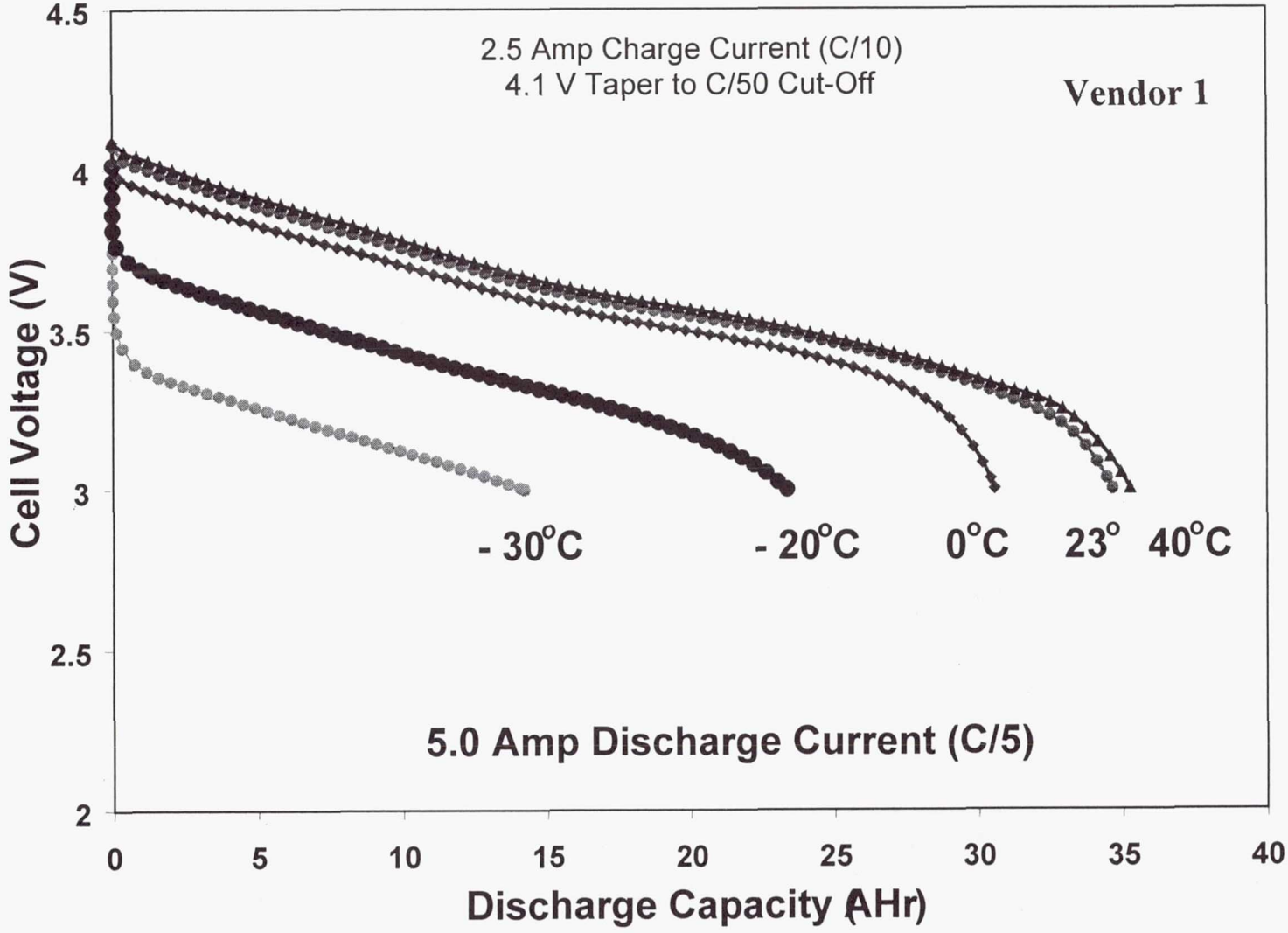
Rate characterization at various temperatures (-20, 0, 20 and 40°C)
Range of charge and discharge rates (C/2, C/3.3, C/5 and C/10)

Possible Evaluation Criteria:

Low temperature discharge capacity (@ -20°C)
Low temperature charge characteristics
Capacity delivered over range of temperatures
Discharge energy (Wh/Kg)
Watt-hour efficiency (round-trip efficiency)
Heat generation
Effect of cell history upon rate capability

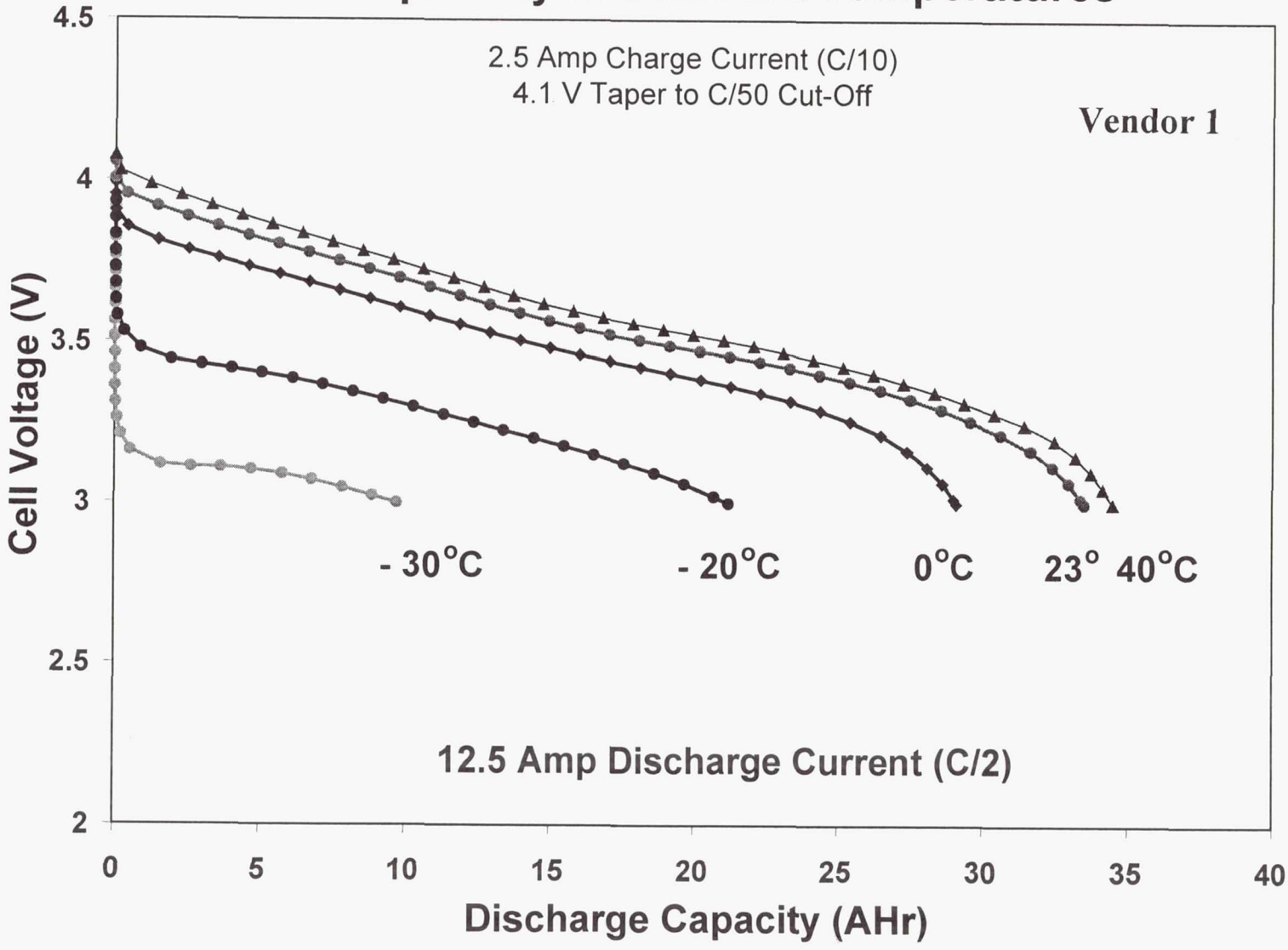
Lithium-Ion Cells for Mars Surveyor 2001 Lander

Rate Capability at Different Temperatures



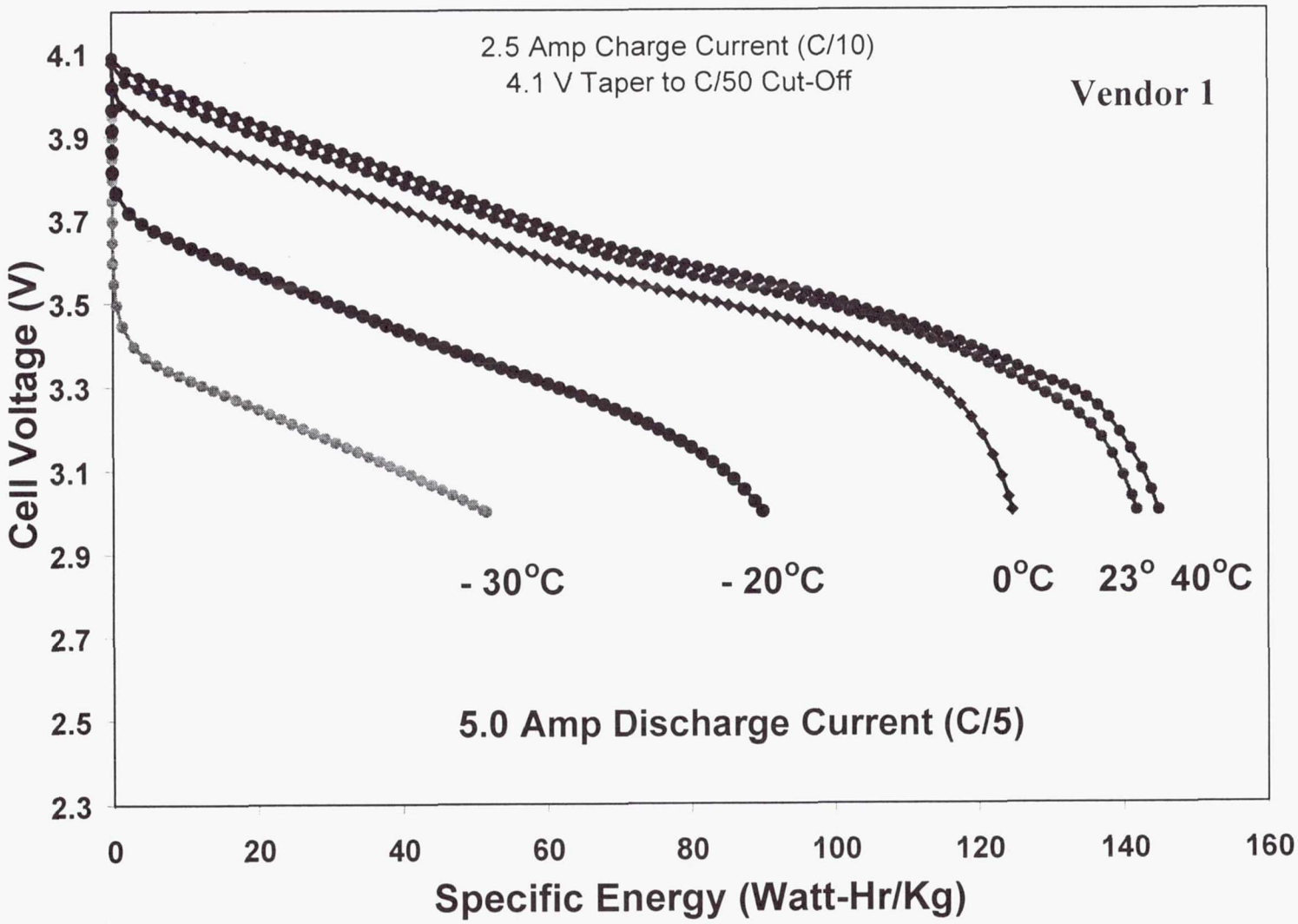
Lithium-Ion Cells for Mars Surveyor 2001 Lander

Rate Capability at Different Temperatures

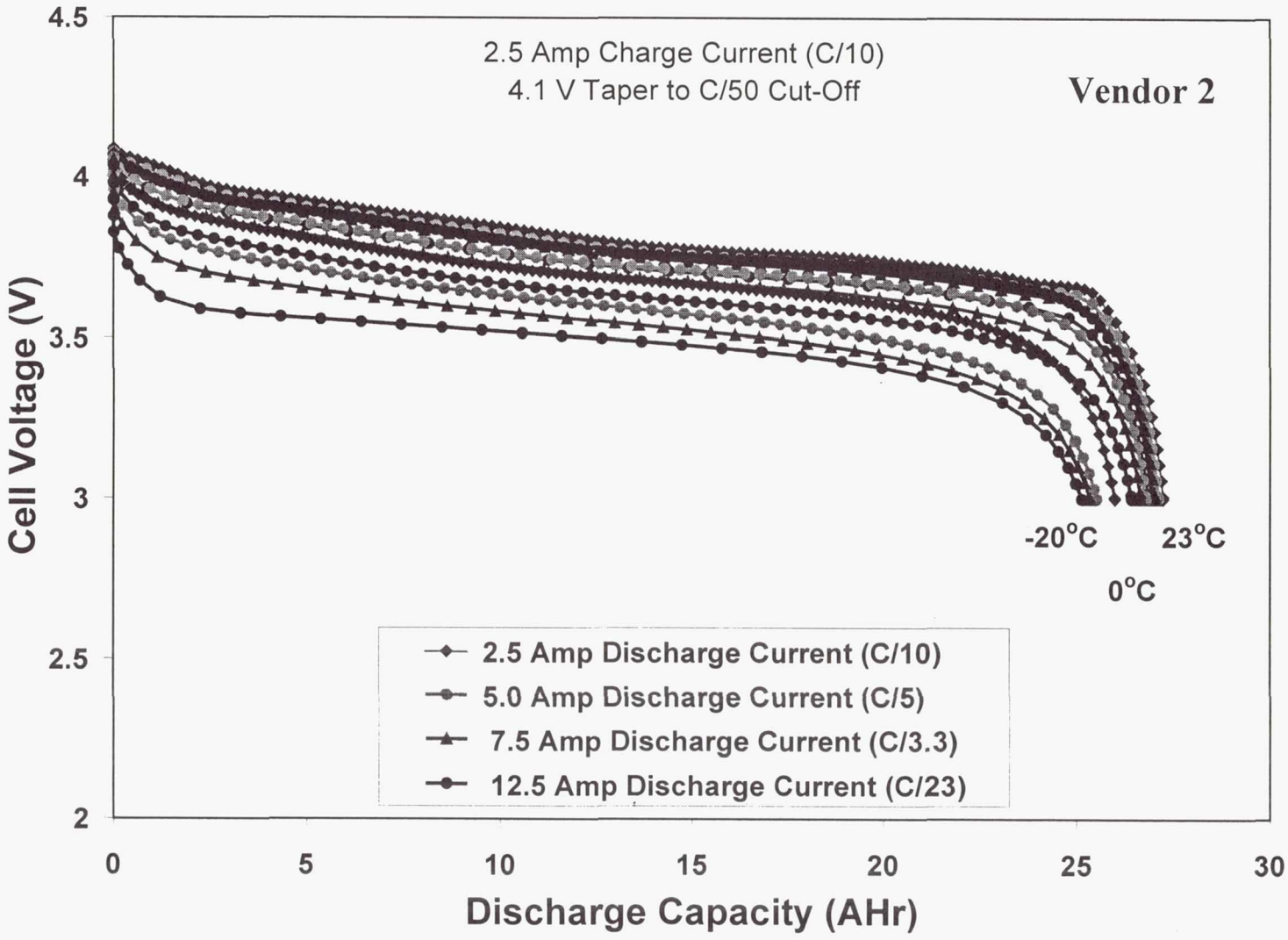


Lithium-Ion Cells for Mars Surveyor 2001 Lander

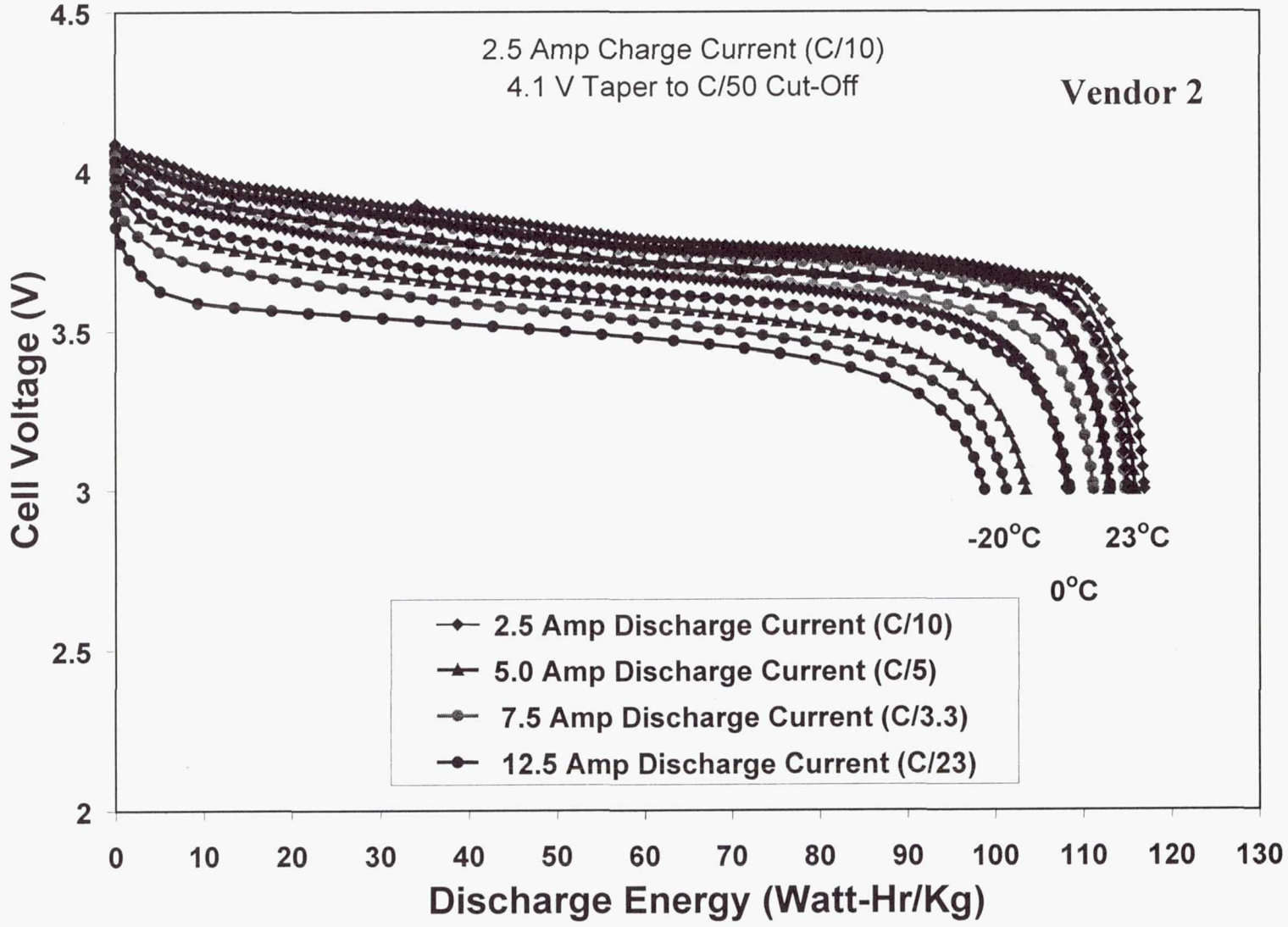
Cell Specific Energy as a Function of Temperature



Lithium-Ion Cells for Mars Surveyor 2001 Lander
Rate Capability at Different Temperatures



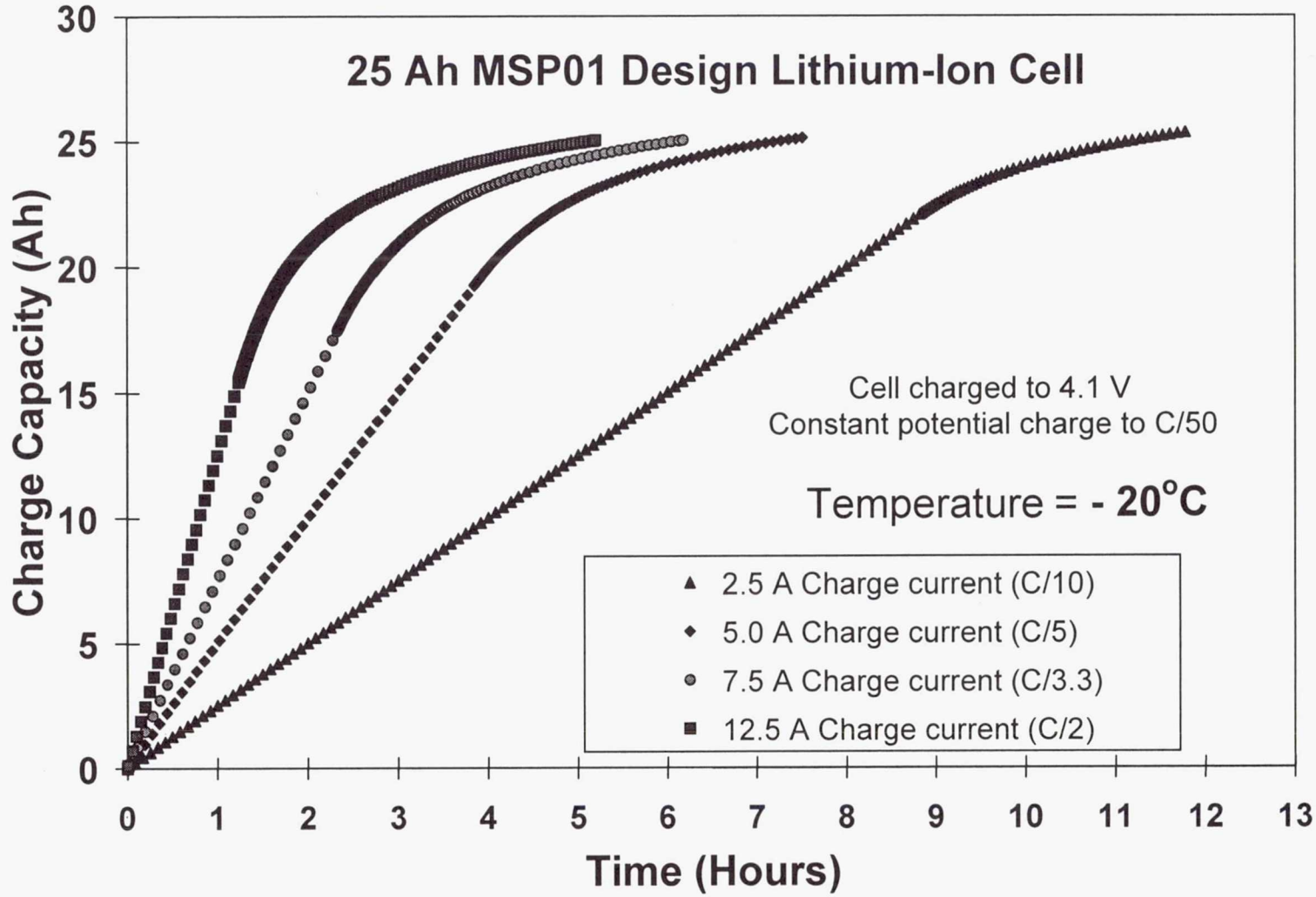
Lithium-Ion Cells for Mars Surveyor 2001 Lander
Discharge Rate Capability at Different Temperatures



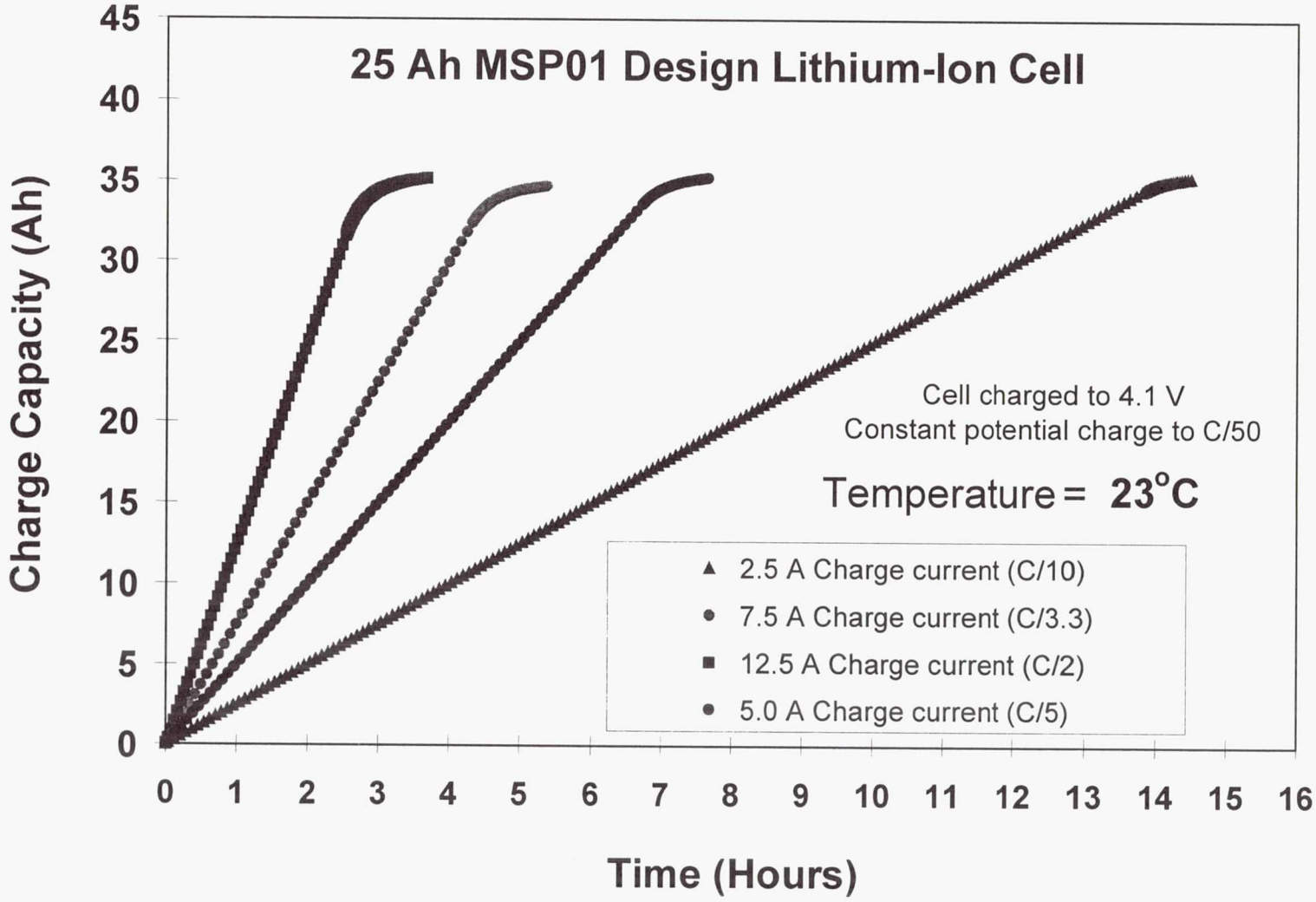
Cell Charge Characteristics

- Charge acceptance at various rates and temperatures
- Effect of cycle life upon charge characteristics
- Effect of charge voltage upon cell performance
  - V/T characterization
- Effect of charge methodology

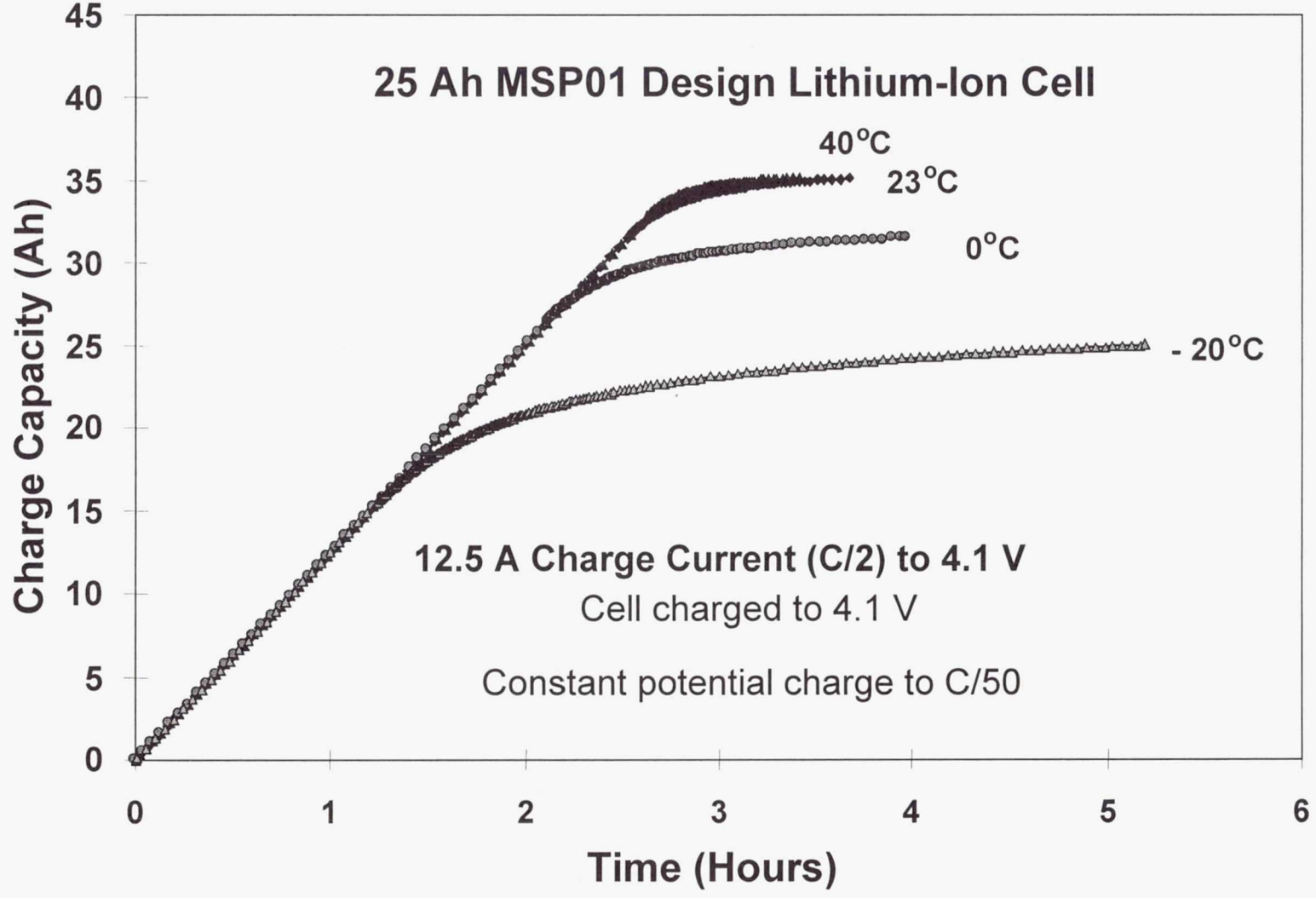
Lithium-Ion Cells for Mars Surveyor 2001 Lander
Low Temperature Charge Characteristics



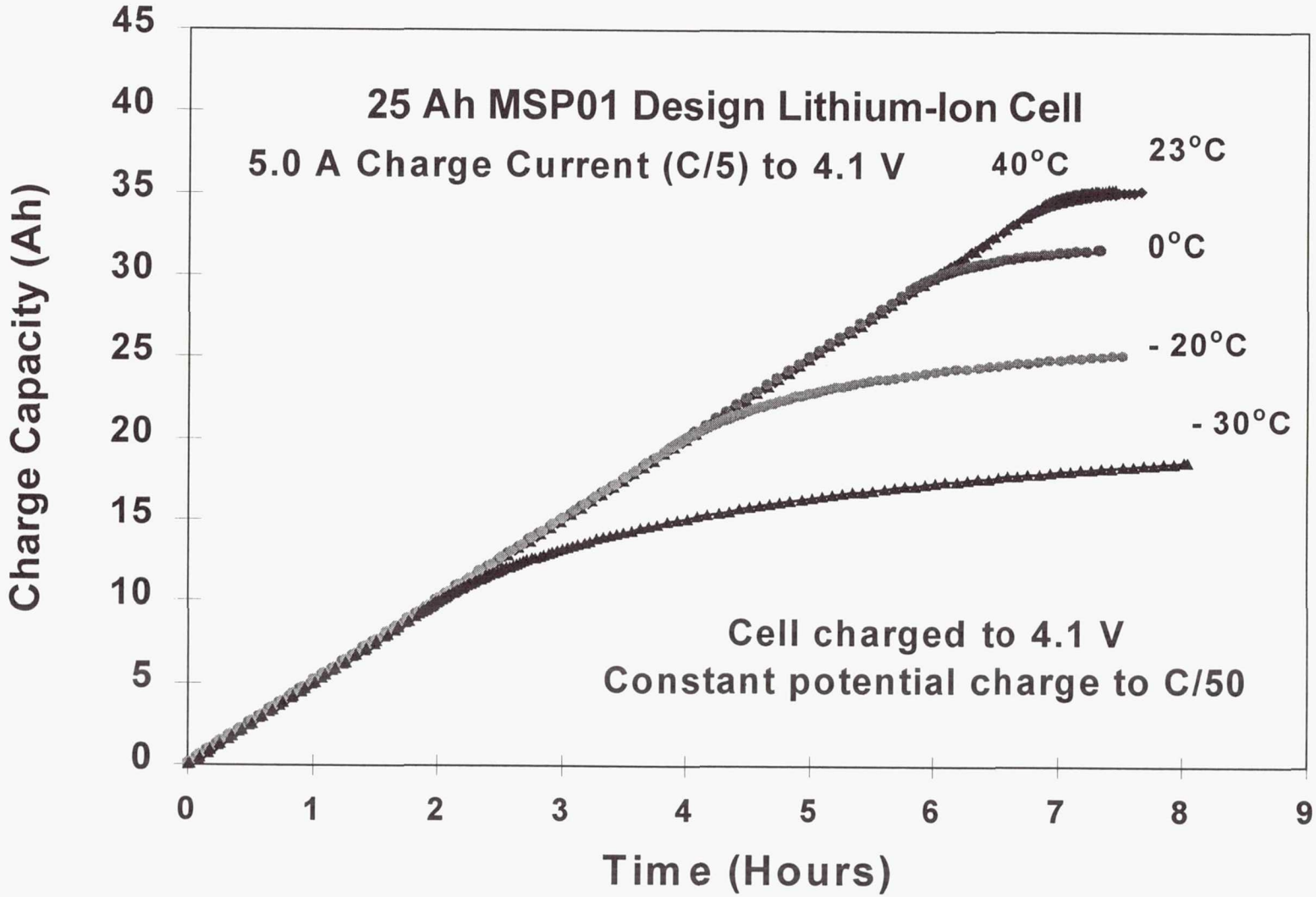
Lithium-Ion Cells for Mars Surveyor 2001 Lander
Room Temperature Charge Characteristics



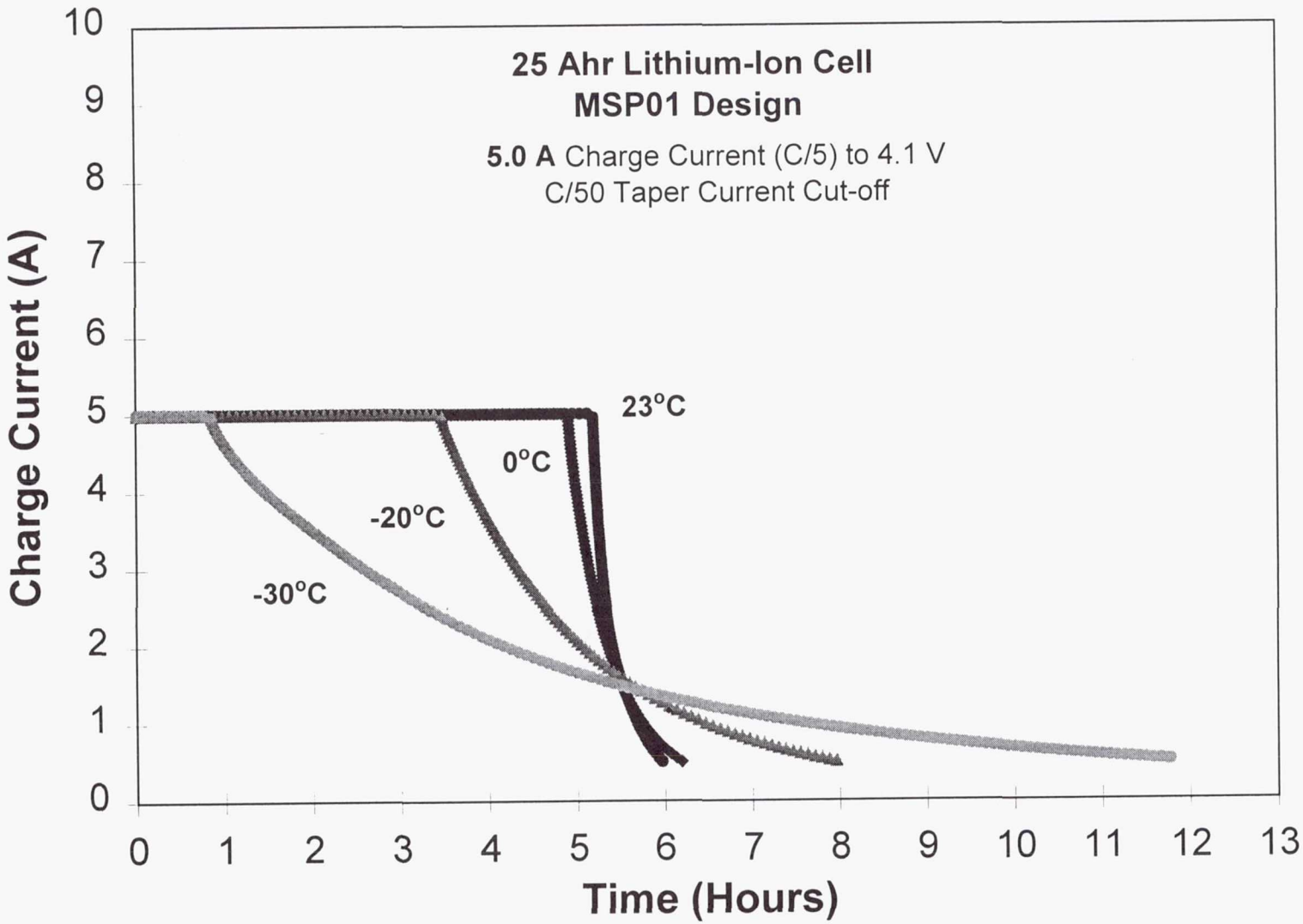
Lithium-Ion Cells for Mars Surveyor 2001 Lander
Charge Characteristics



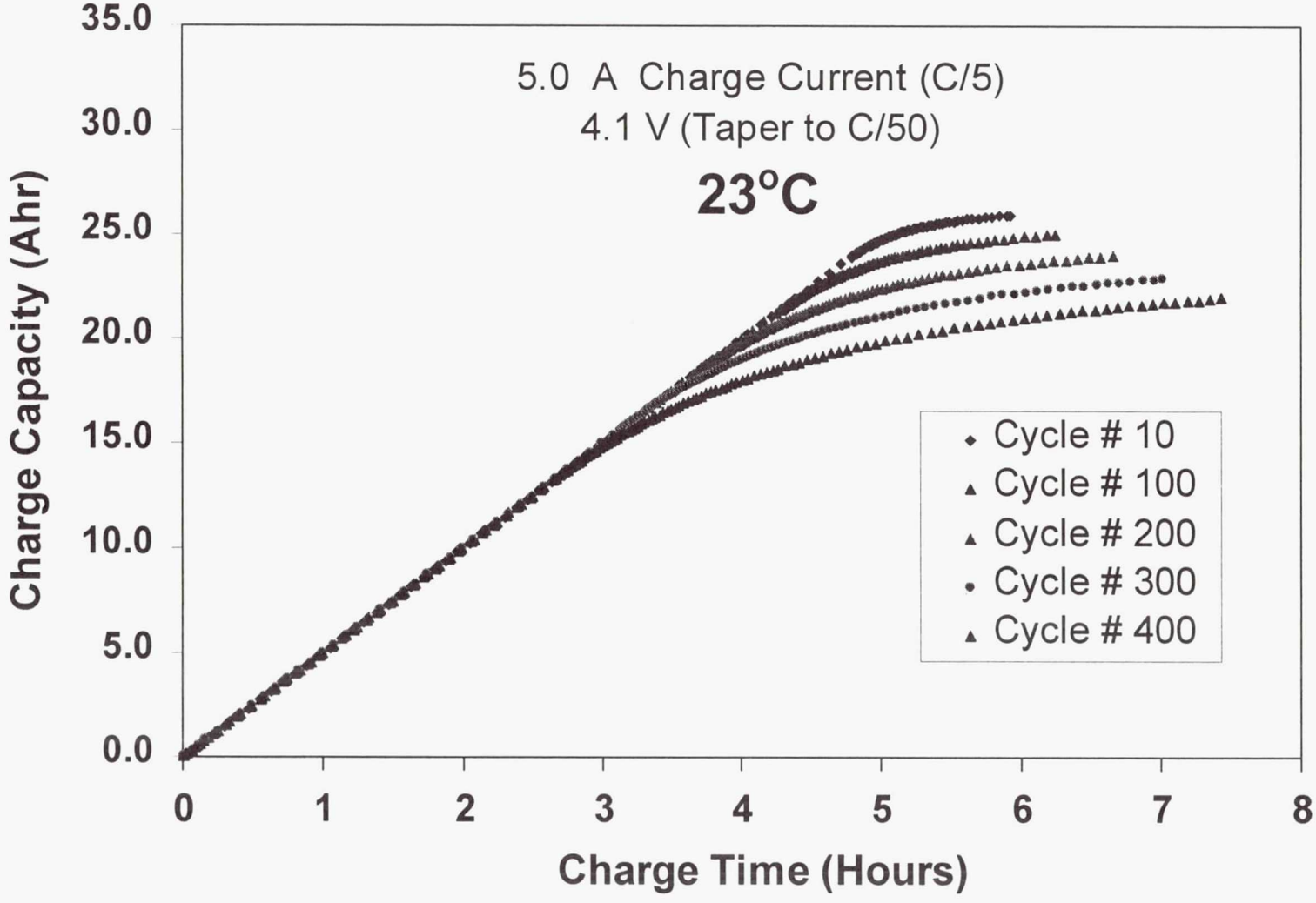
Lithium-Ion Cells for Mars Surveyor 2001 Lander
Charge Characteristics



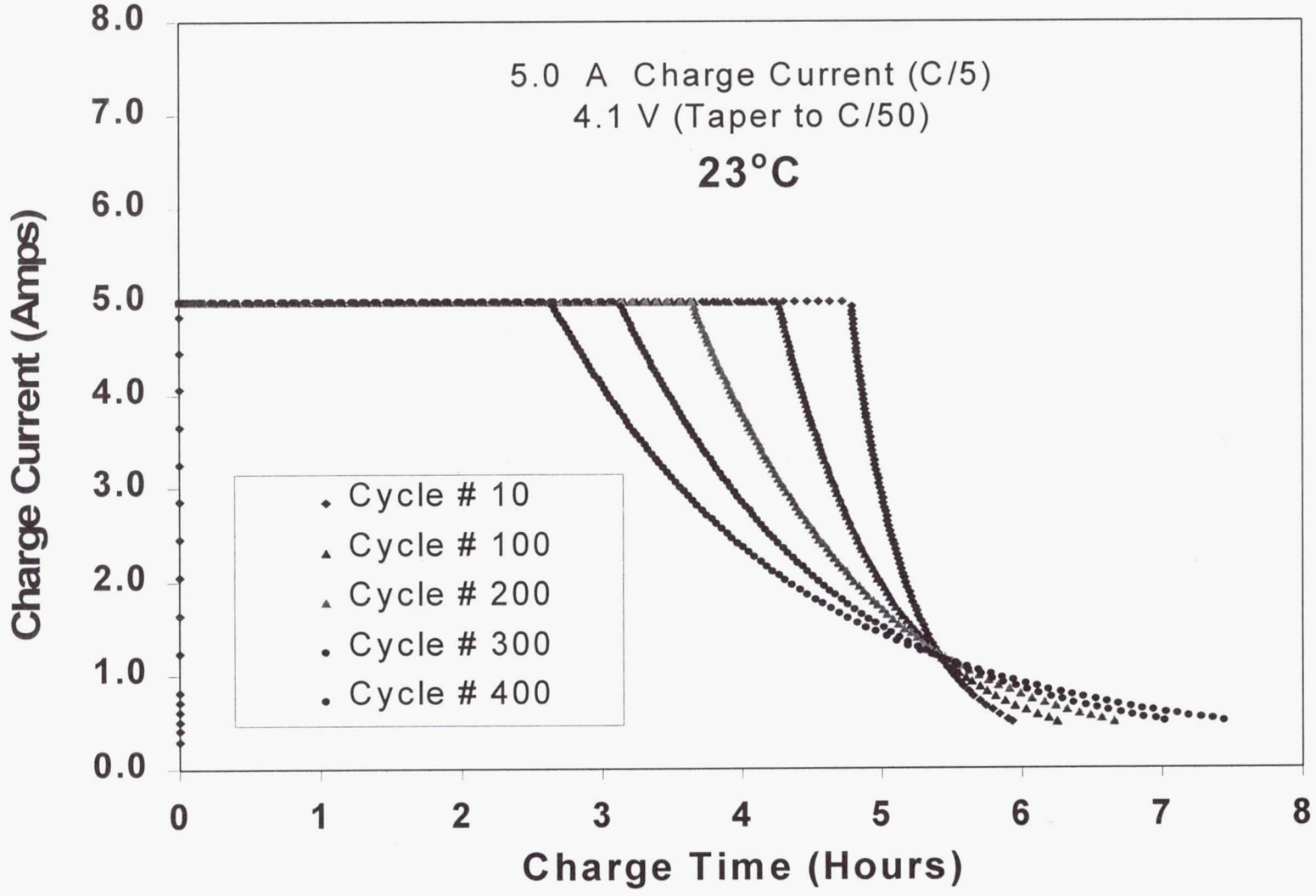
Large Capacity Lithium-Ion Cells for Mars Lander Applications
Room Temperature Charge Characteristics



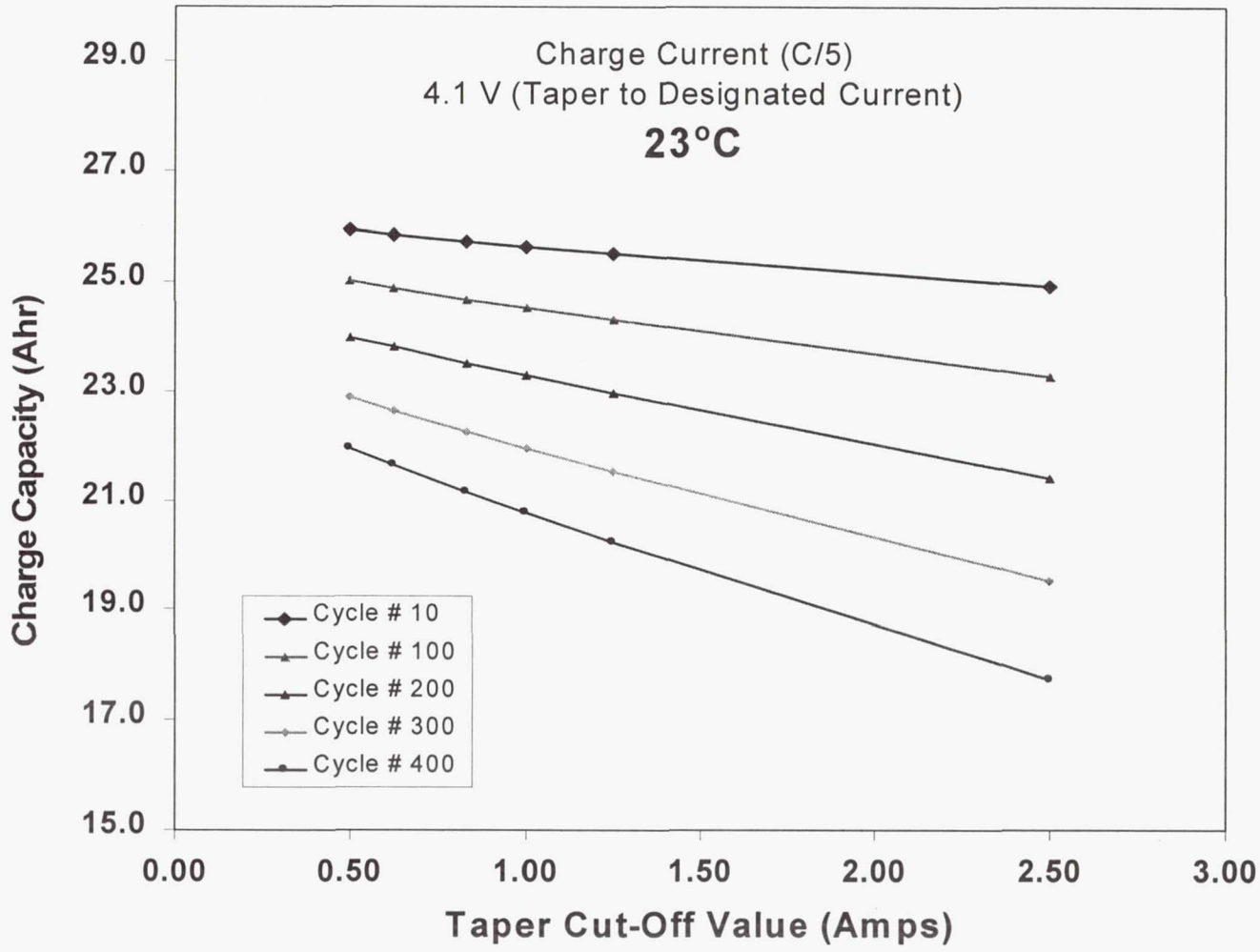
Lithium-Ion Cells for Mars Surveyor 2001 Lander
Effect of Cycle Life on Charge Characteristics



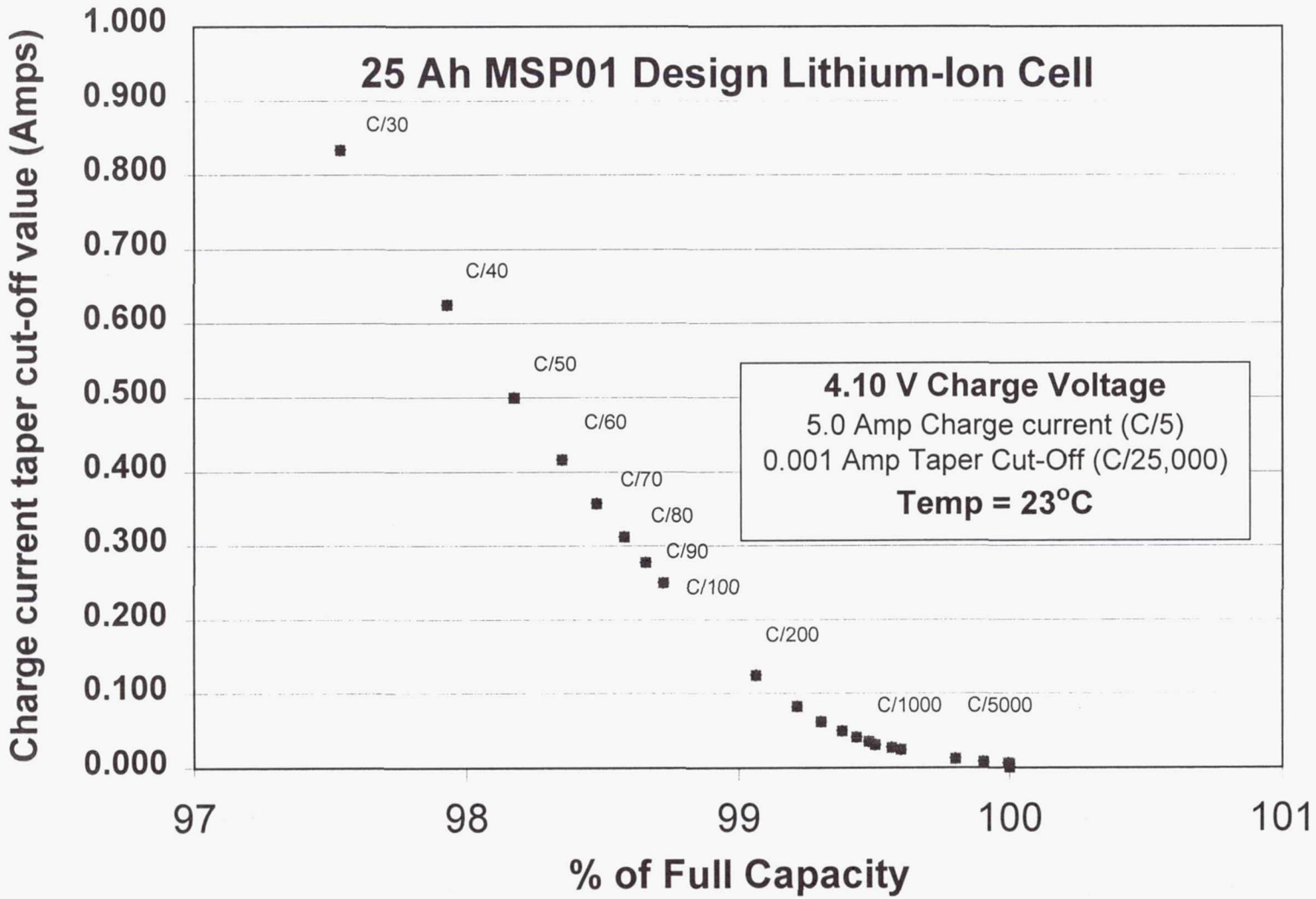
Lithium-Ion Cells for Mars Surveyor 2001 Lander
Effect of Cycle Life on Charge Characteristics



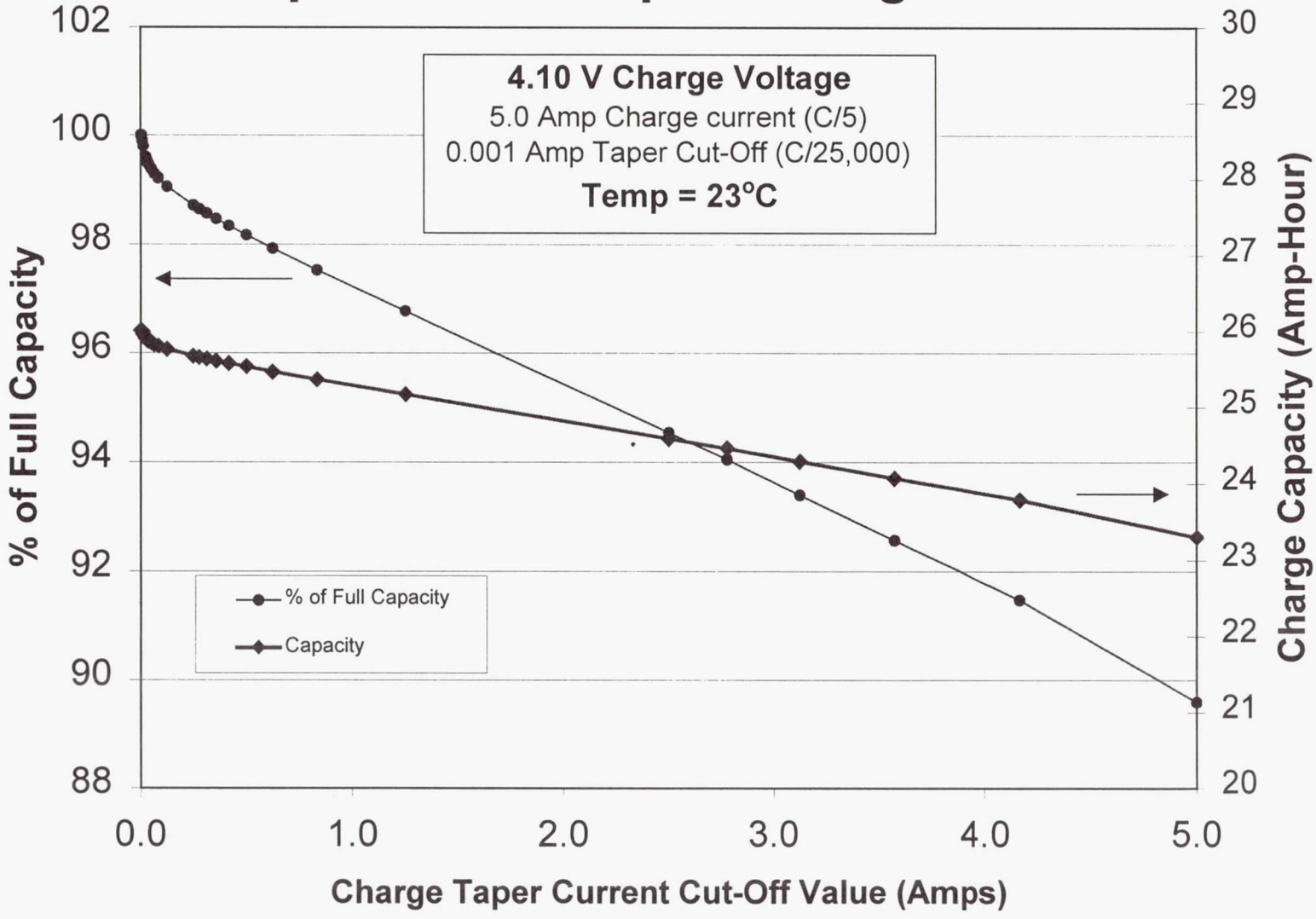
Lithium-Ion Cells for Mars Surveyor 2001 Lander
Effect of Cell Life Upon Charge Characteristics



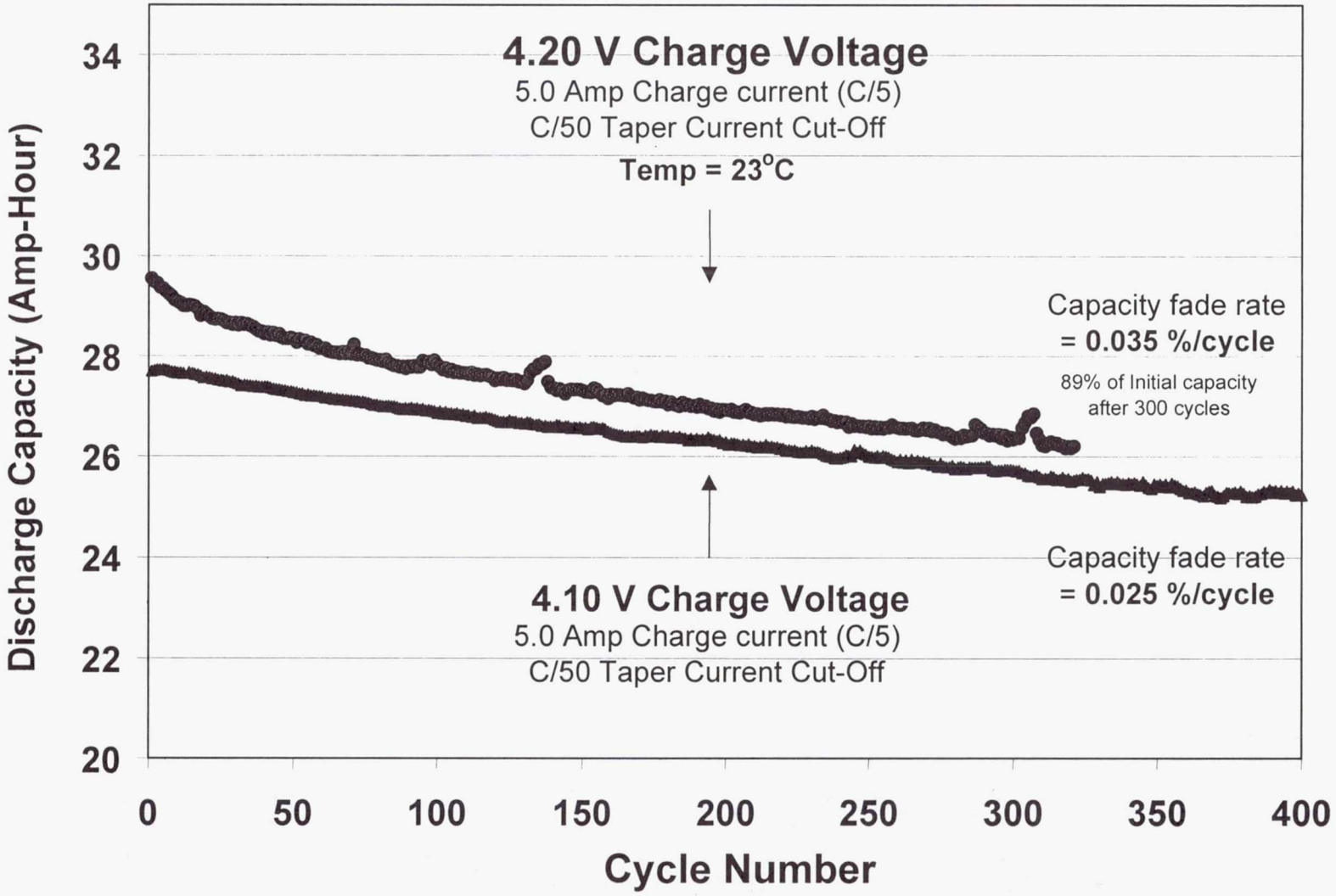
Lithium-Ion Cells for Mars Surveyor 2001 Lander
Effect of Taper Current Upon Charge Characteristics



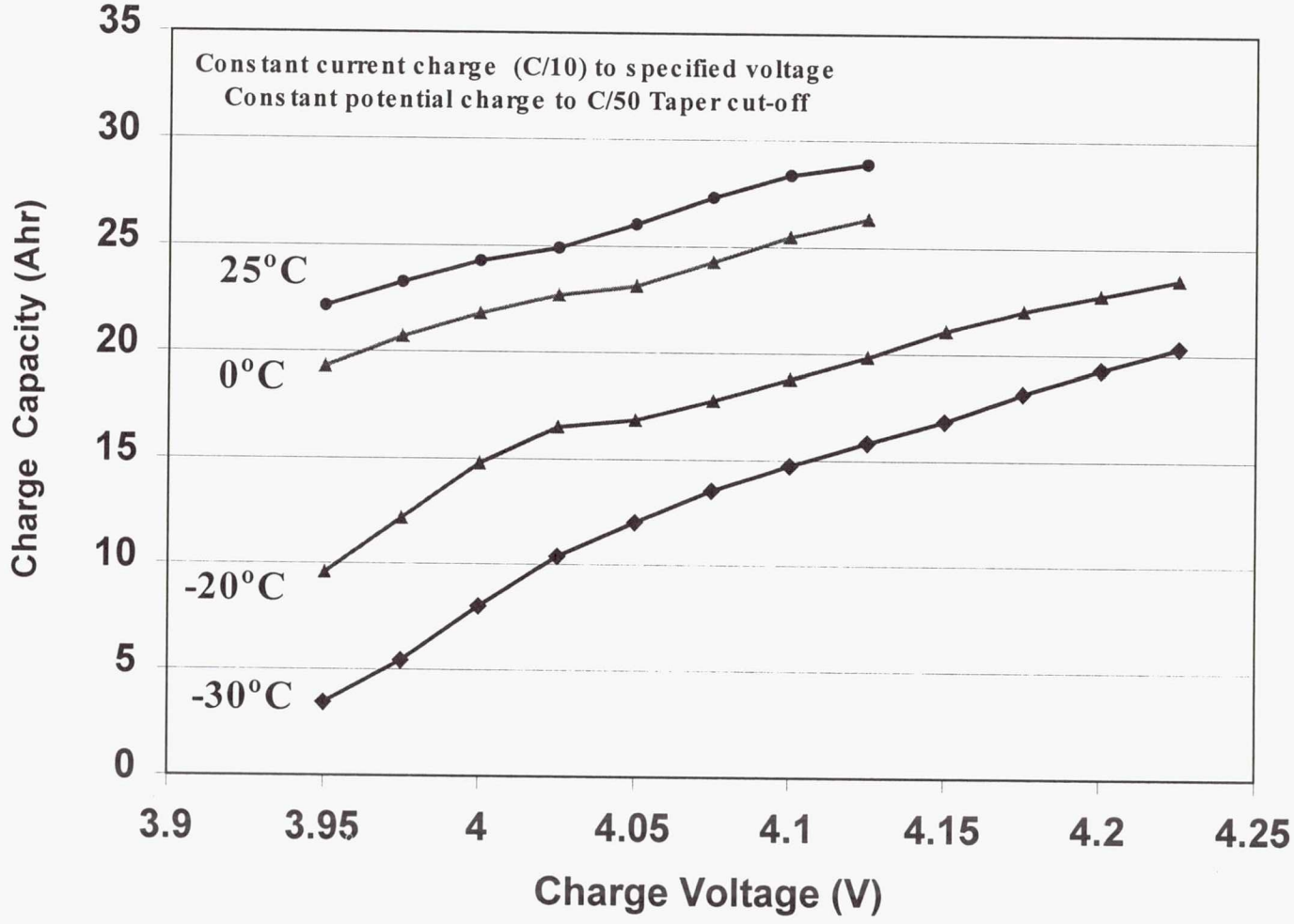
Lithium-Ion Cells for Mars Surveyor 2001 Lander
Effect of Taper Current Upon Charge Characteristics



Lithium-Ion Cells for Mars Surveyor 2001 Lander
Effect of Charge Voltage Upon Cycle Life 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).

Lithium-Ion Cells for Mars Surveyor 2001 Lander Capacity Retention Characterization Tests

Requirement :

- Should be capable of meeting all other requirements after prolonged storage period (>10 months)

Approach:

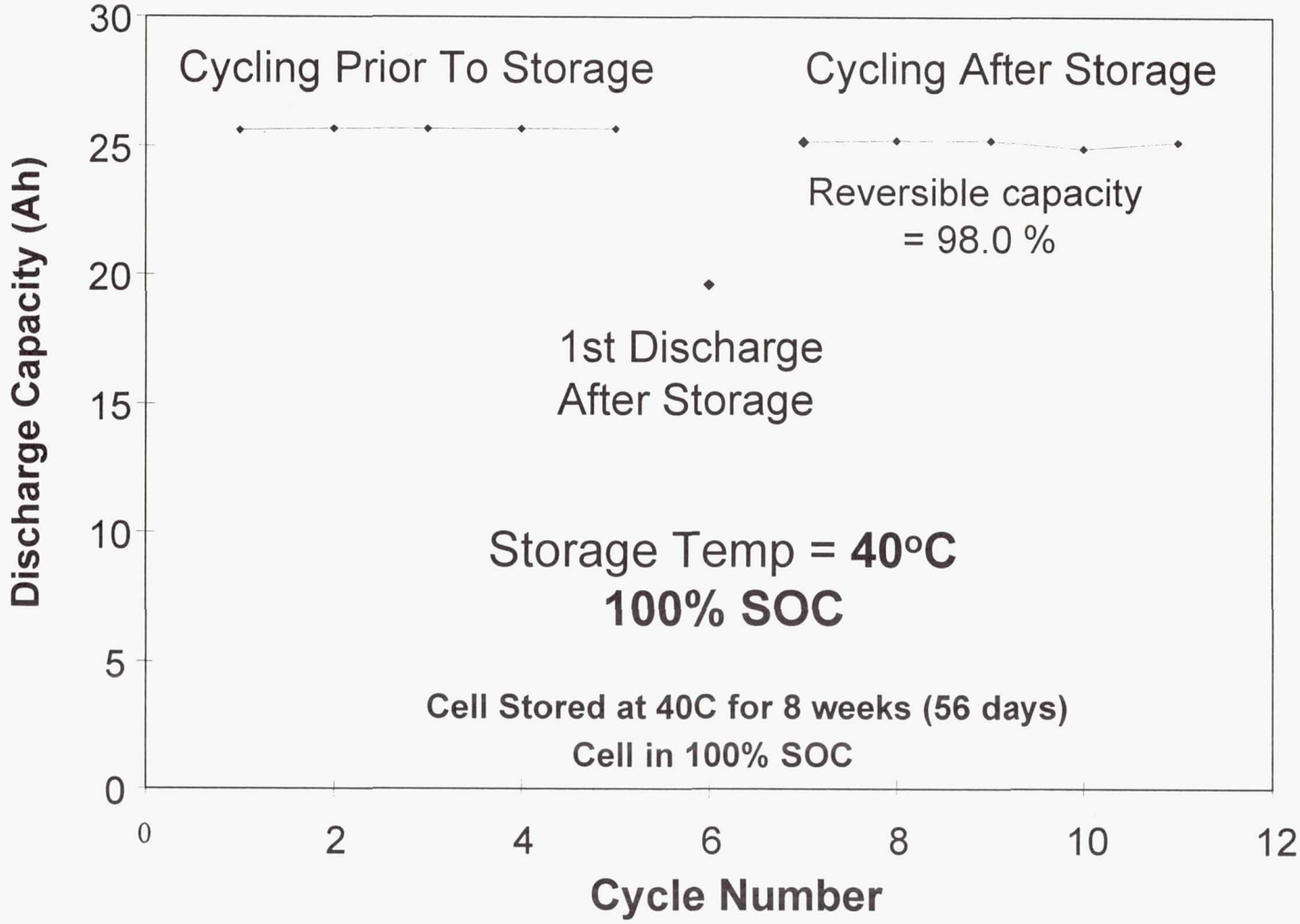
- Identify optimum storage conditions
- Quantify performance degradation due to storage
  - 2 Month storage test (0 and 40°C, 50 and 100% SOC)
  - 10 Month storage test (0 and 40°C, 50 and 100% SOC)
  - Accelerated storage test: (at different SOC (50, 70,100% SOC), temperatures (0, 25, 40, 50°C), and storage conditions.

Possible Evaluation Criteria:

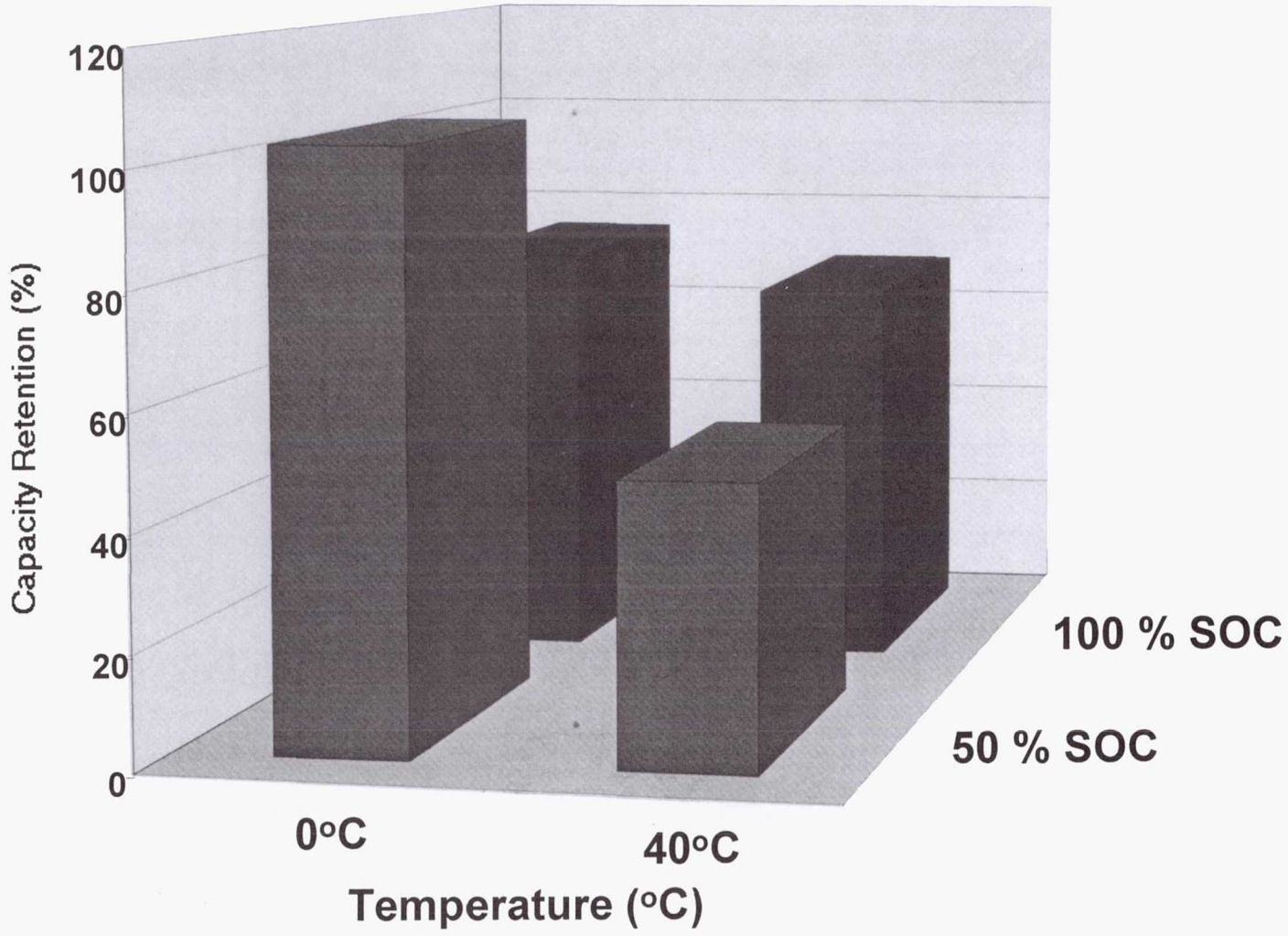
- Self-discharge of stored capacity
- Permanent loss of reversible capacity
- Impact upon low temperature performance

Lithium-Ion Cells for Mars Surveyor 2001 Lander

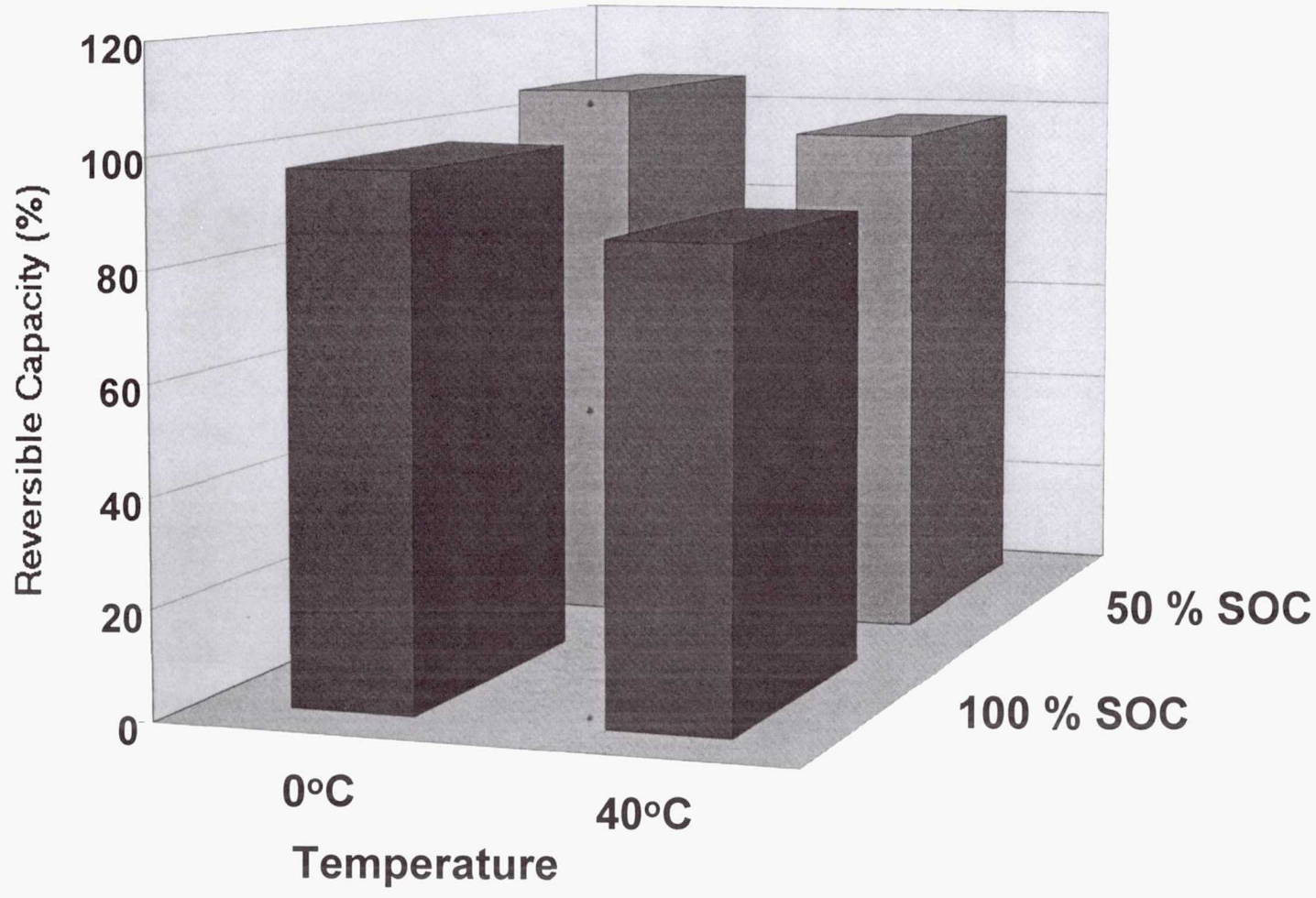
Storage Characteristics - Capacity Retention



Lithium-Ion Cells for Mars Surveyor 2001 Lander
Self Discharge Characteristics



Lithium-Ion Cells for Mars Surveyor 2001 Lander Storage Characteristics



Lithium-Ion Cells for Mars Surveyor 2001 Lander Storage Characteristics - Capacity Retention 25 Ah Prototype Cells

Storage Temp (°C)	State of Charge	Capacity Loss (Ah)	Reversible Capacity
0	50 %	12.03 Ah	98.4 %
0	100 %	6.10 Ah	97.1 %
40	50 %	14.00 Ah	99.4 %
40	100 %	2.37 Ah	98.0 %

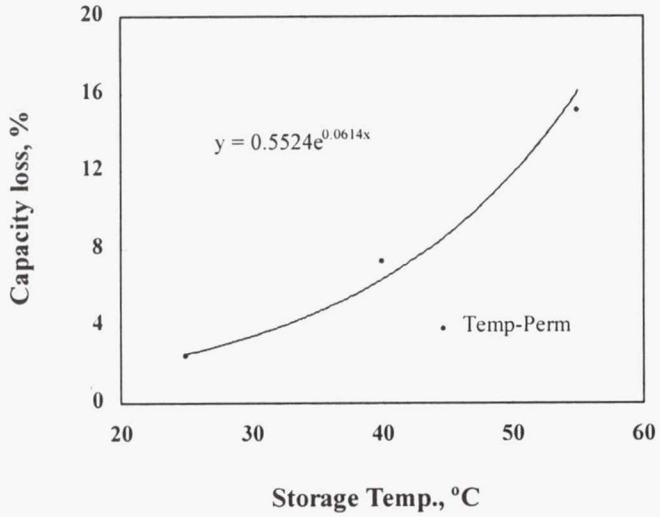
Lithium-Ion Cells for Mars Surveyor 2001 Lander

Design Experiments for Cruise Conditions

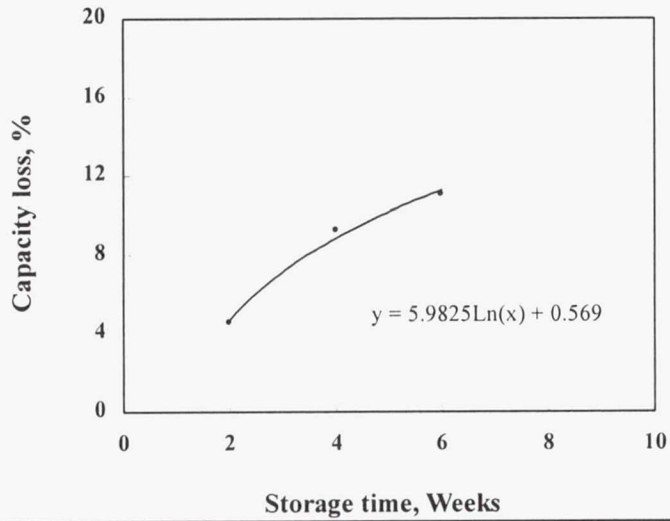
Experiment #	Storage time, weeks	Storage Temp	State of charge	Storage condition
1	2	25	50	Open Circuit
2	2	40	70	On Buss
3	2	55	100	Cycling
4	4	25	70	Cycling
5	4	40	100	Open Circuit
6	4	55	50	On Buss
7	6	25	100	On Buss
8	6	40	50	Cycling
9	6	55	70	Open Circuit

Parametric Storage Studies

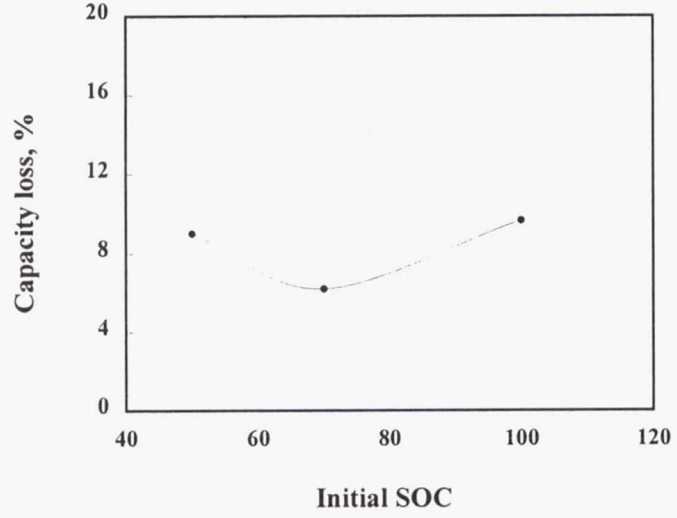
Effect of Temp on Permanent capacity loss



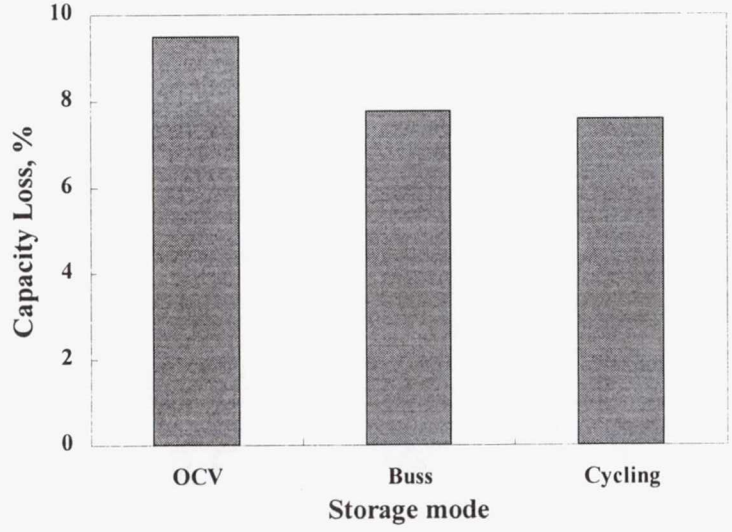
Effect of Time on Permanent capacity loss



Effect of SOC on Permanent capacity loss



Effect of Storage mode on Permanent Capacity loss



SUMMARY

- ***Li Ion cells meet the MSP 2001 Lander mission requirements in***
  - ***Cycle Life Performance***
    - Room Temperature = Excellent (>90% @ 200 cycles)
    - Low Temperature (-20) = Sufficient
    - High Temperature (40°C) = Sufficient (>70% @ 200 cycles)
  - ***Discharge Rate Capability at Various Temperatures***
    - Room Temperature = Excellent
    - Low Temperature (-20) = Sufficient (~ 24 Ah @ C/5 rate)
    - High Temperature (40°C) = Excellent
  - ***Storage Characteristics***
    - Demonstrated minimal reversible capacity loss (2 months)
    - Identified temperature as most crucial storage parameter
    - Demonstrated efficacy of storage "on the buss"
  - ***Mission simulation (Variable Temperature Cycling)***
    - Identified potential performance limiting conditions (worst case)
    - Implemented characterization test to quantify behavior

Acknowledgments

The work described here was carried out at the Jet Propulsion Laboratory (JPL), California Institute of Technology, for the **Mars 2001 Surveyor and NASA Code S Battery Programs** under contract with the National Aeronautics and Space Administration (NASA).