Performance Characteristics of Lithium Ion Prototype Cells for 2003 Mars Sample Return Athena Rover

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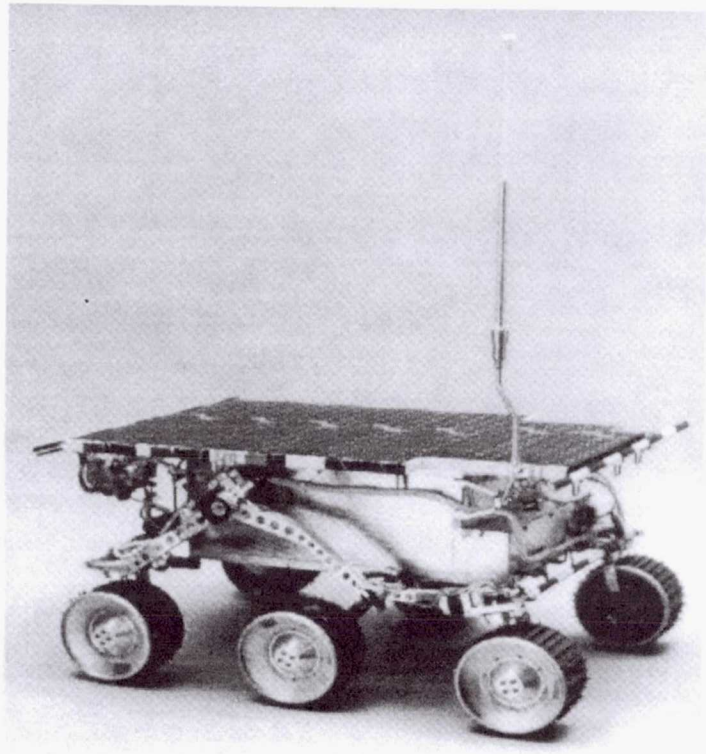
2003 MSR Athena Rover

Mission Objectives

To determine the geologic and climatic history of Martian site with conditions favorable to possible life

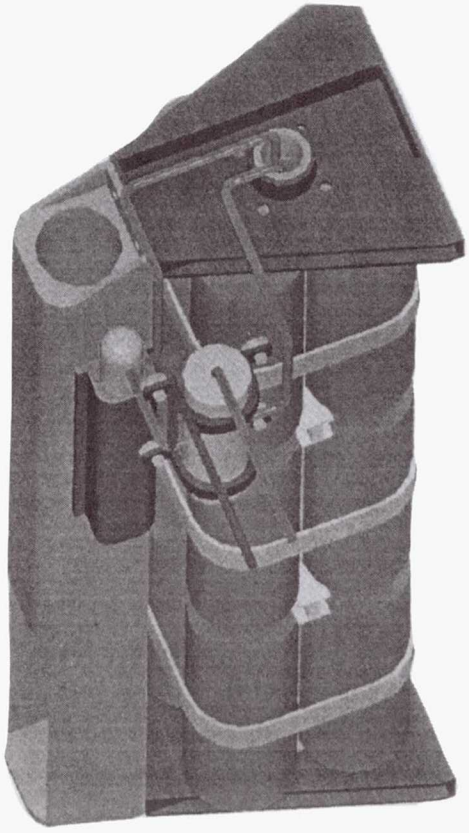
- **Specific objective include**
  - taking color stereo images of the Martian surface
  - determining elemental and mineralogical compositions
  - obtaining microscopic images of rocks
  - Collecting samples with evidence of ancient environmental conditions and possible life
- **Payloads Elements**
  - Pancam for stereo imaging
  - alpha proton X-ray spectrometer
  - Mossbauer, Mine TES and Raman spectrometers for mineralogical composition
  - microscopic imager and
  - mini-corer



2003 MSR Athena Rover

Power Subsystem

- Primary Source : Ga-As solar array
- Auxiliary Power Sources : Li ion Battery
- Li Ion Battery Characteristics
  - 16 V, 150 Wh
  - Mass 3 kg (max) and Volume 2 lit (max)
  - Three (N+1) parallel batteries of four cells each
  - EOL (200 cycles) performance
    - 5 Ah @ 0°C at C/2
    - 3.5 Ah @ -20°C at C/2
  - Calendar life : 2 years
  - Cylindrical or prismatic
  - In-house charger
    - individual cell monitoring and cell balancing



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 2003 MSR Athena Rover
Program Objectives

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

- Demonstrate applicability of using lithium-ion technology for future 2003 Mars Sample Return Athena Rover applications.

Lithium-Ion Cells for 2003 MSR Athena Rover

Evaluation Tests On-Going 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
- Storage characterization tests (cruise conditions)
- VT charge characterization tests
- Electrical characterization by a.c. impedance
- Thermal characterization

Lithium-Ion Cells for 2003 MSR Athena Rover

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 5 Ah @ 0°C**

***Approach*:**

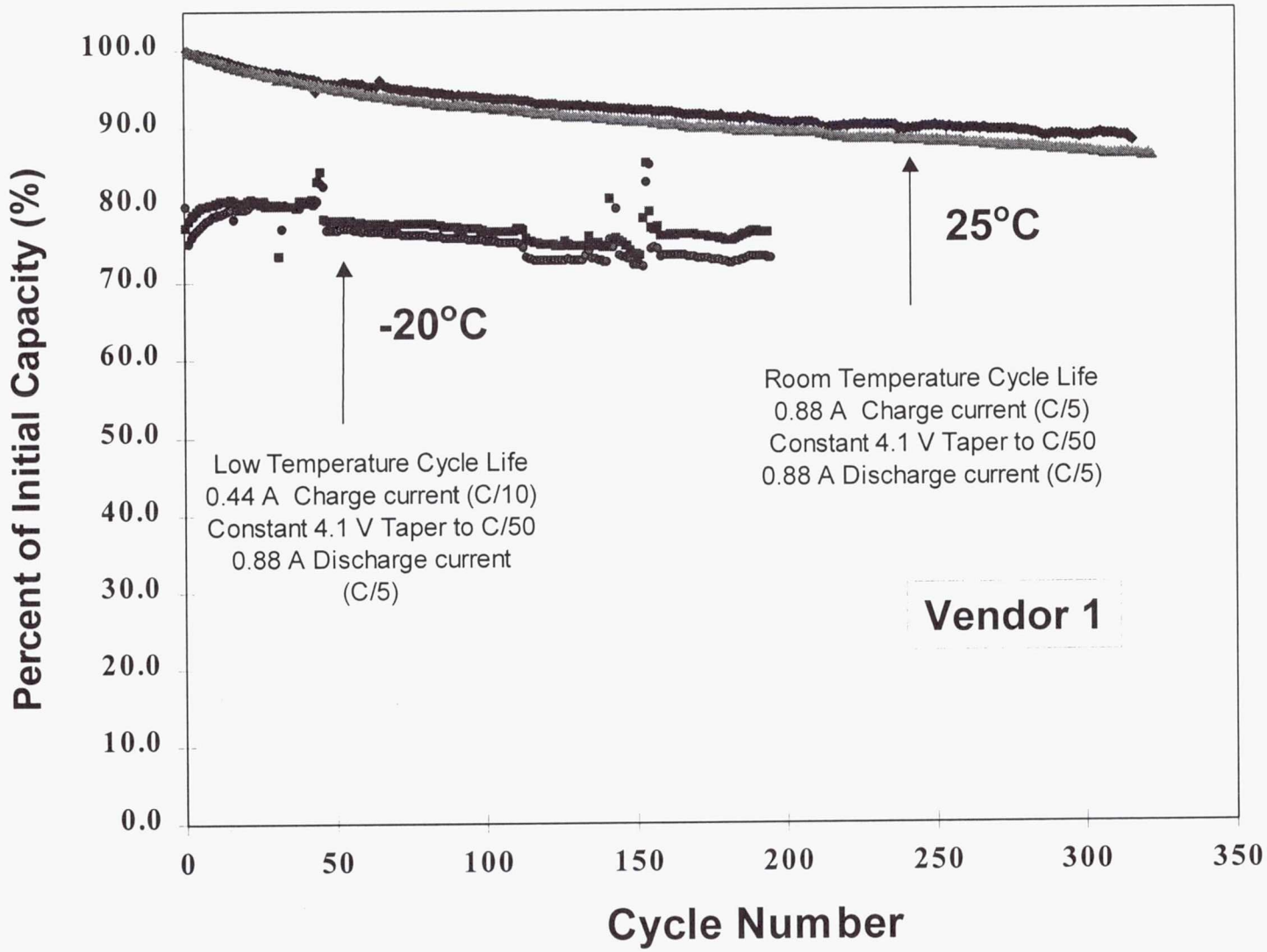
100 % DOD cycling @ 23°C (C/5 charge, C/5 discharge)
100 % DOD cycling @ -20°C (C/10 charge, C/5 discharge.)
100 % DOD cycling @ 40°C (C/5 charge, C/5 discharge)
Variable temperature cycling (temperature extremes)
Mission simulation cycling

***Possible Evaluation Criteria*:**

Initial capacity (must exceed 5 Ah)
Capacity after 200 cycles (Ah)
Capacity fade rates
Capacity delivered over range of temperatures

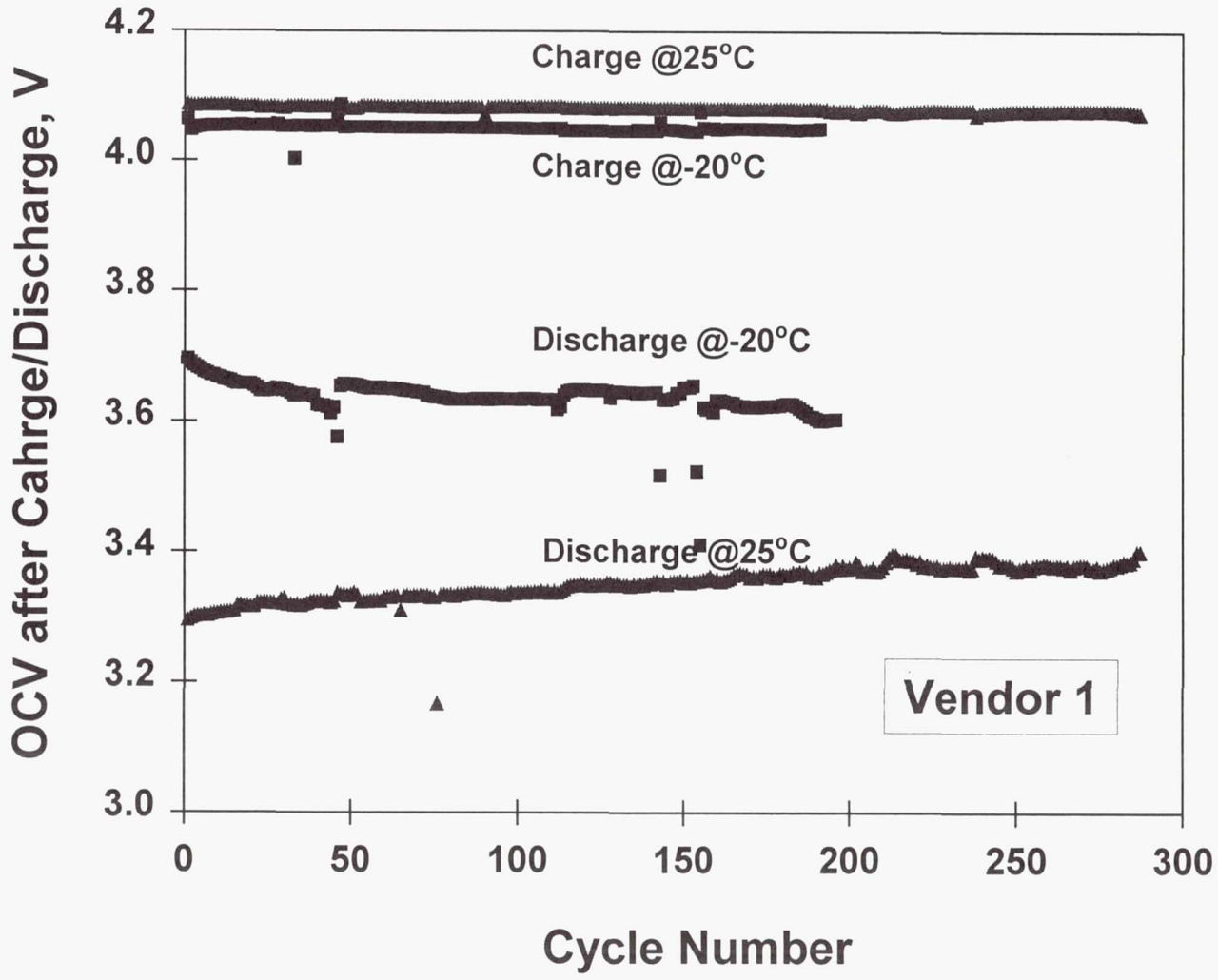
Lithium-Ion Cells for 2003 MSR Athena Rover

Cycling at 25°C and -20°C

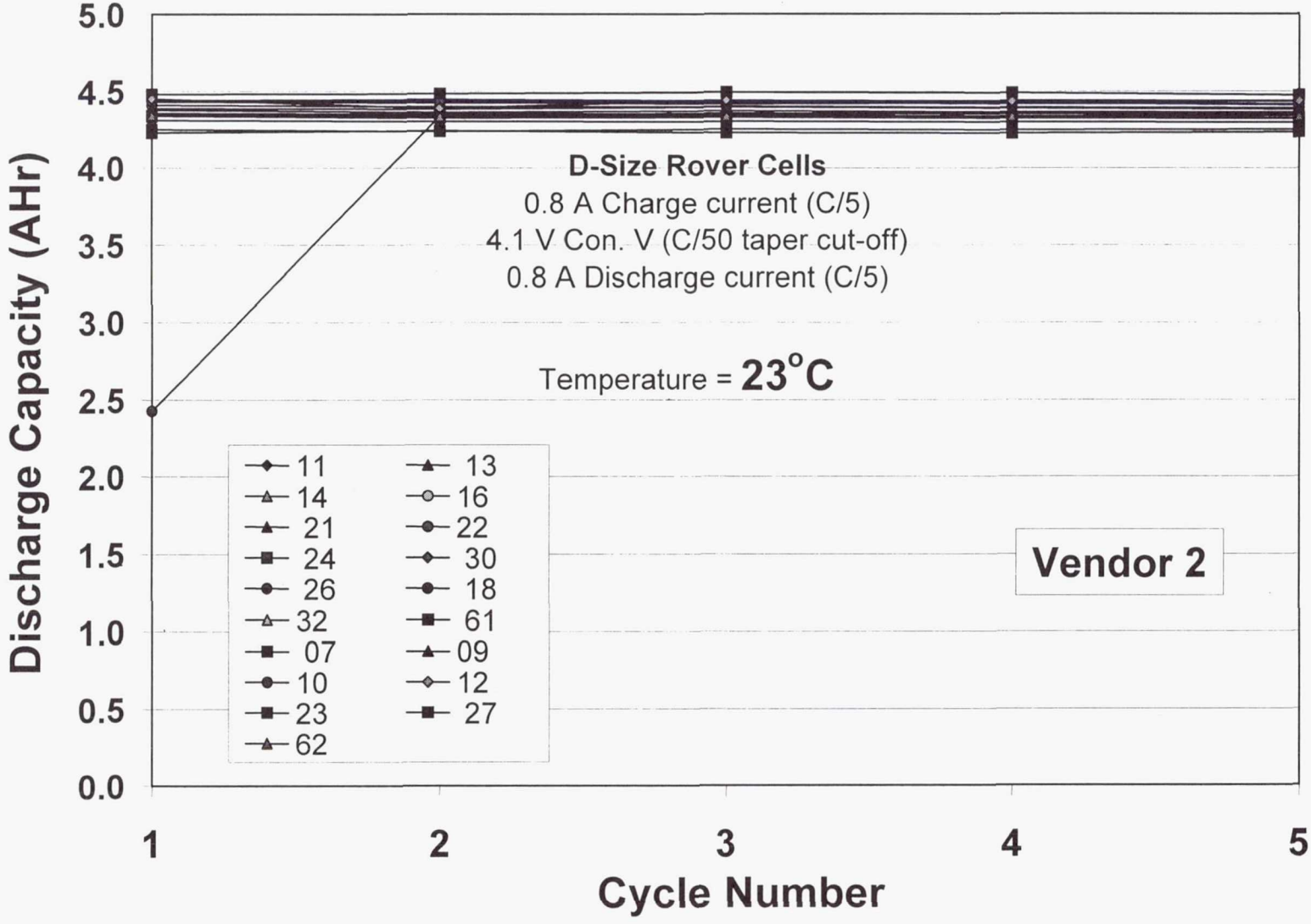


Lithium-Ion Cells for 2003 MSR Athena Rover

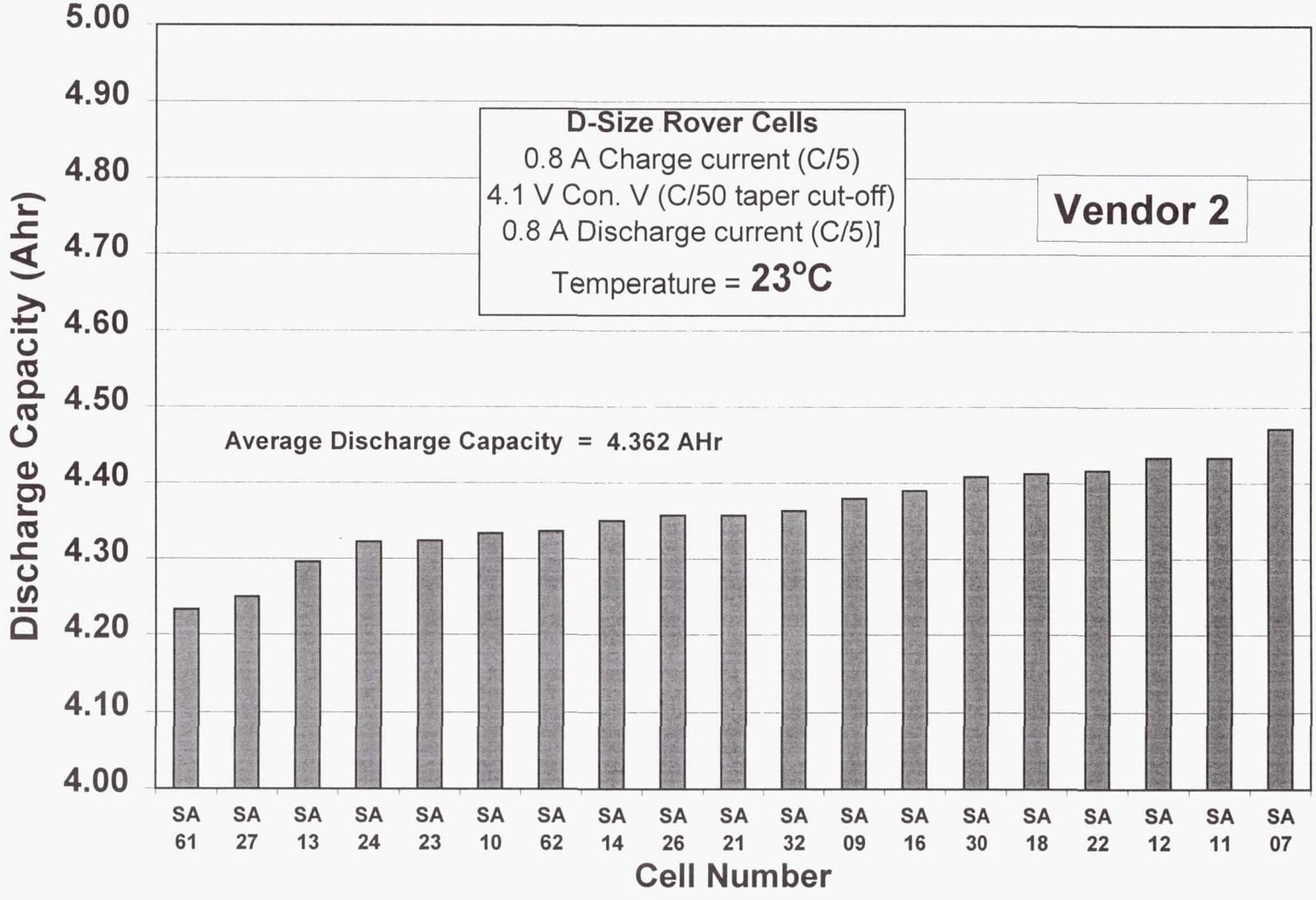
OCV During Cycling at 25°C and -20°C



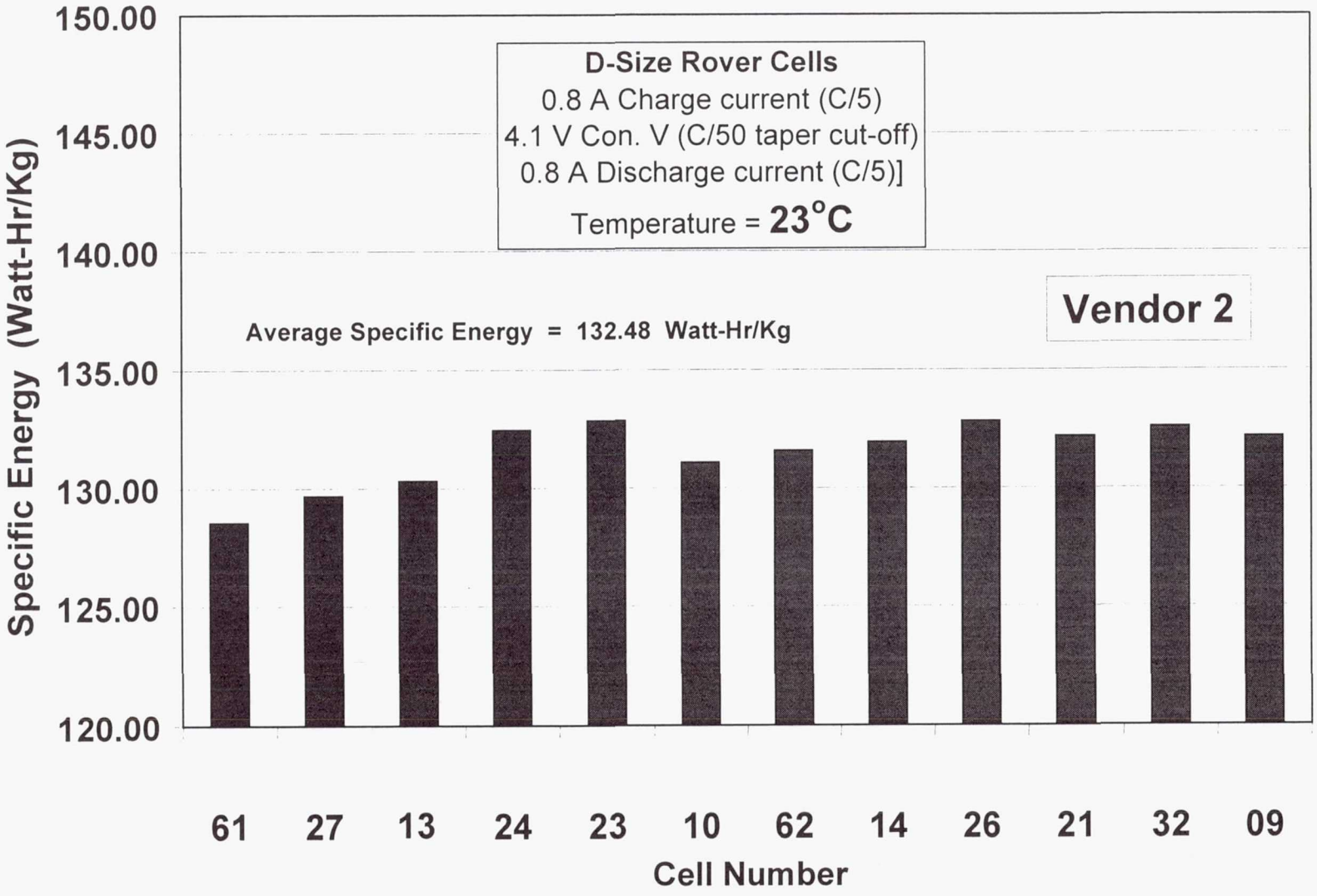
Lithium-Ion Cells (D-Size) for Mars Rover Applications
Characteristics of Conditioning Cycles



Lithium-Ion Cells (D-Size) for Mars Rover Applications
Cycle Life Performance at Different Temperatures



Lithium-Ion Cells (D-Size) for Mars Rover Applications
EIS Measurements of Cells After Conditioning Cycles



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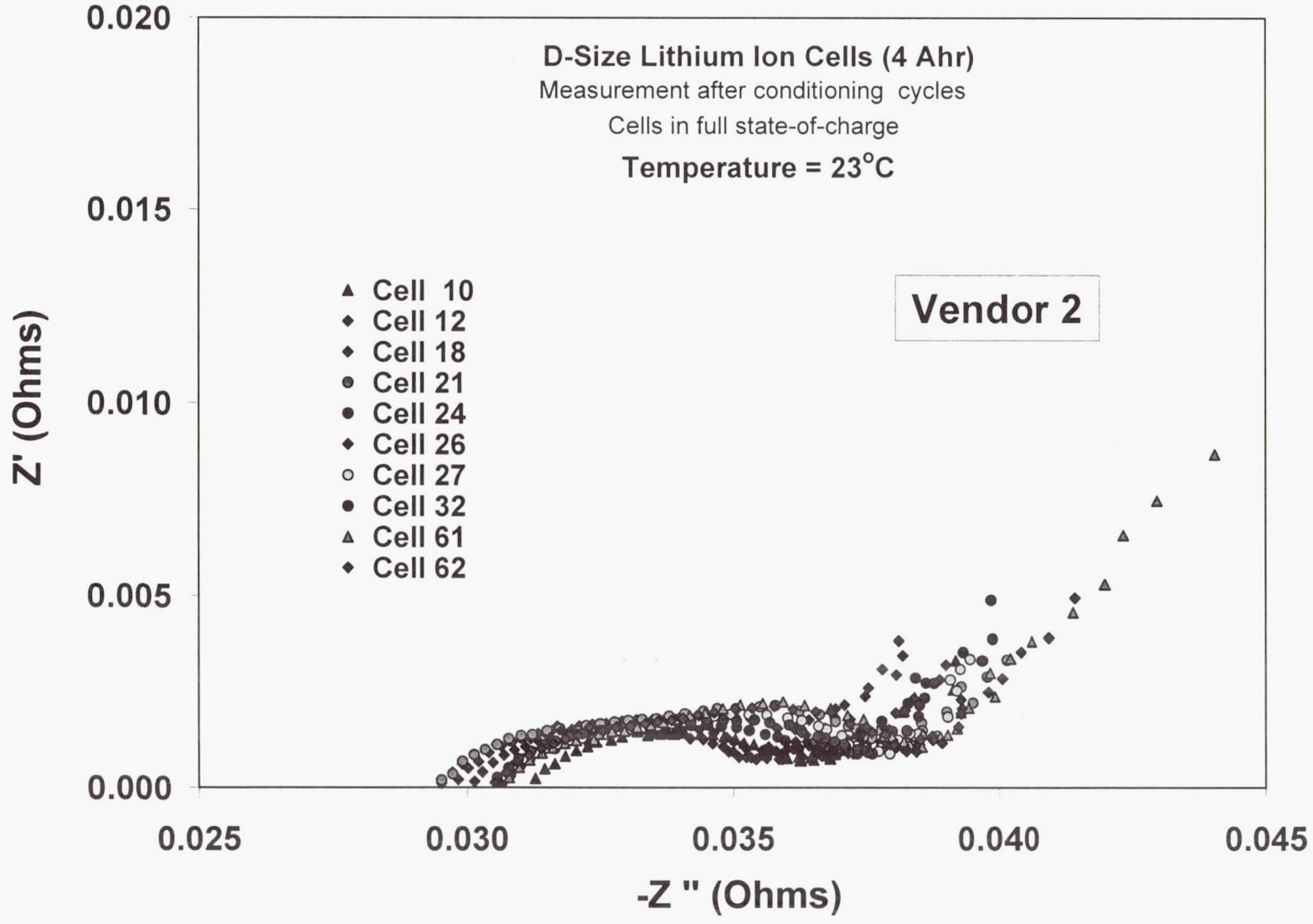

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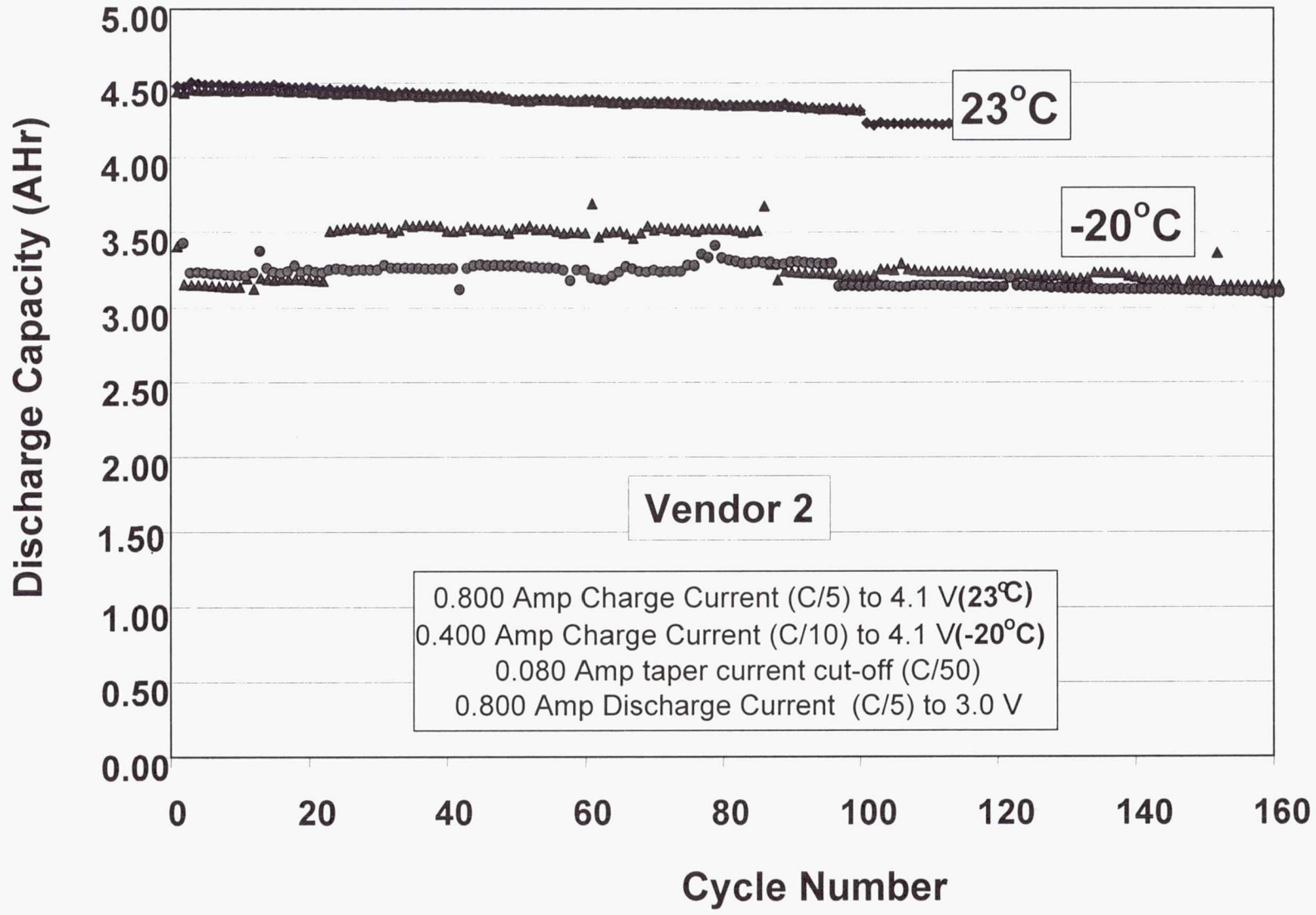

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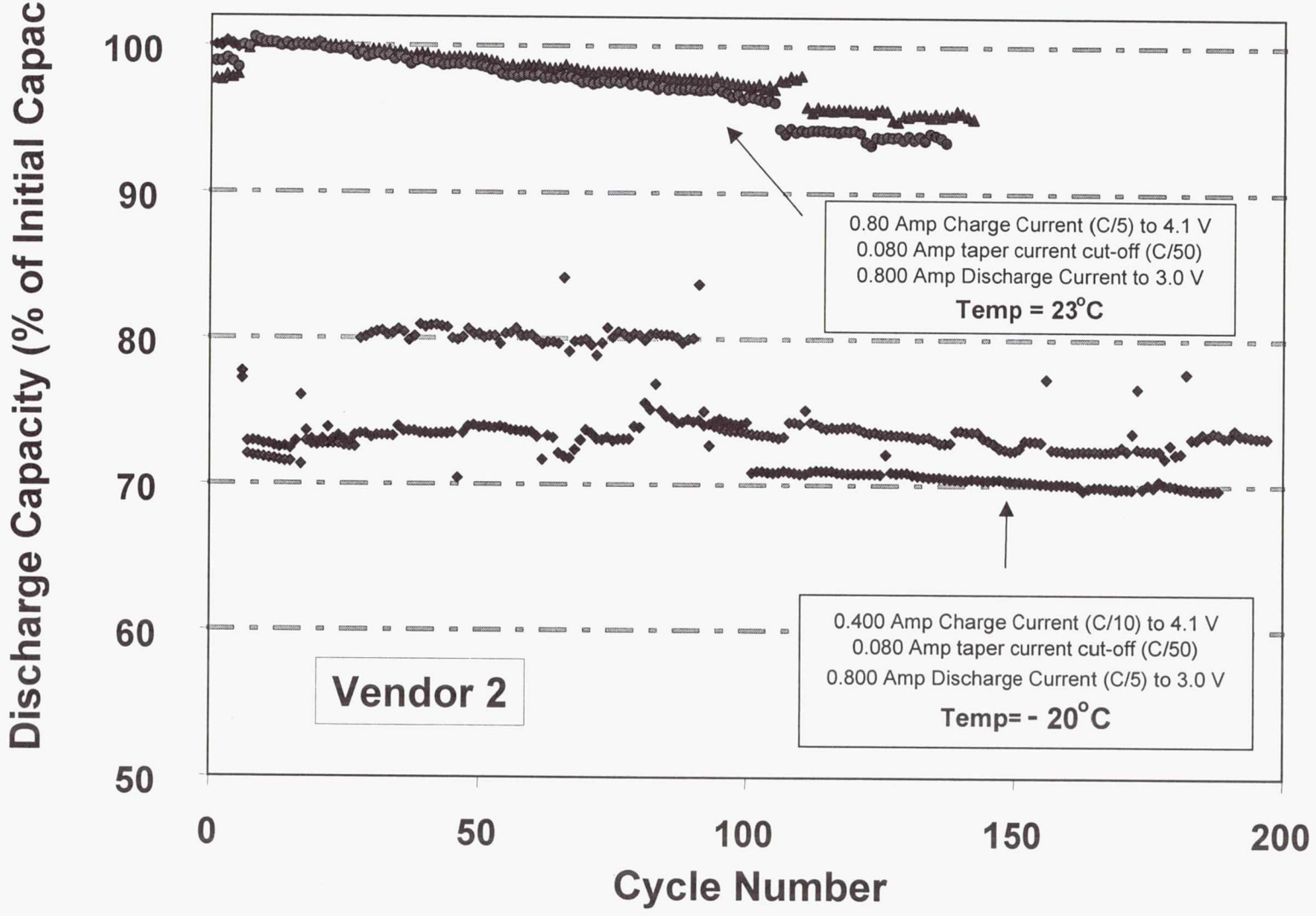
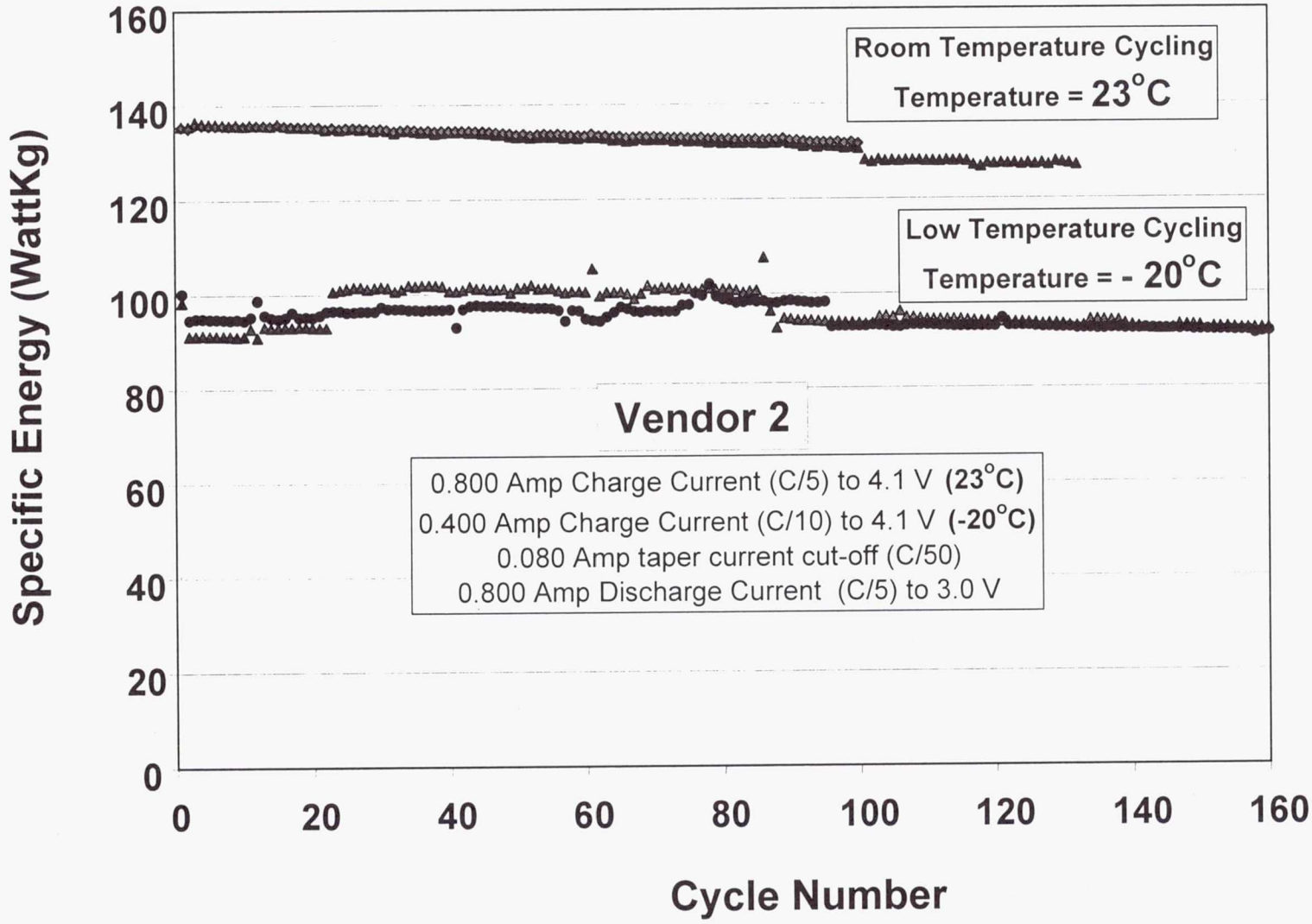


Lithium-Ion Cells (D-Size) for Mars Rover Applications
Cycle Life Performance at Different Temperatures



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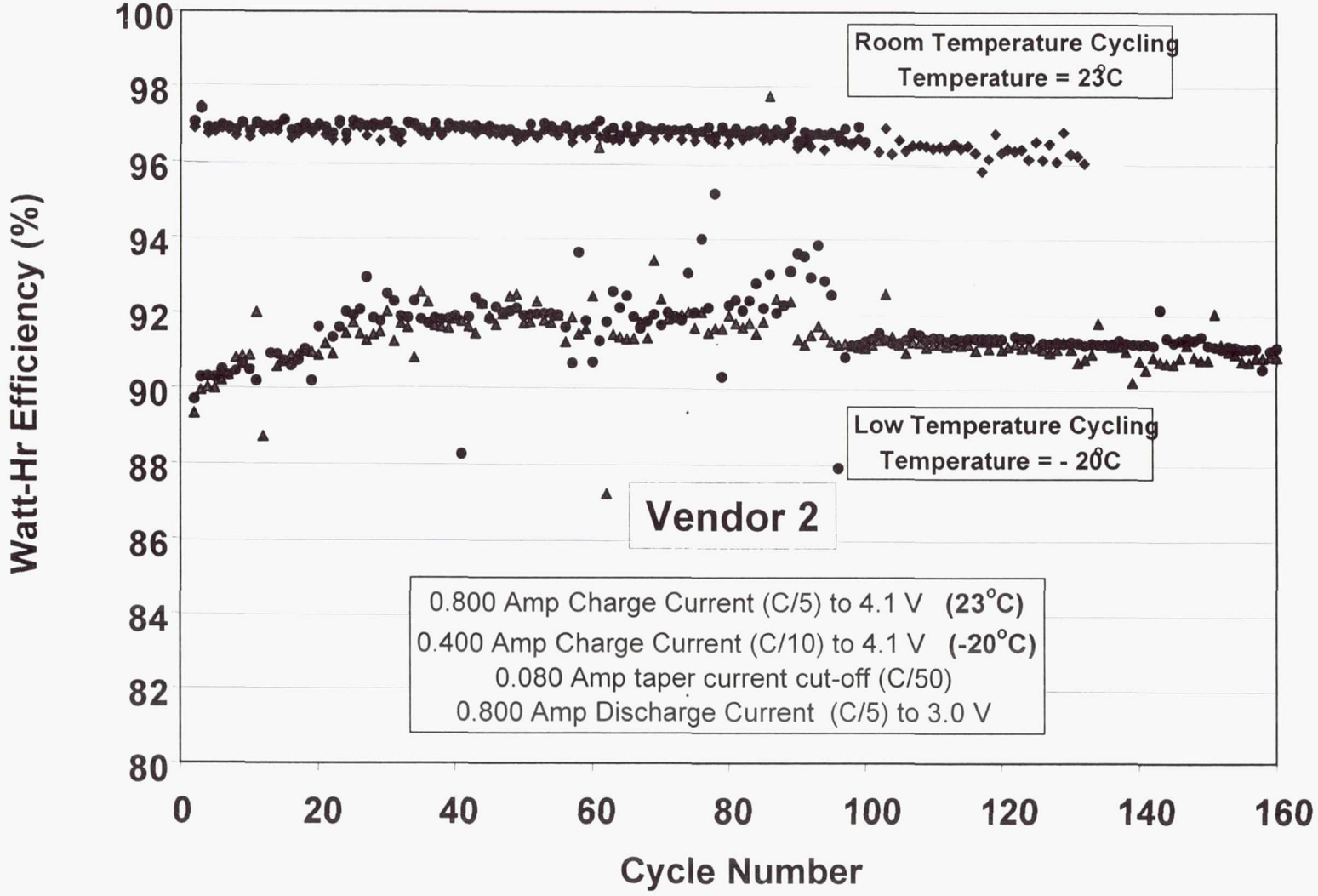
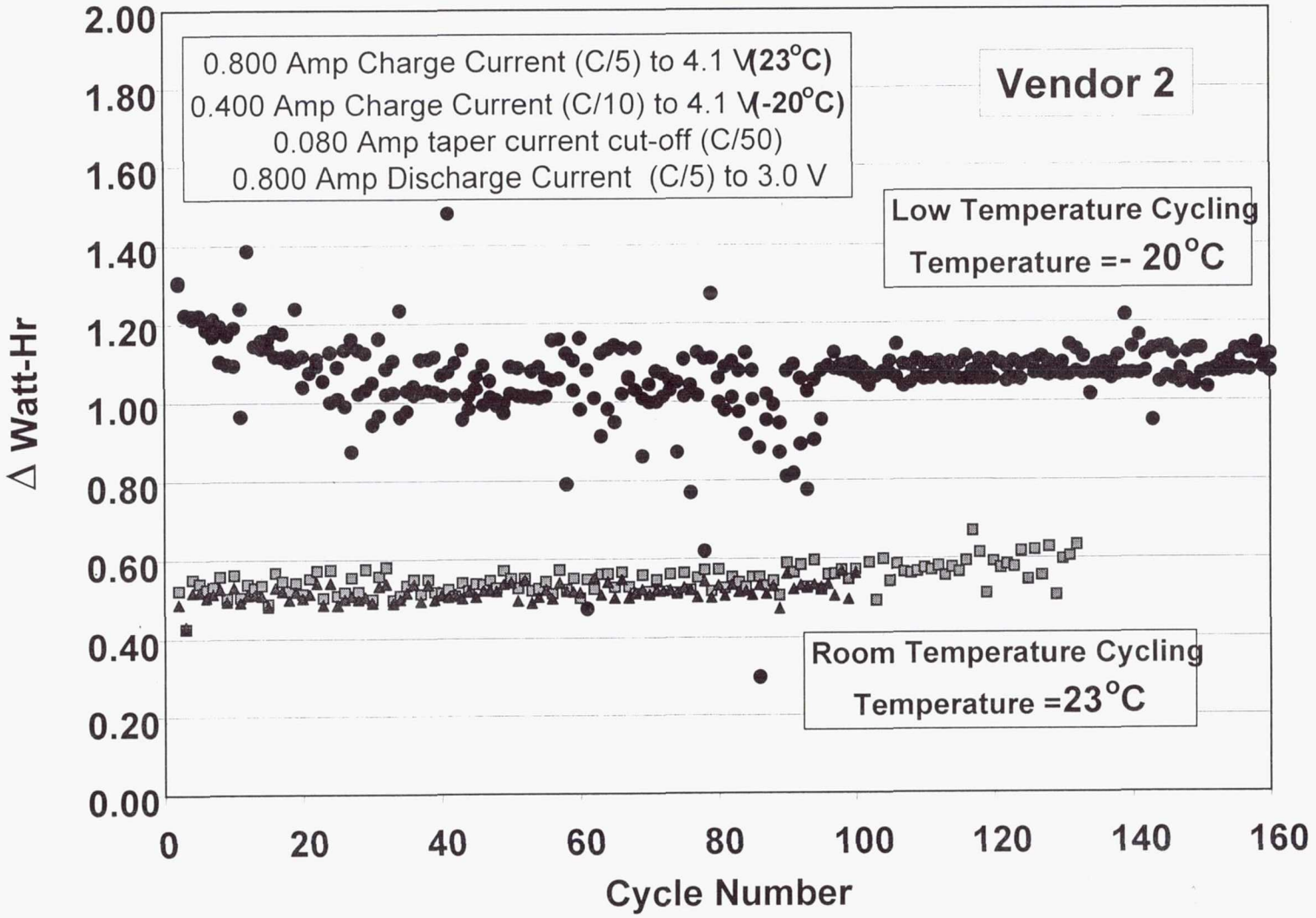
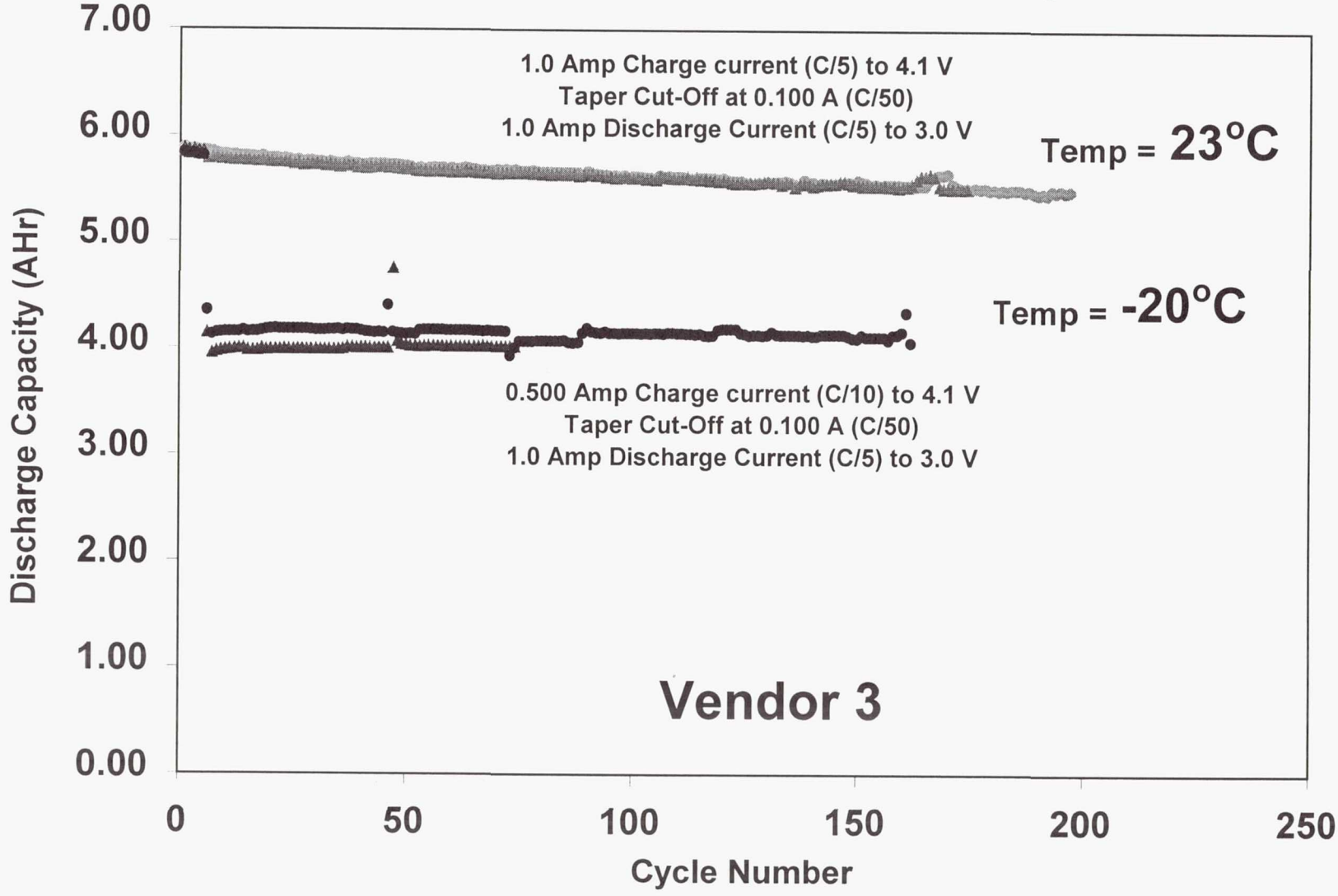
Cycle Life Performance at Different Temperatures



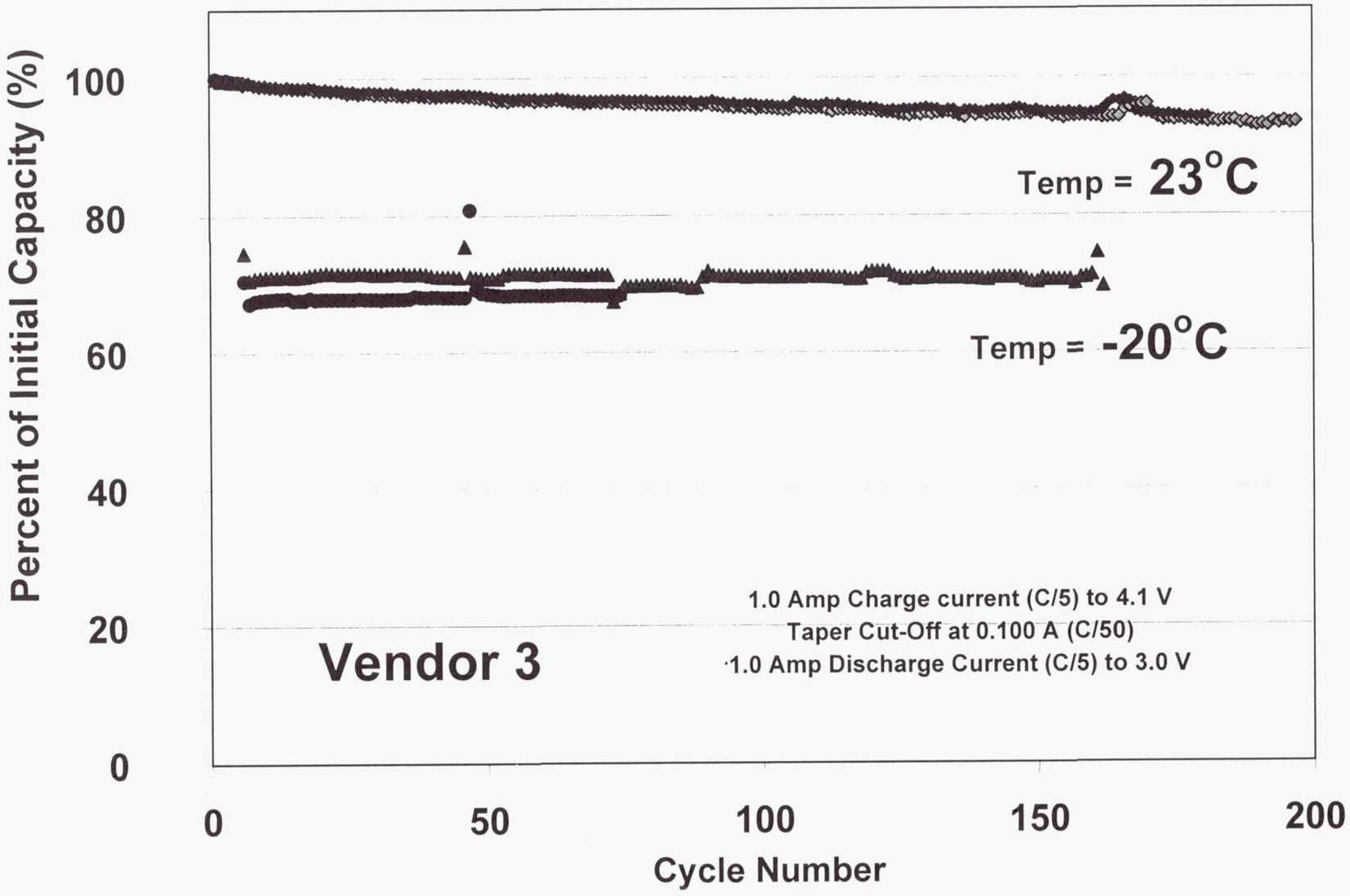
Lithium-Ion Cells (D-Size) for Mars Rover Applications
Cycle Life Performance at Different Temperatures



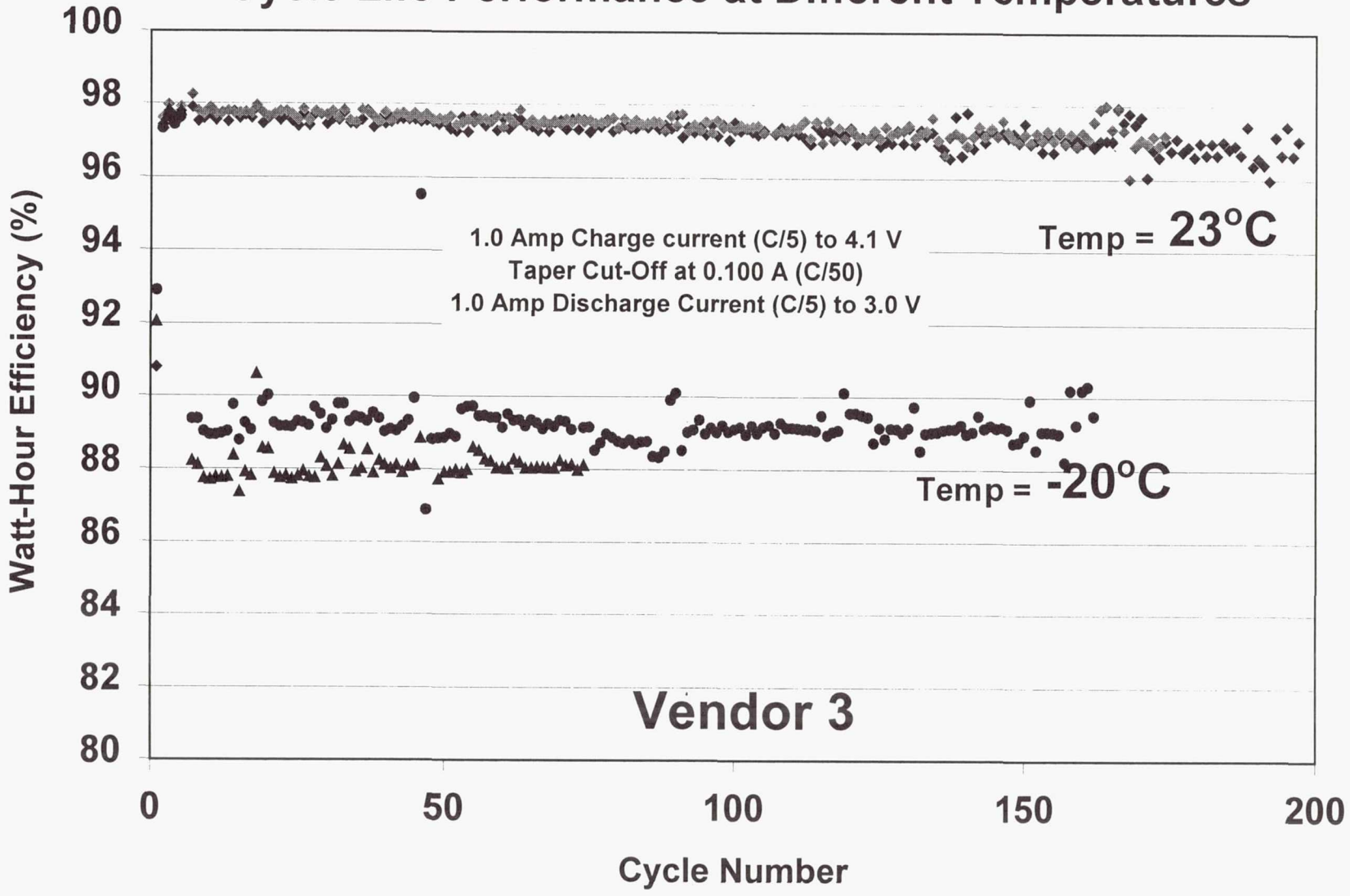
Prismatic Lithium-Ion Cells (5Ahr) for Mars Rover Applications
Cycle Life Performance at Different Temperatures



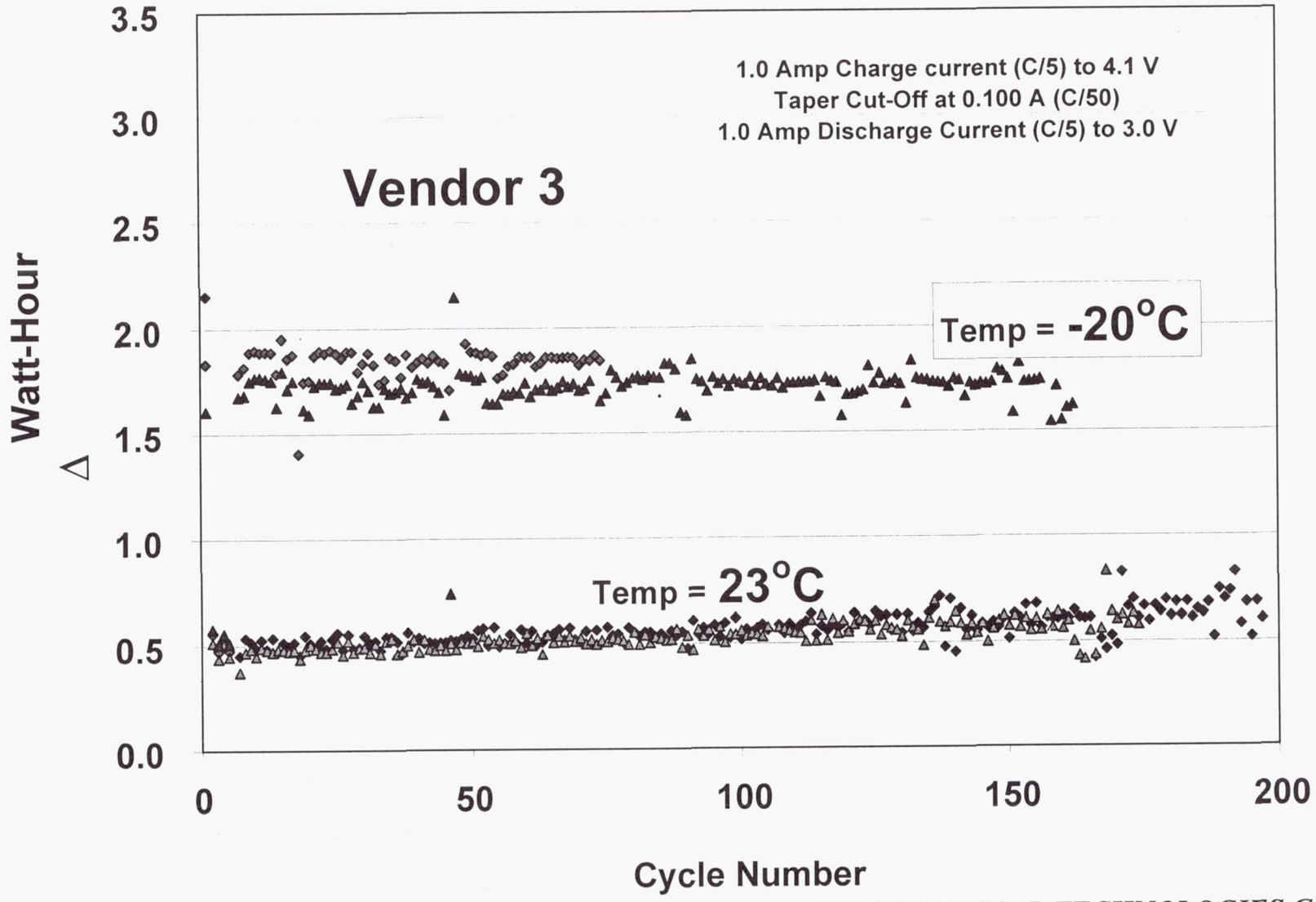
Prismatic Lithium-Ion Cells (5Ah) for Mars Rover Applications
Cycle Life Performance at Different Temperatures



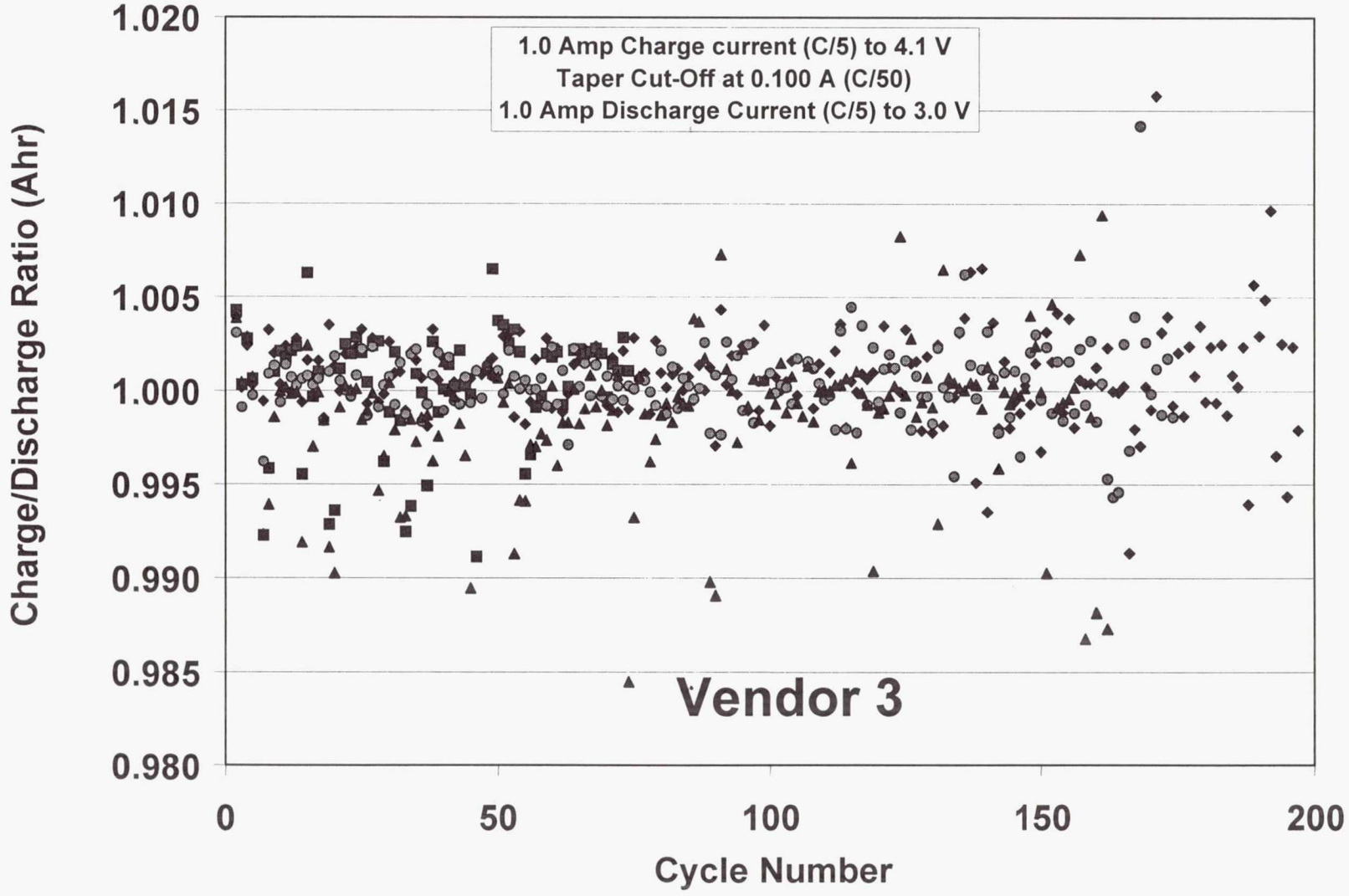
Prismatic Lithium-Ion Cells (5Ah) for Mars Rover Applications
Cycle Life Performance at Different Temperatures



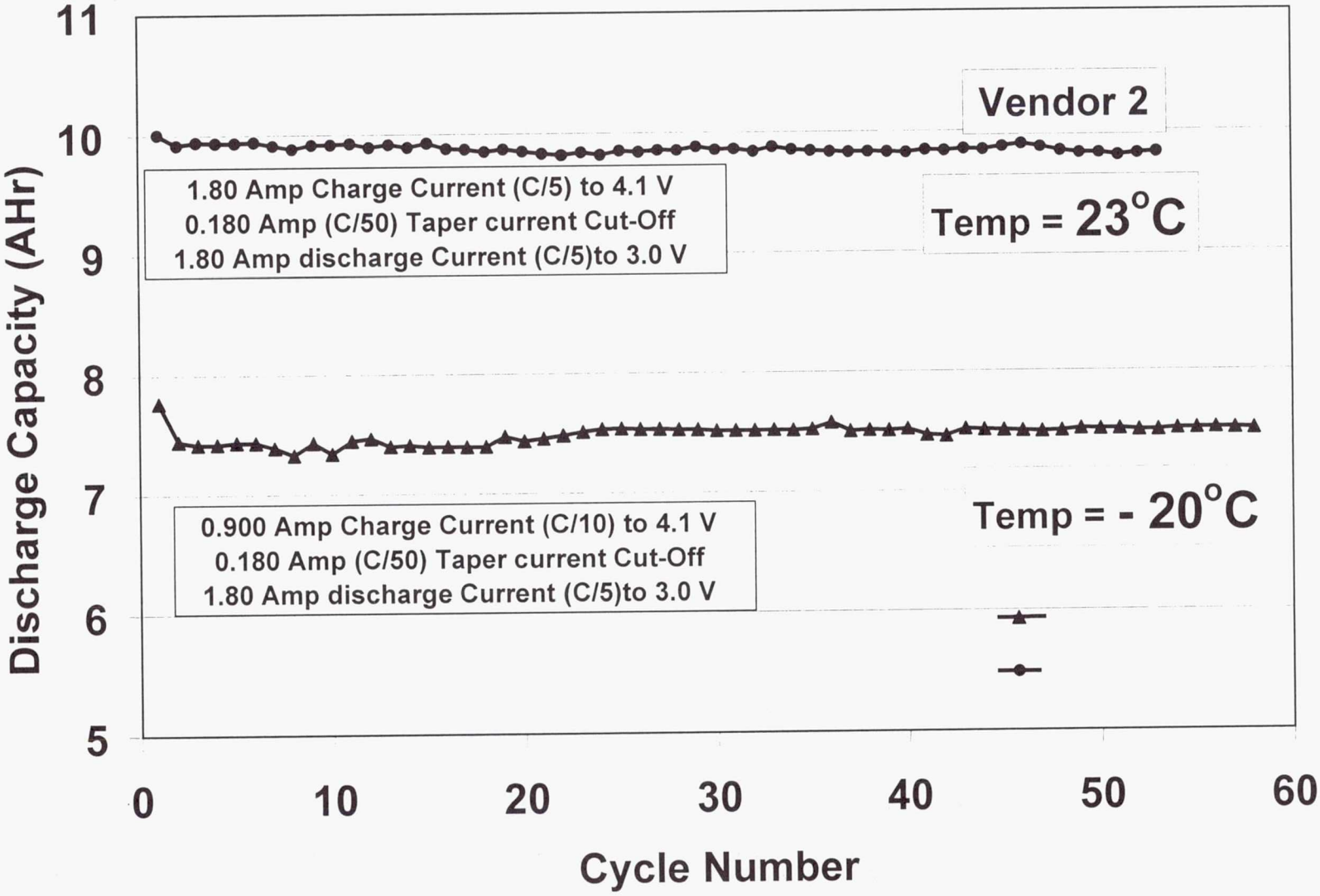
Prismatic Lithium-Ion Cells (5Ahr) for Mars Rover Applications
Cycle Life Characteristics at Different Temperatures



Prismatic Lithium-Ion Cells (5Ahr) for Mars Rover Applications
Cycle Life Characteristics



DD-Size Lithium-Ion Cells for Mars Rover Applications
Cycle Life Characteristics at Different Temperature (Gen I)



Rate Characterization Tests

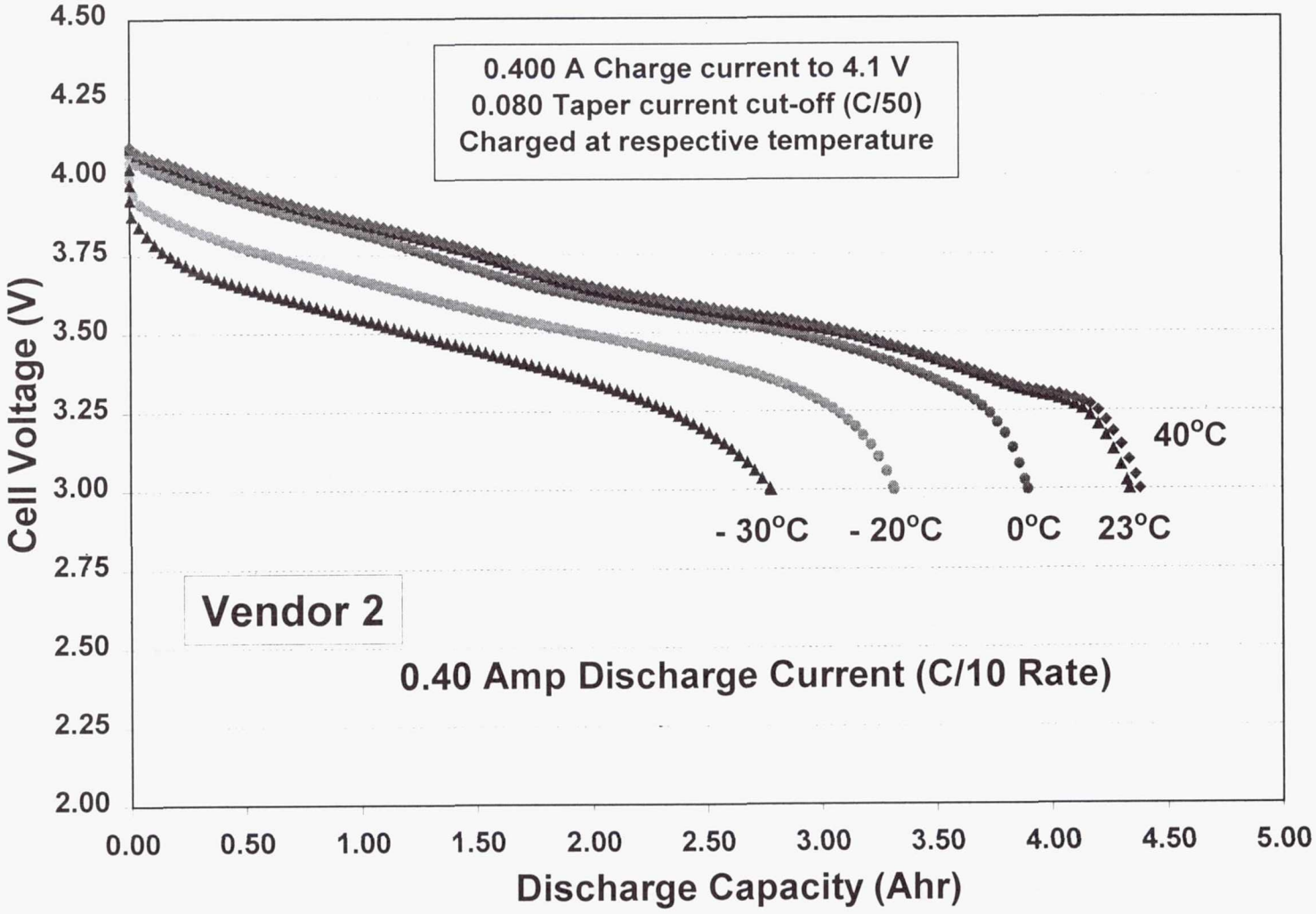
Approach:

- Range of charge and discharge rates (C/2, C/3.3, C/5 and C/10)
- Range of temperatures investigated (-20, 0, 23, 40°C)
- Pulse capability (40 and 60A)

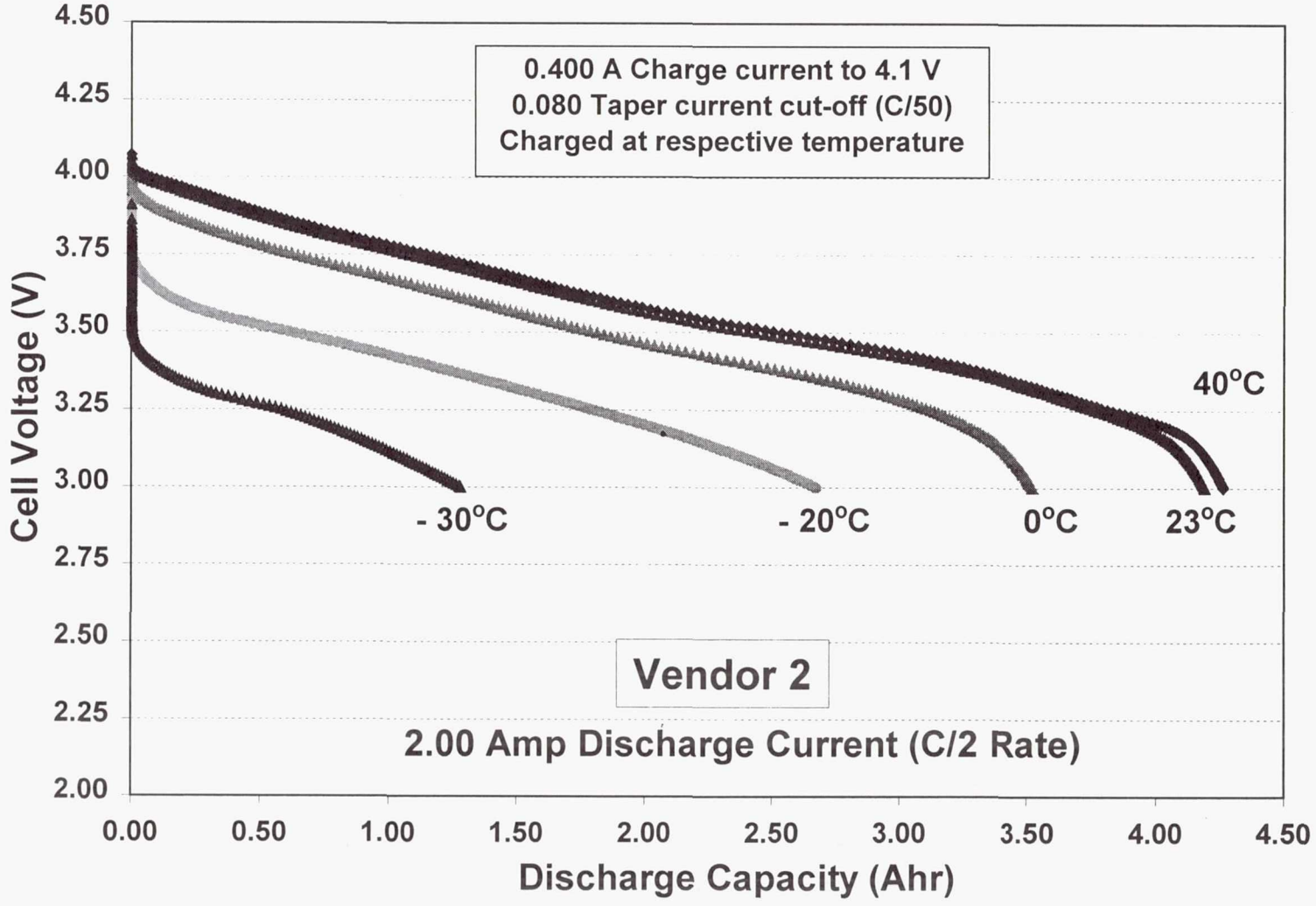
Cell Performance Aspects

- Discharge/charge capacity (Ah)
- Discharge energy (Wh/Kg)
- Watt-hour efficiency (round-trip efficiency)
- Heat generation
- Effect of cell history upon rate capability

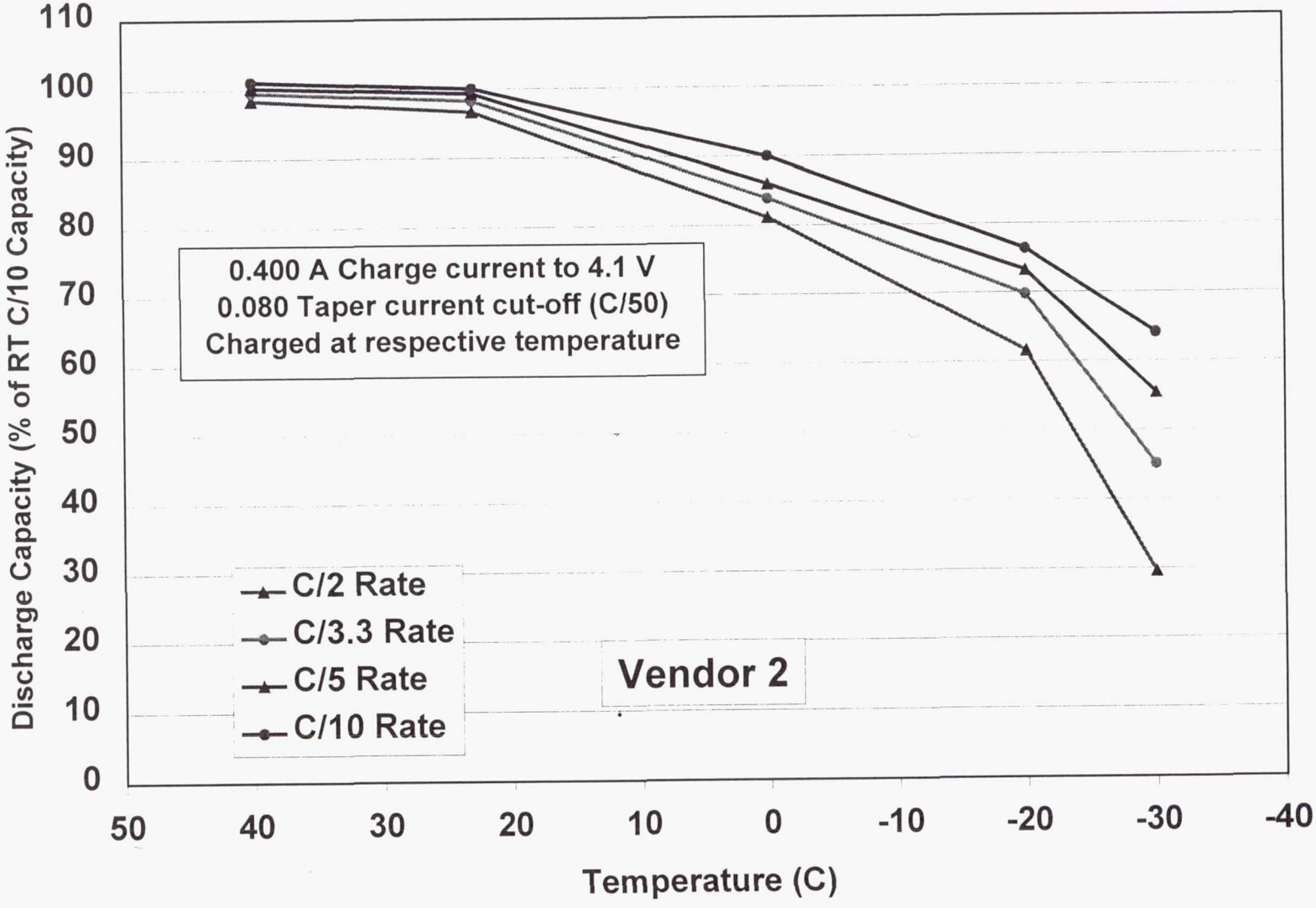
Lithium-Ion Cells (D-Size) for Mars Rover Applications
Discharge Capacity at Various Temperatures (C/10 Rate)



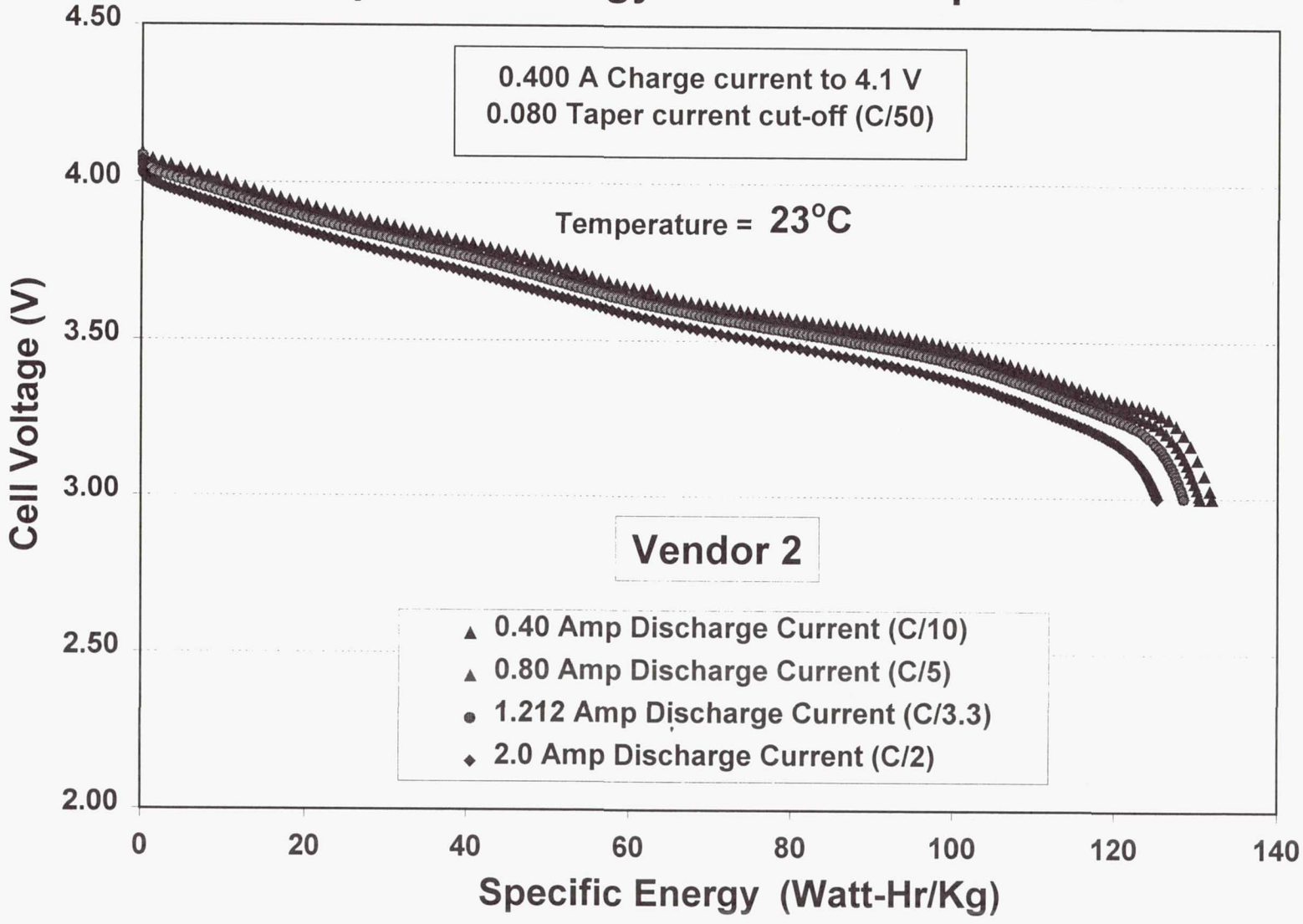
Lithium-Ion Cells (D-Size) for Mars Rover Applications
Discharge Capacity at Various Temperatures (C/2 Rate)



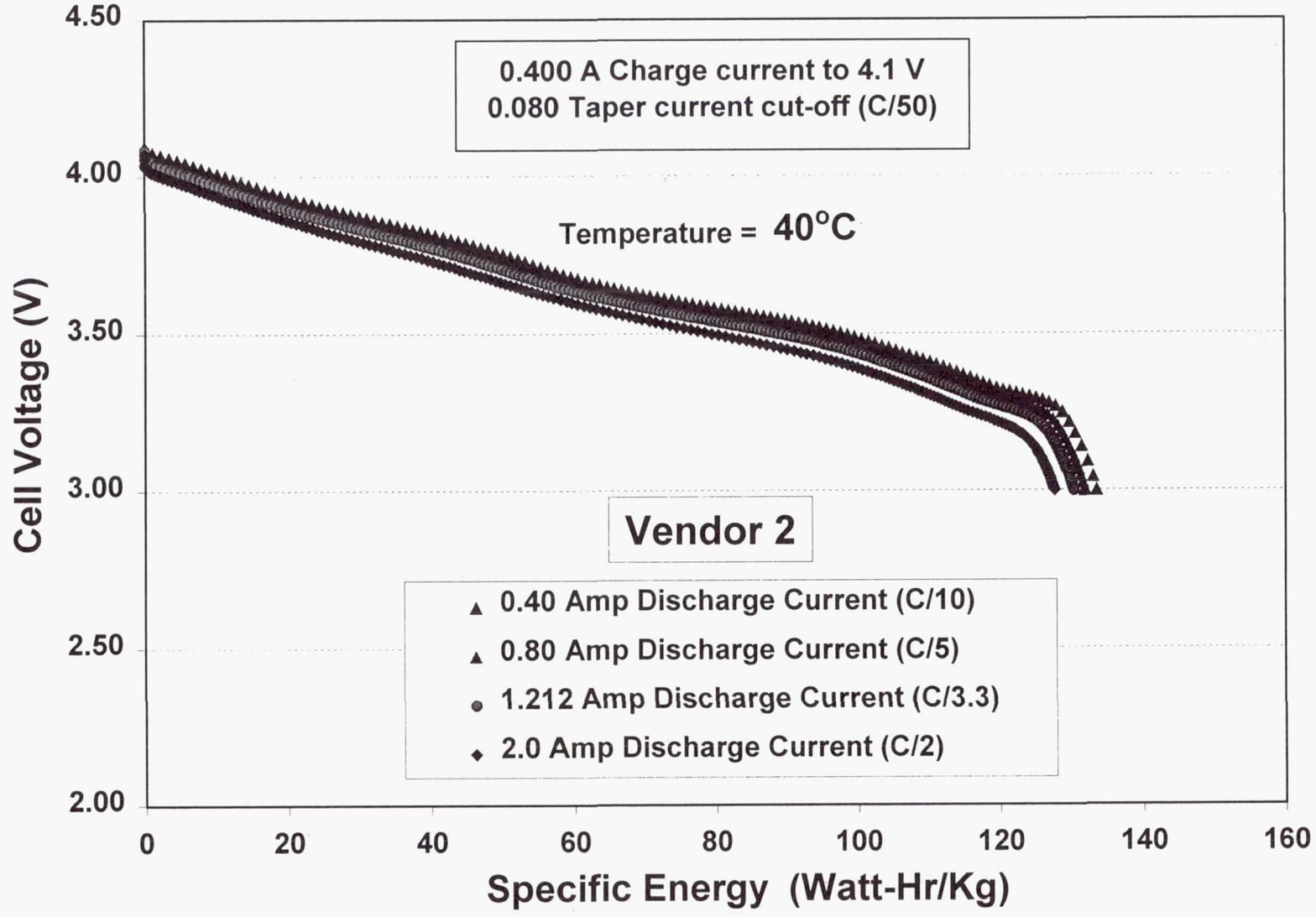
Lithium-Ion Cells (D-Size) for Mars Rover Applications
Discharge Behavior as a Function of Temperature



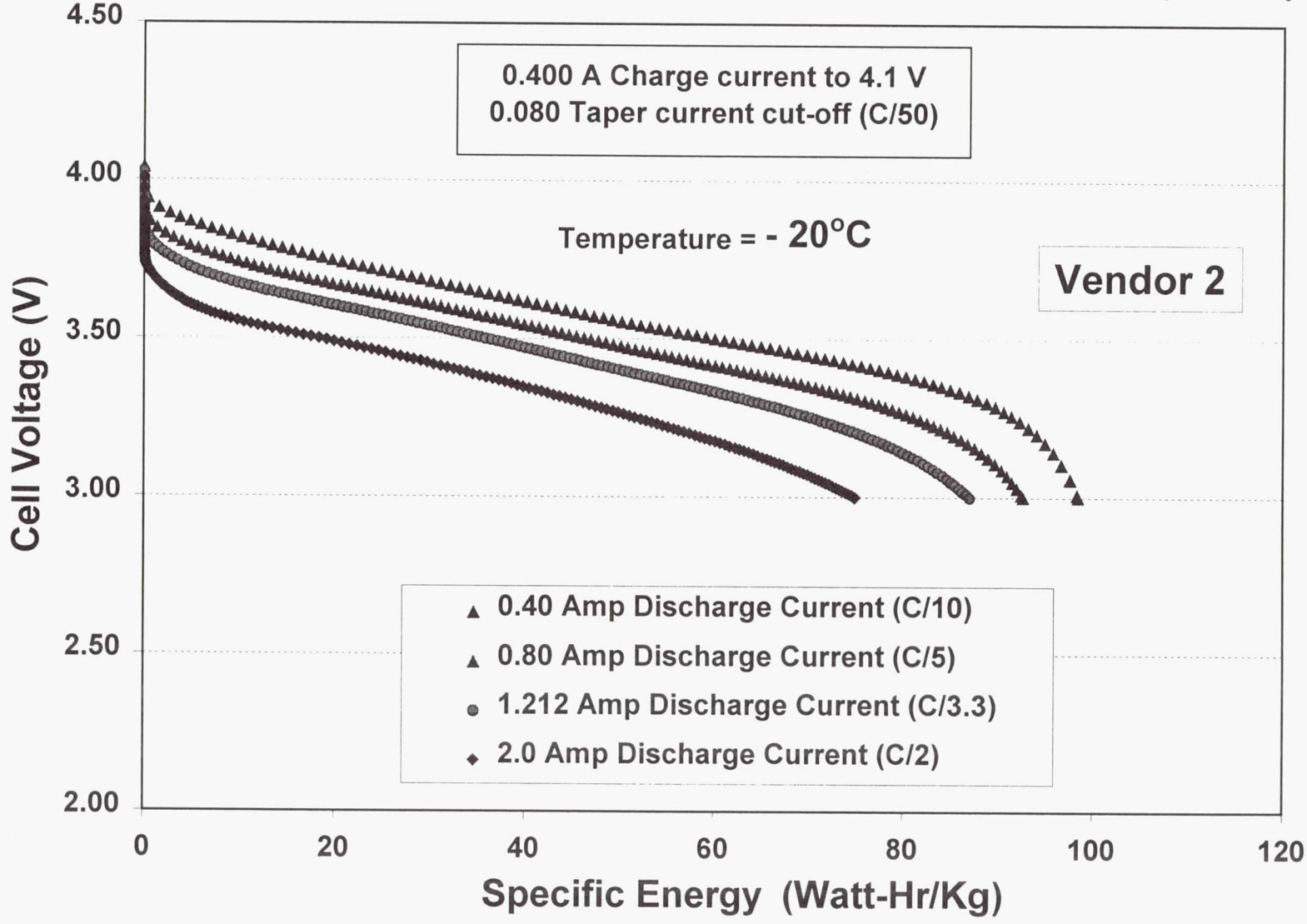
Lithium-Ion Cells (D-Size) for Mars Rover Applications
Specific Energy at Room Temperature



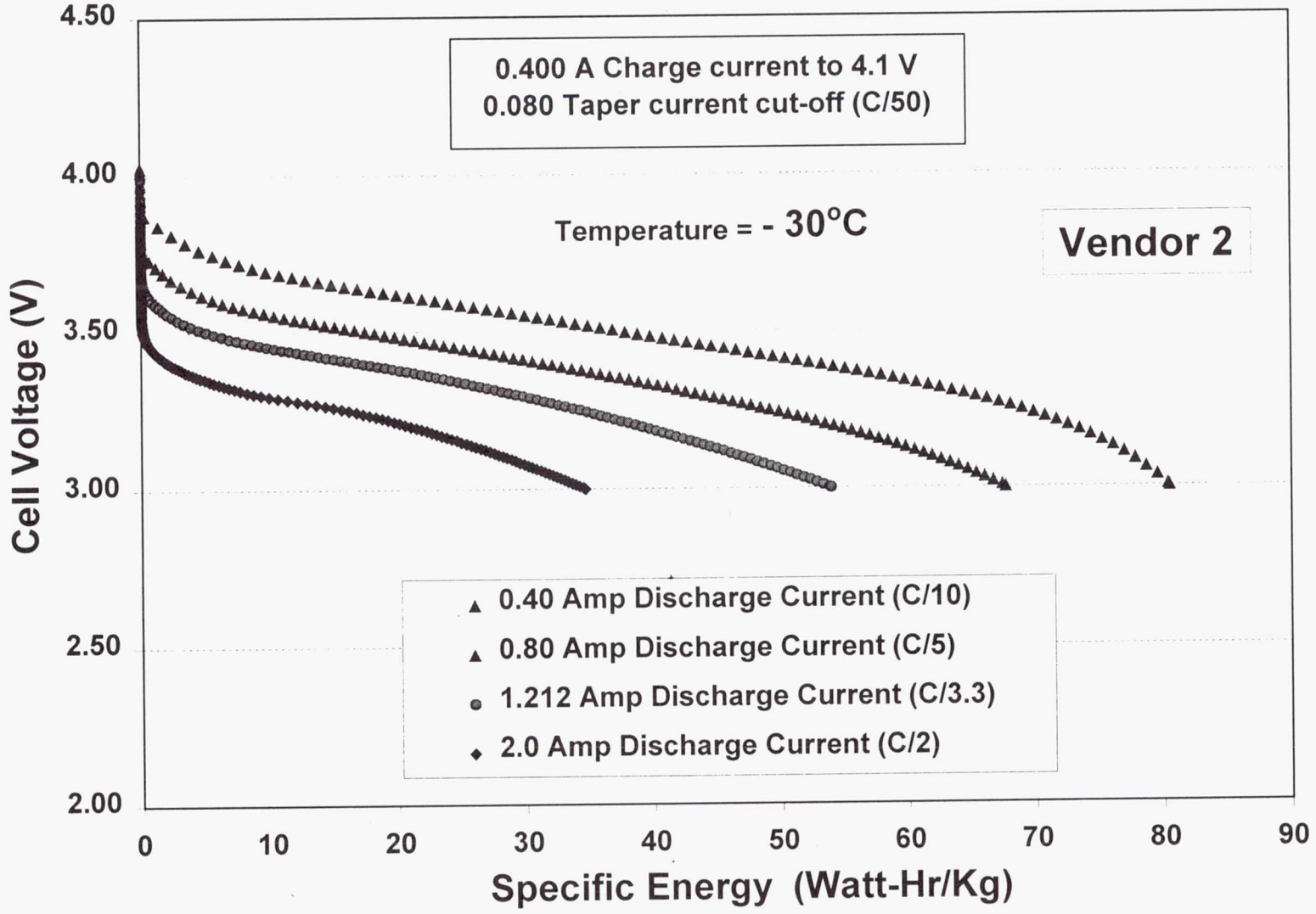
Lithium-Ion Cells (D-Size) for Mars Rover Applications
Specific Energy at High Temperature (40°C)



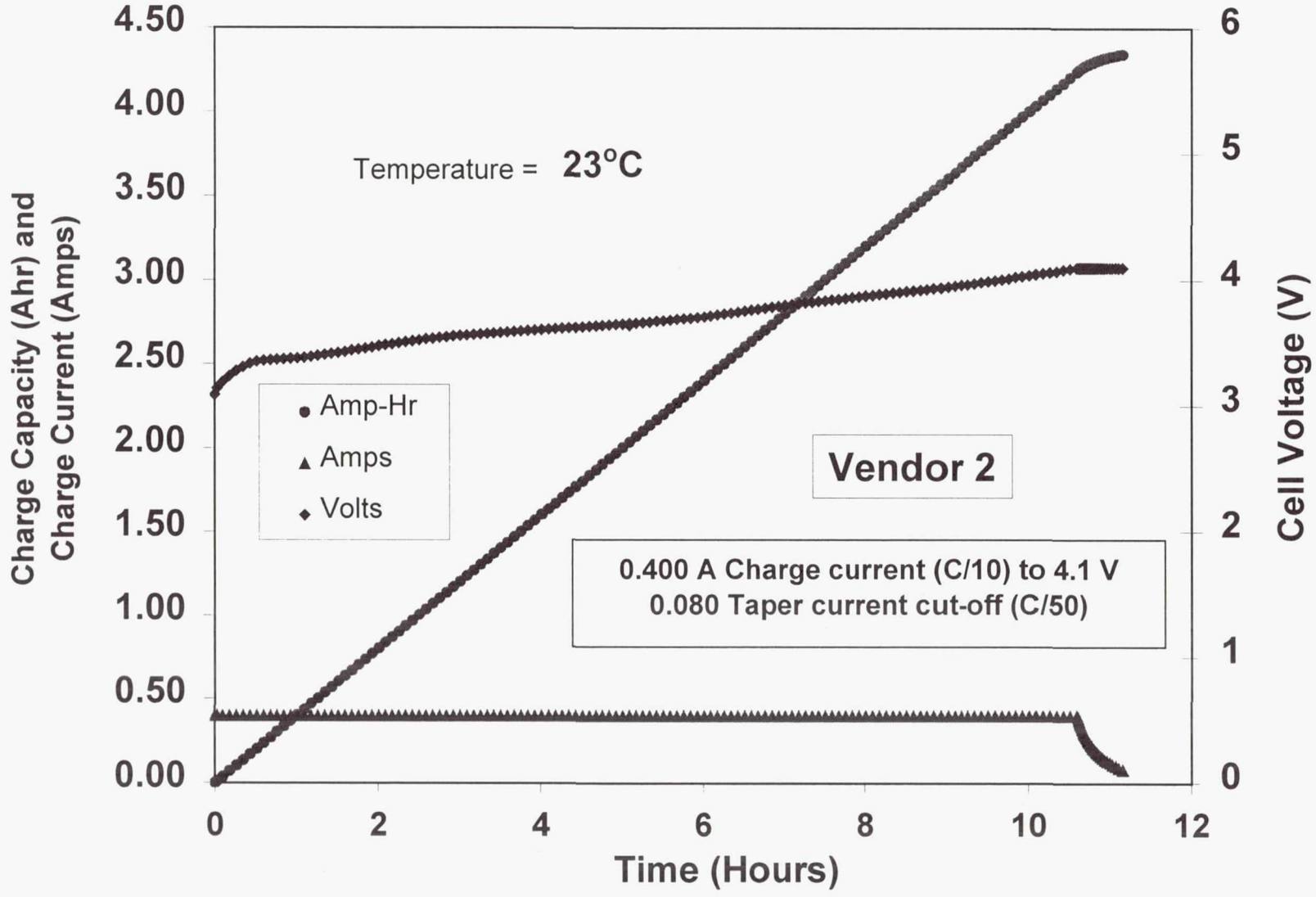
Lithium-Ion Cells (D-Size) for Mars Rover Applications
Discharge Characteristics at Low Temperature (-20°C)



Lithium-Ion Cells (D-Size) for Mars Rover Applications
Discharge Characteristics at Low Temperature (-30°C)



Lithium-Ion Cells (D-Size) for Mars Rover Applications
Charge Characteristics at Room Temperature



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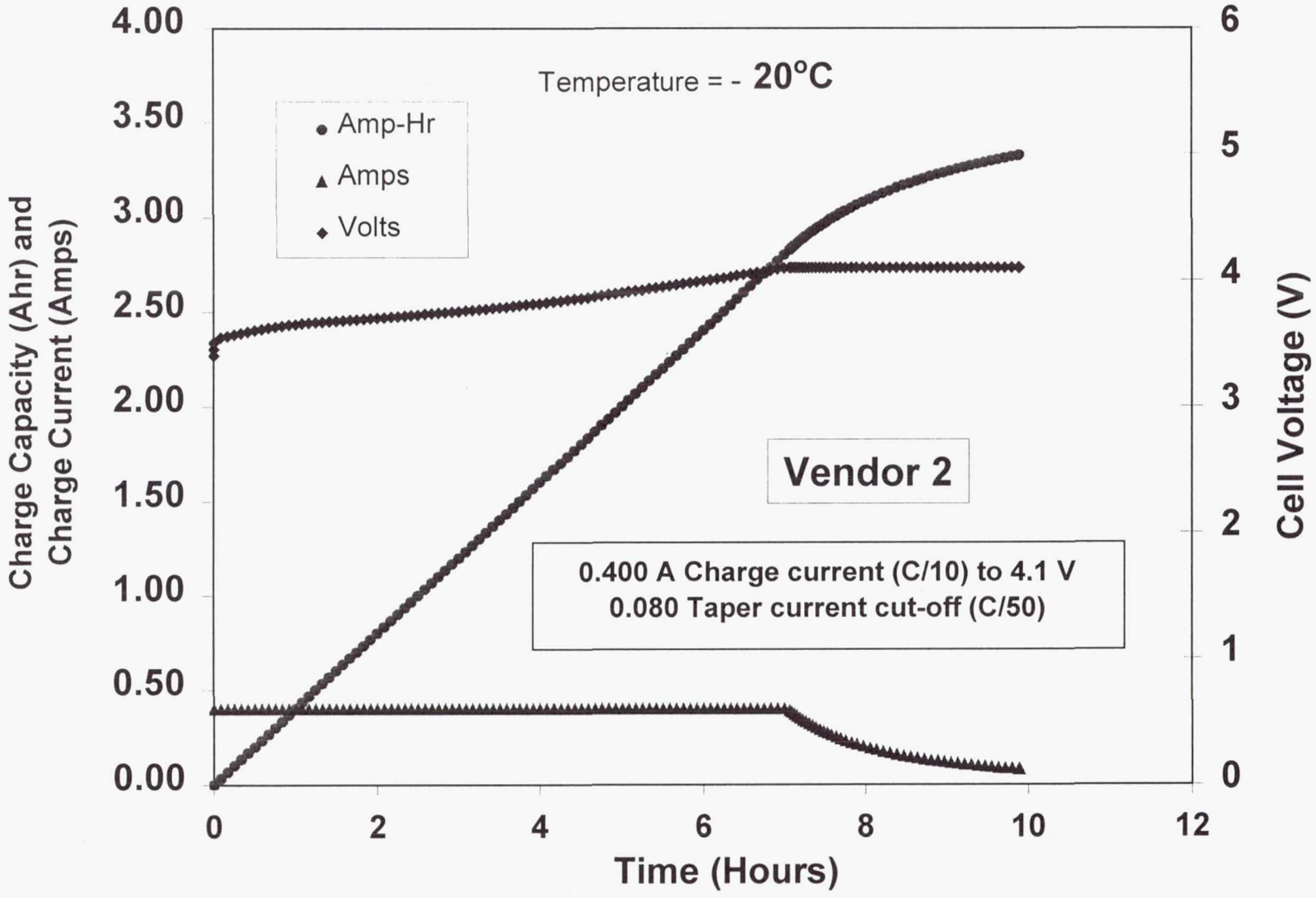
Charge Characteristics at Low Temperature (-20°C)



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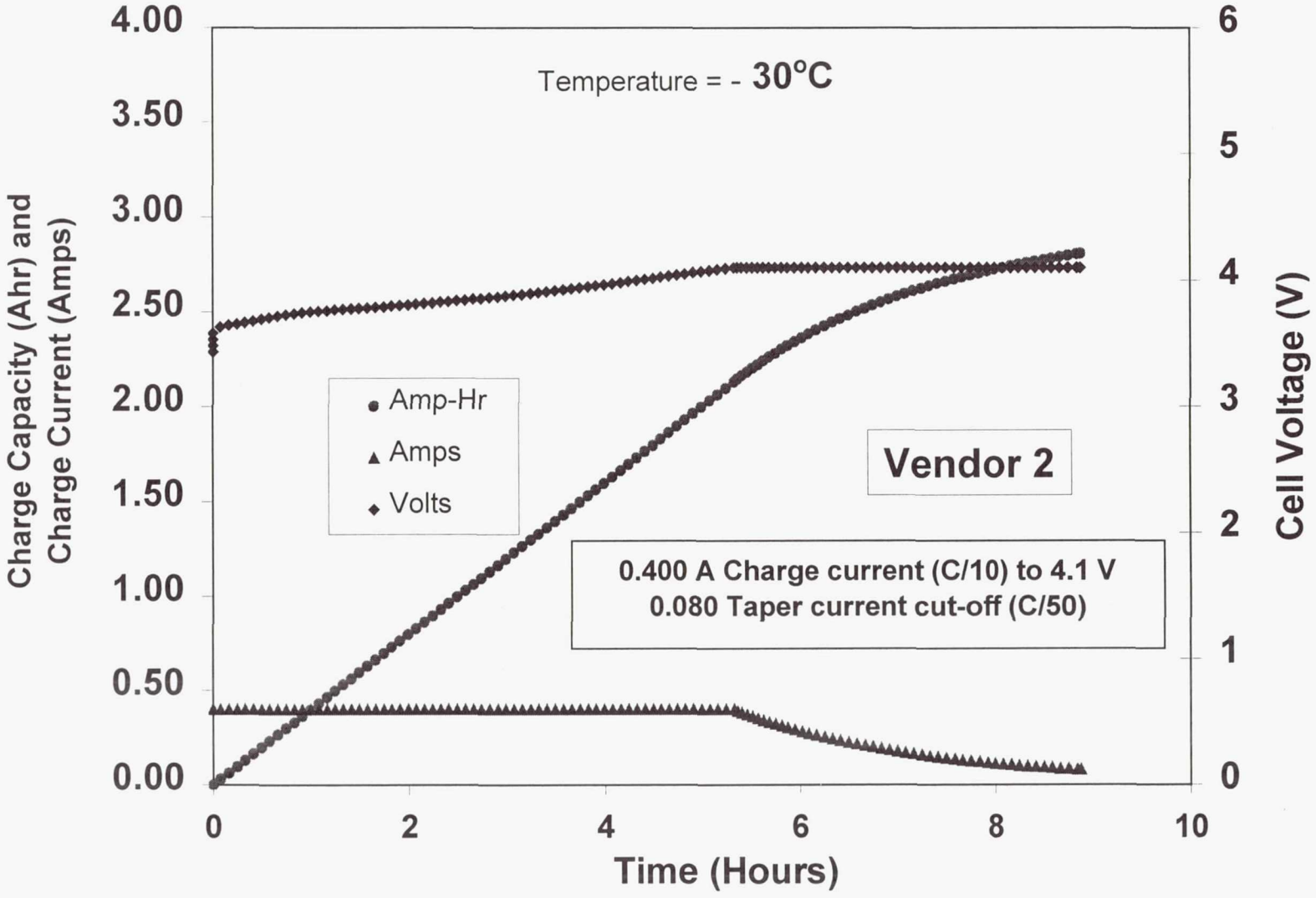
Charge Characteristics at Low Temperature (-30°C)



Lithium-Ion Cells for 2003 MSR Athena Rover

Capacity Retention Characterization Tests

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)

Performance Evaluation Criteria:

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

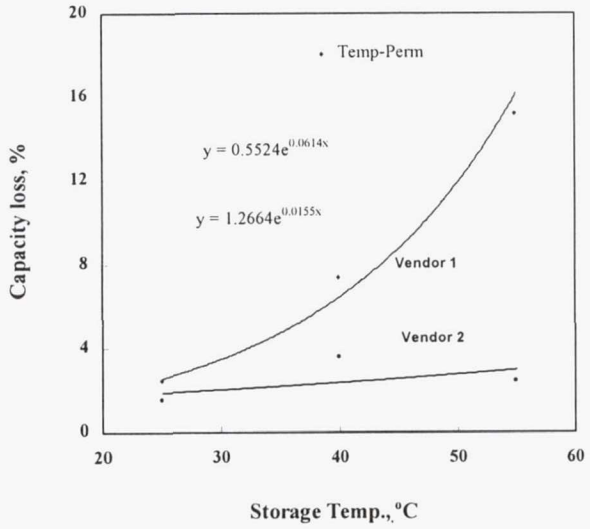
Lithium-Ion Cells for Mars Surveyor 2001 Lander

Design Experiments for Cruise Conditions

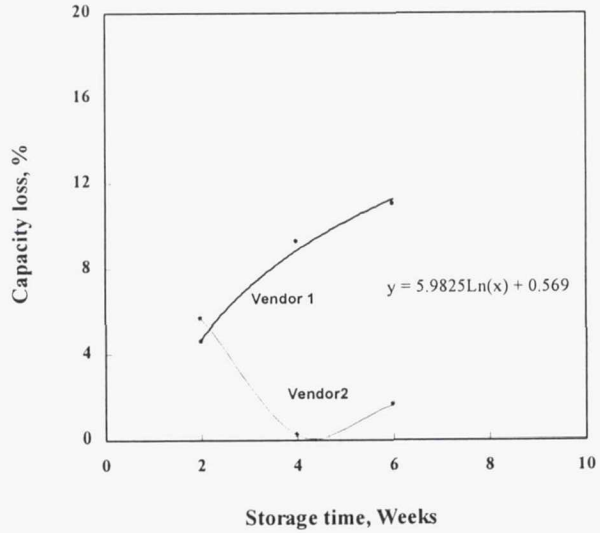
Experiment #	Storage time, weeks	Storage Temp	State of charge	Storage condition
1	2	25	50	Open Circuit
2	2	40	70	On Buss
3	2	55	100	Cycling
4	4	25	70	Cycling
5	4	40	100	Open Circuit
6	4	55	50	On Buss
7	6	25	100	On Buss
8	6	40	50	Cycling
9	6	55	70	Open Circuit

Parametric Storage Studies

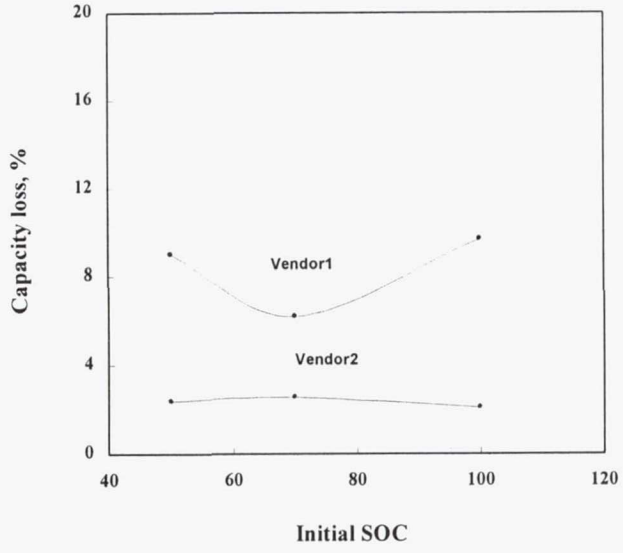
Effect of Temp on Permanent capacity loss



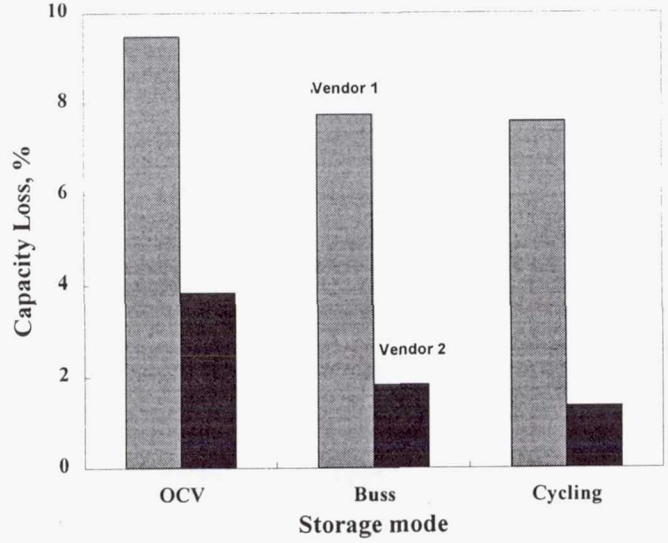
Effect of Time on Permanent capacity loss



Effect of SOC on Permanent capacity loss



Effect of Storage mode on Permanent Capacity loss



SUMMARY

- **Lithium ion cells of capacity 4-7 Ah, fabricated in U.S and being tested for 2003 Mars Rover mission at JPL under the NASA-DoD joint effort have shown**
  - **Excellent cycling characteristics at RT and LT**
  - **Improved low temperature performance and**
  - **Good storage characteristics during cruise**
- **Low temperature performance after frequent exposure to high temperatures and long storage is yet to be established.**
- **Optimum storage conditions for battery during cruise needs to be identified.**

Acknowledgments

The work described here was carried out at the Jet Propulsion Laboratory (JPL), California Institute of Technology, for the 2003 **Mars Sample Return Athena Rover and NASA Code S Battery Programs** under contract with the National Aeronautics and Space Administration (NASA).