QUALLION

Light Weight, High Power and Wide Operating Temperature Capable Li-Ion Battery

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16 November 2010

Powering Life.

2010 NASA Aerospace Battery Workshop

Purpose

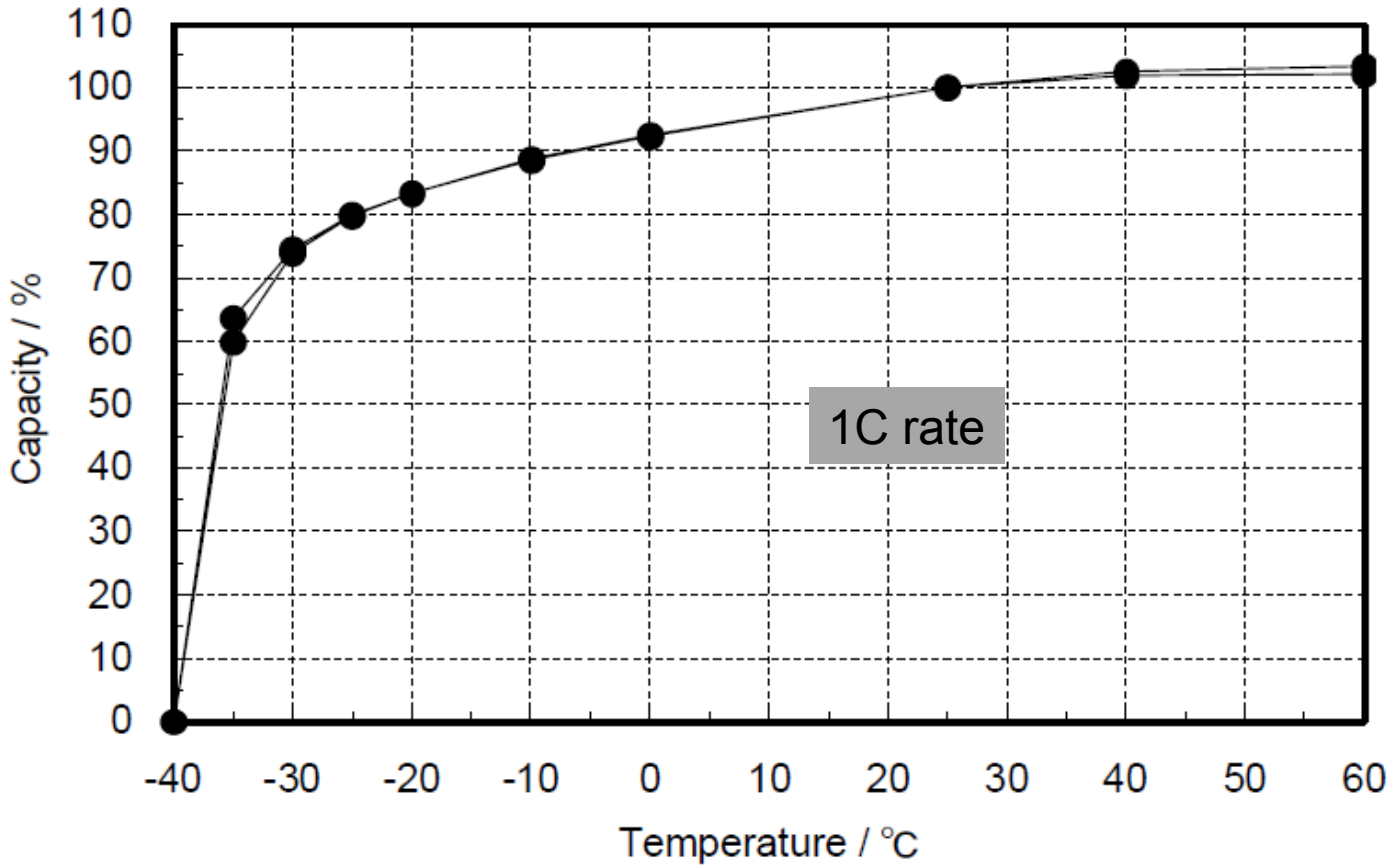
- Quallion has been in development of expanding the operating temperature of lithium-ion cells.
- The primary goal of this project is to minimize the electrode design change and utilize the same class of active materials to be produced under the Title III contract.
- Electrode design was based on prior work for high power electrodes and long life chemistry utilized in our medical and satellite lithium cells.
- In addition, under a SBIR contract with NASA, Quallion evaluated various electrolytes to optimize the low temperature performance (charge/discharge). Some of these electrolytes were provide through a collaboration with NASA/JPL
- The following presentation shows the performance of the down-selected electrolytes in various cell form factors and electrode designs

Outline

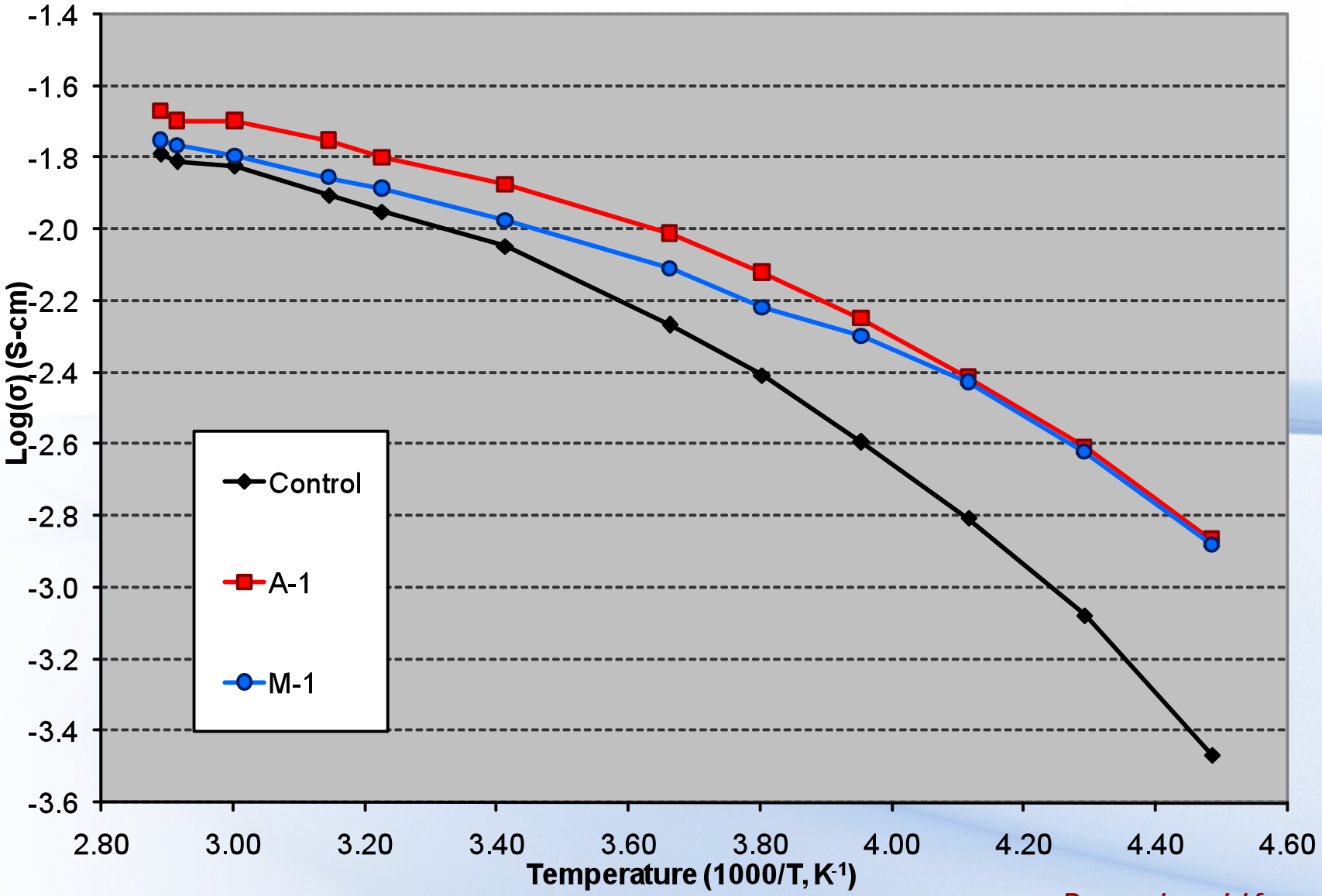
- Electrolyte Conductivity
- 300mAh High Power Baseline Test Cells
  - Wide temperature rate capabilities
  - High temperature storage stability
  - Cycle life
- 300mAh Power-Energy Balance Test Cells
  - Wide temperature rate capabilities
  - High temperature storage stability
- Q18650-HP
  - Mechanical design trade study
  - Rate capabilities
  - Preliminary cycle life
- Prototype Small Prismatic Cell
  - Room and low temperature rate capabilities
  - Low temperature cycle life
  - Preliminary cycle life
- Prototype Large Satellite Cell Build
- Conclusions & Acknowledgements

SOA COTS Cell

COTS cell solution is an inexpensive solution, but it has limitation- "Low Temperature Capability".



Electrolyte Conductivity



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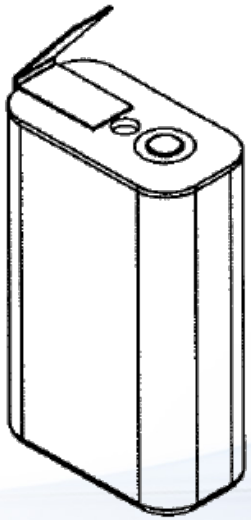
Baseline High Power Cell Design

- Small, 300mAh test cell
- High power electrode design
- 10C (3A) rated cell capability
- Low temperature electrolytes
  - EC/EMC (Control)
  - Quallion low temperature electrolyte A-1
  - JPL low temperature electrolyte M-1

BTE370-HP Mechanical Design



Cell Specifications	
True Capacity / mAh*	300
Energy Density / Wh/kg*	108
Energy Density / Wh/l*	200
Dimensions / mm*	30 x 18 x 10 (H x W x T)
Weight / g*	10.00 ± 0.75

- **Electrical Characteristics**
  - Nominal Capacity = 300 mAh
  - Target Operating Range = -70°C to +85°C
  - Rated for 10C discharge over entire temperature range (15C Possible)
- **Heritage Materials**
  - Active materials are the same as Quallion SATELLITE cells
  - USG T3 program enables Quallion to produce Cathode and Anode materials in-house by 2012

* Designed values

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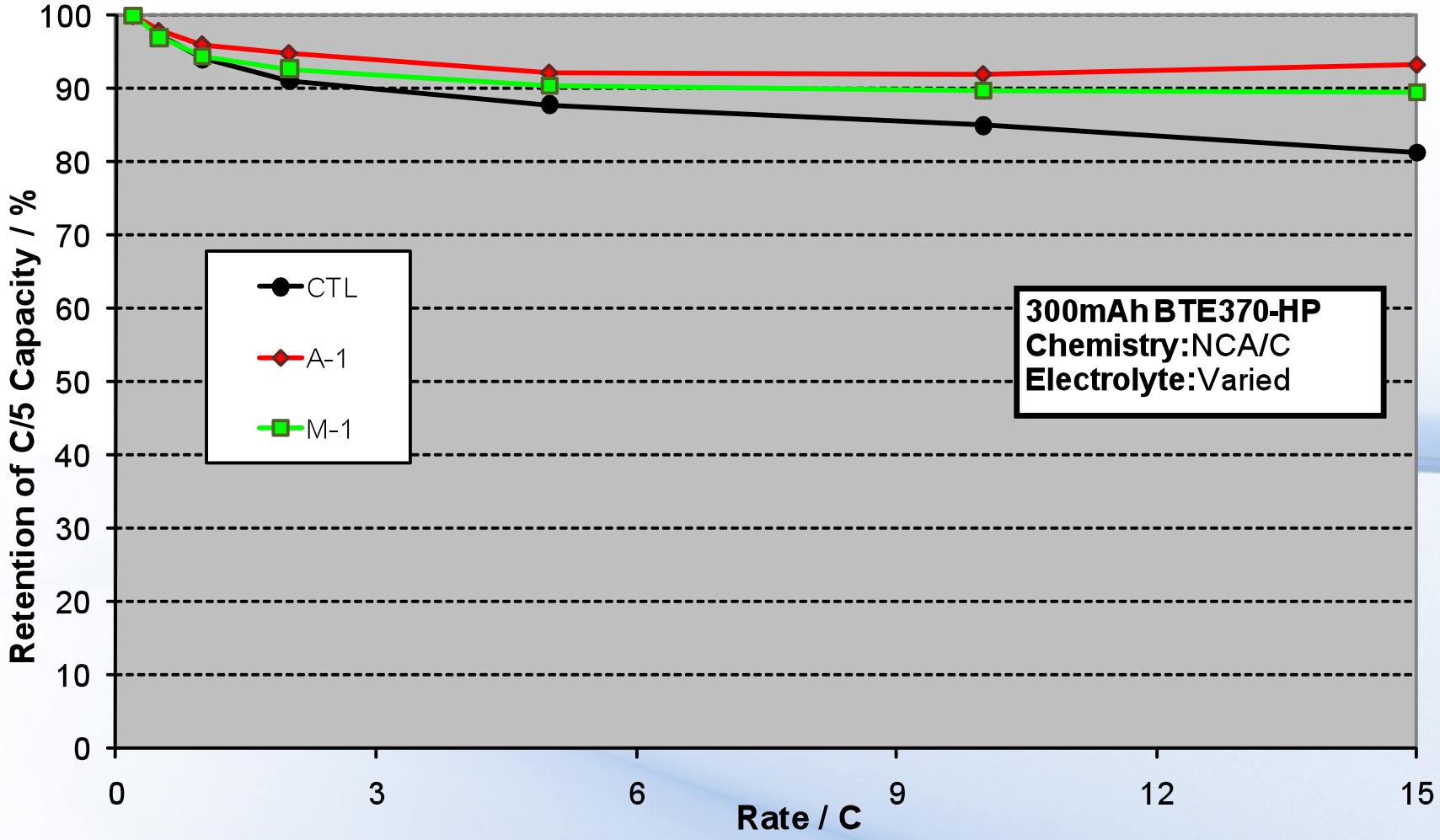
Rate Test Summary for BTE370-HP



Charge : 1.0CmA, 4.1V CCCV C/20 mA cutoff at RT
Discharge : 0.2, 0.5, 1, 2, 5, 10, 15CmA to 2.7 V at RT

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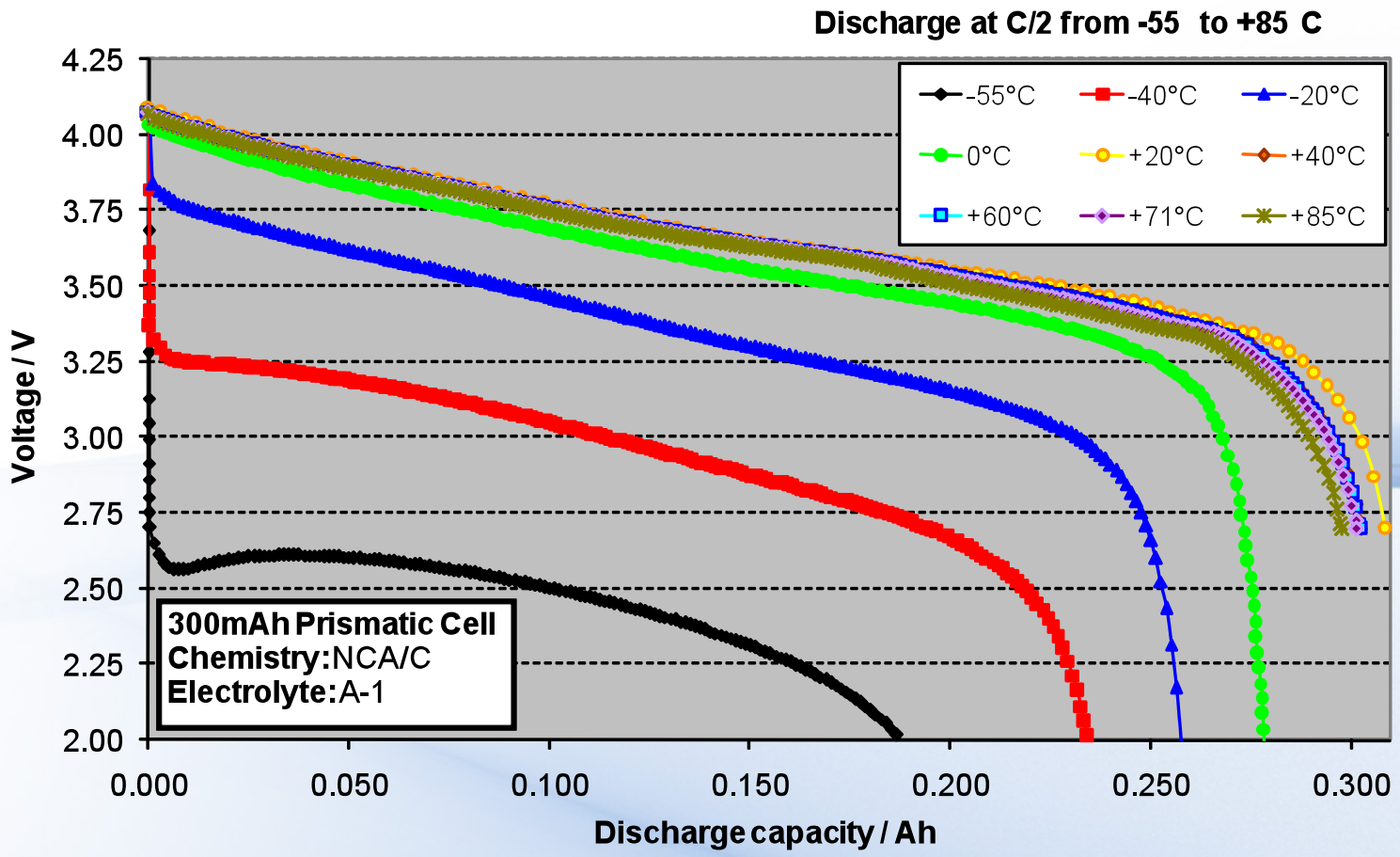
C/2 Discharge from -55° to +85°C for A-1 Cell

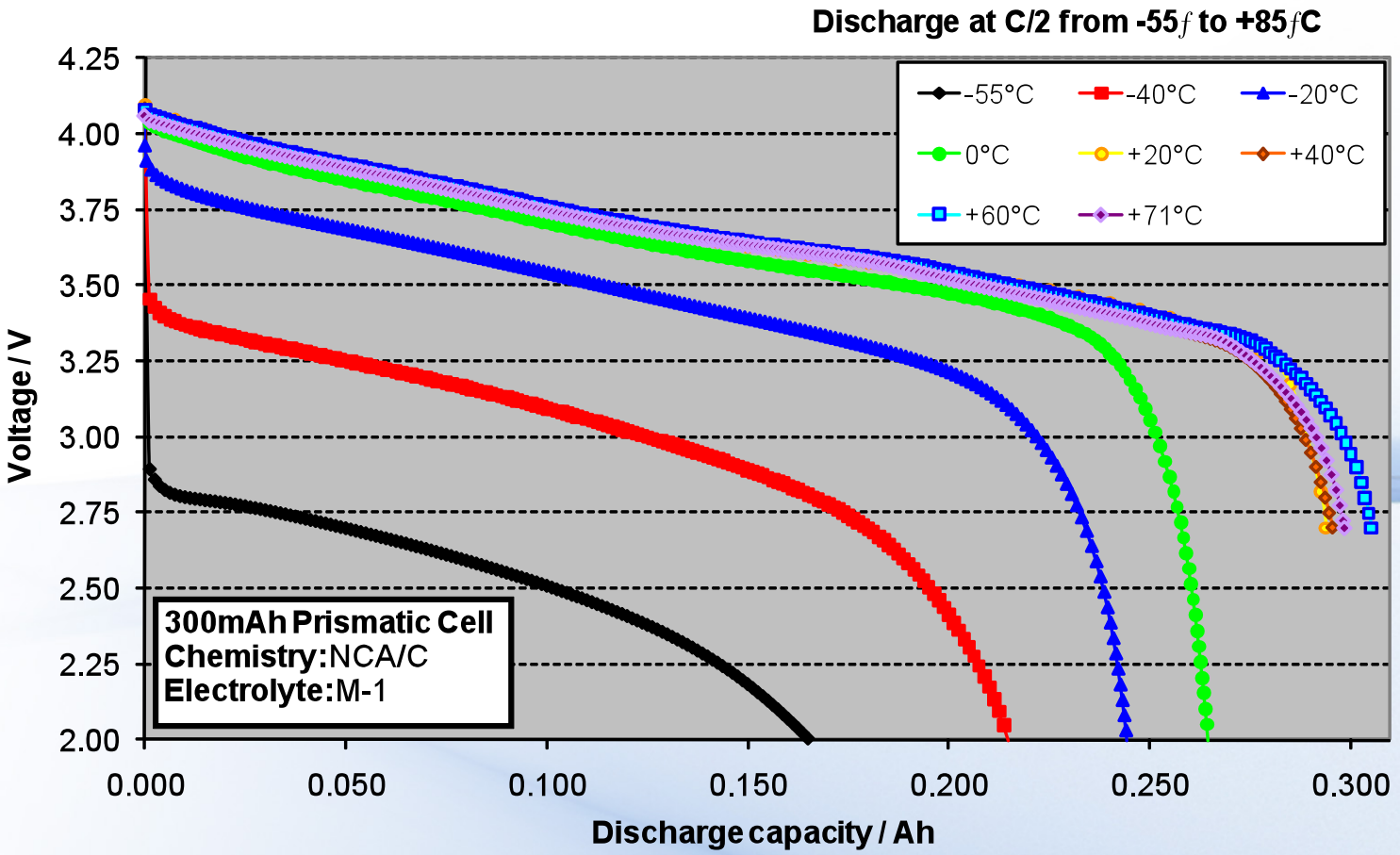


Charge : 1CmA, 4.1V CCCV C/20 mA cutoff at RT
Discharge : 0.5CmA to 2.0V at -55 , -40 , -20 , & 0 & to 2.7 V at +20 , +40 , +60 , +71 , & +85 C

Single cell; Over 32 cycles at different rates and temperatures

Powering Life.

C/2 Discharge from -55° to +71°C for M-1 Cell

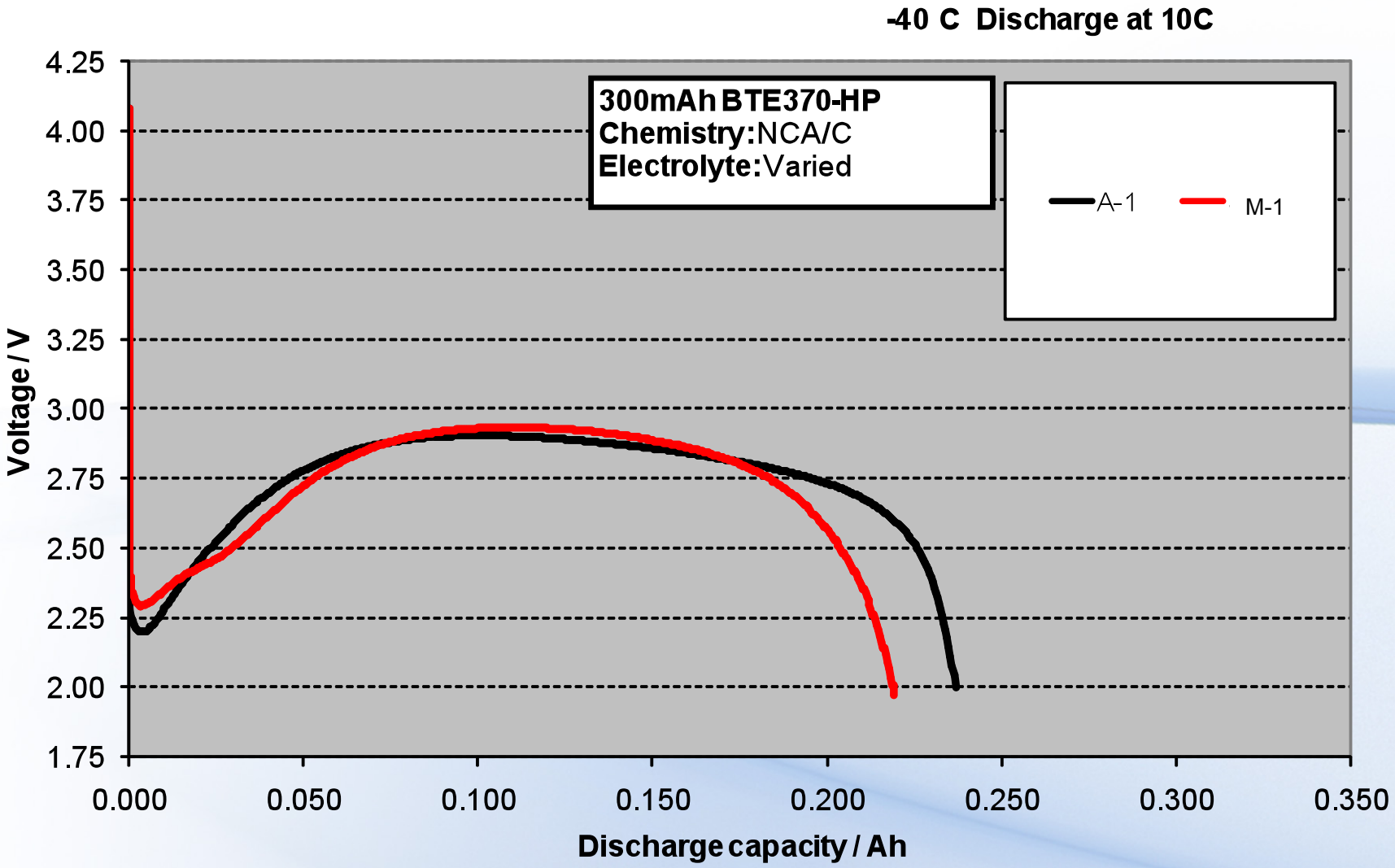


Charge : 1CmA, 4.1V CCCV C/20 mA cutoff at RT
Discharge : 0.5CmA to 2.0V at -55ƒ, -40ƒ, -20ƒ, & 0ƒ & to 2.7 V at +20ƒ, +40ƒ, +60ƒ, & +71ƒC

Single cell; Over 32 cycles at different rates and temperatures

Powering Life.

10C Discharge at -40°C for A-1 and M-1



Charge : 1 CmA, 4.1V CCCV C/20 mA cutoff at RT
Discharge : 10 CmA to 2.0 V at -40 C

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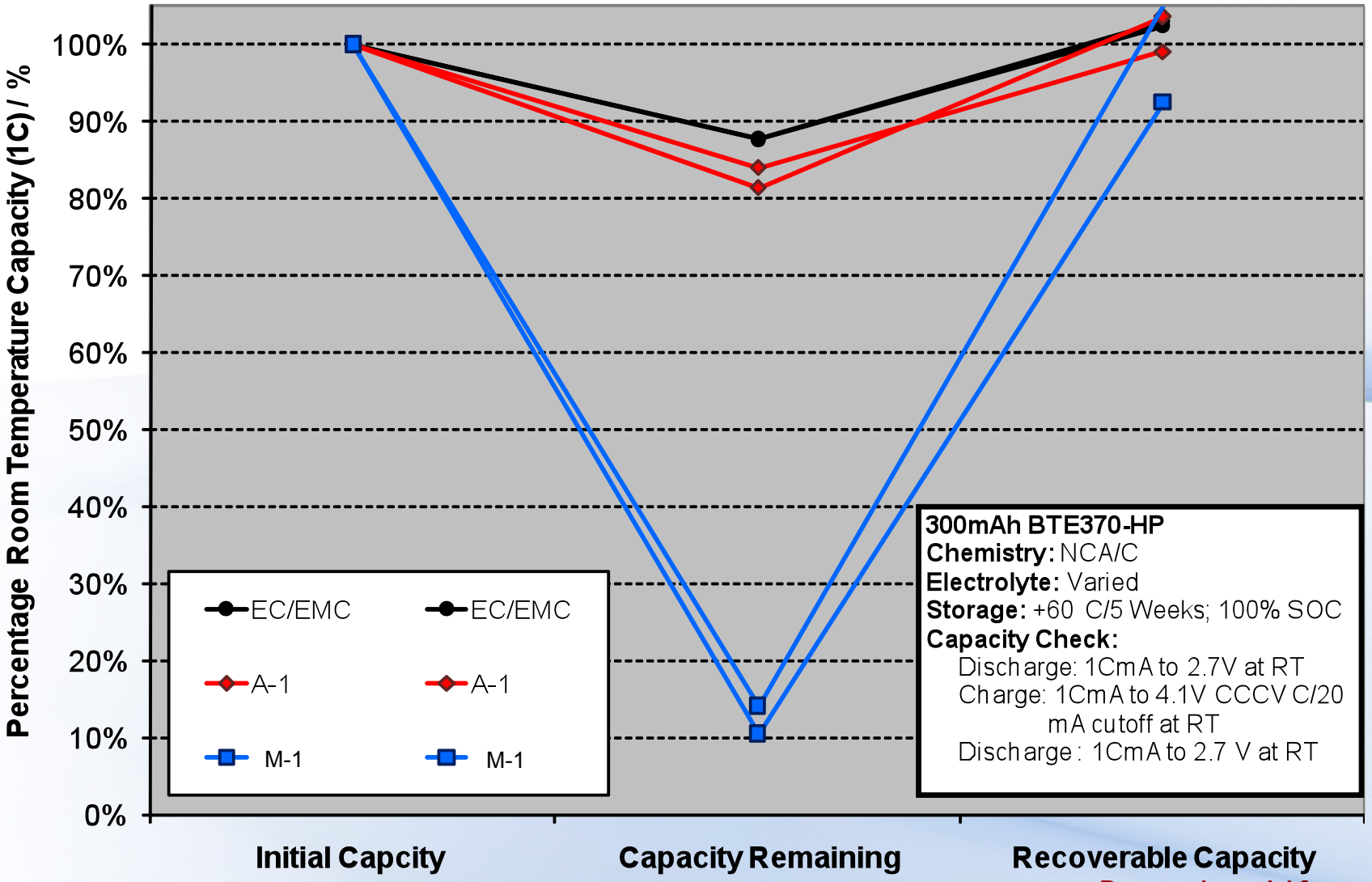
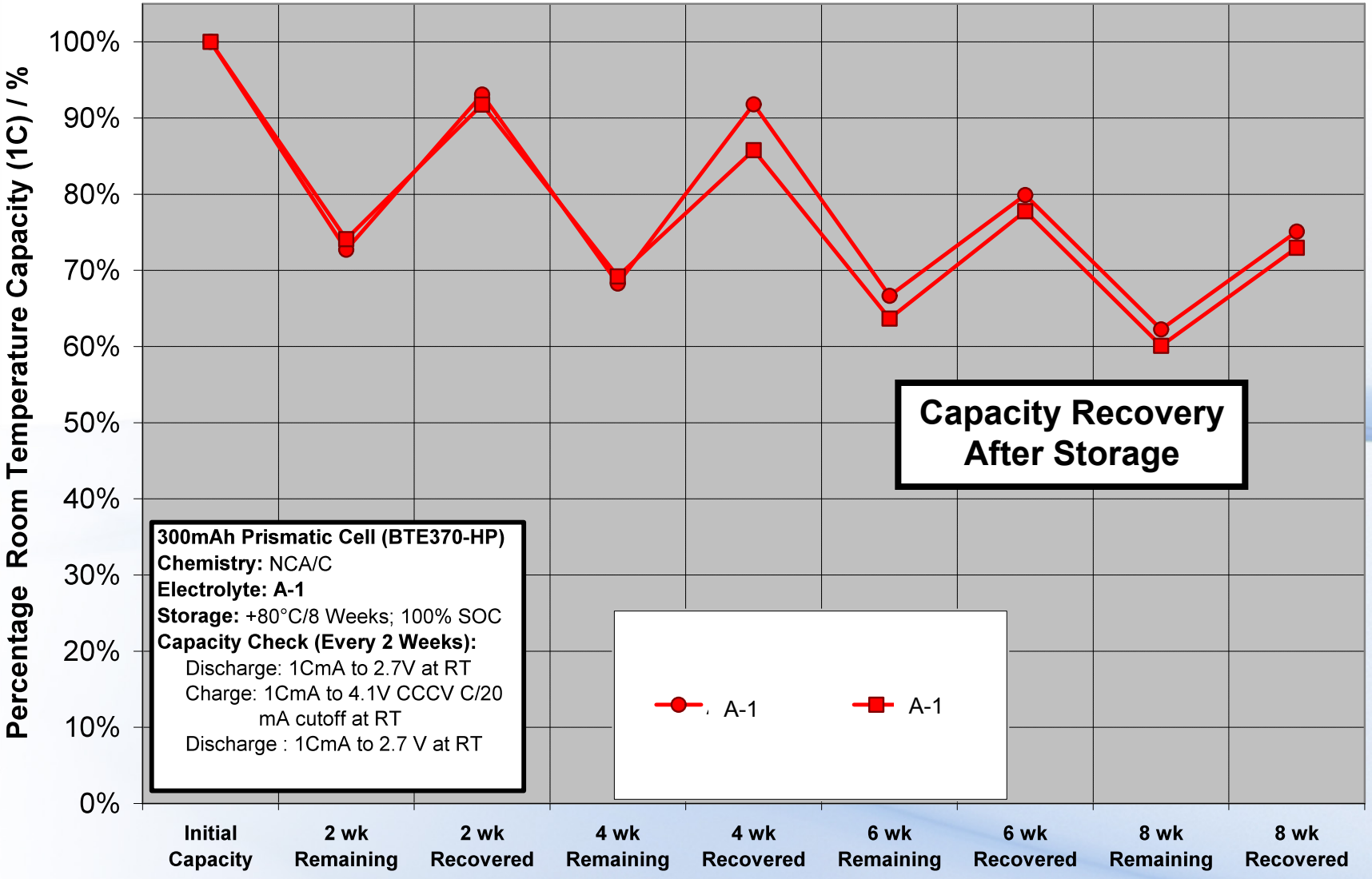
Storage of BTE370-HP Cell at +60°C/5 Weeks & 100% SOC



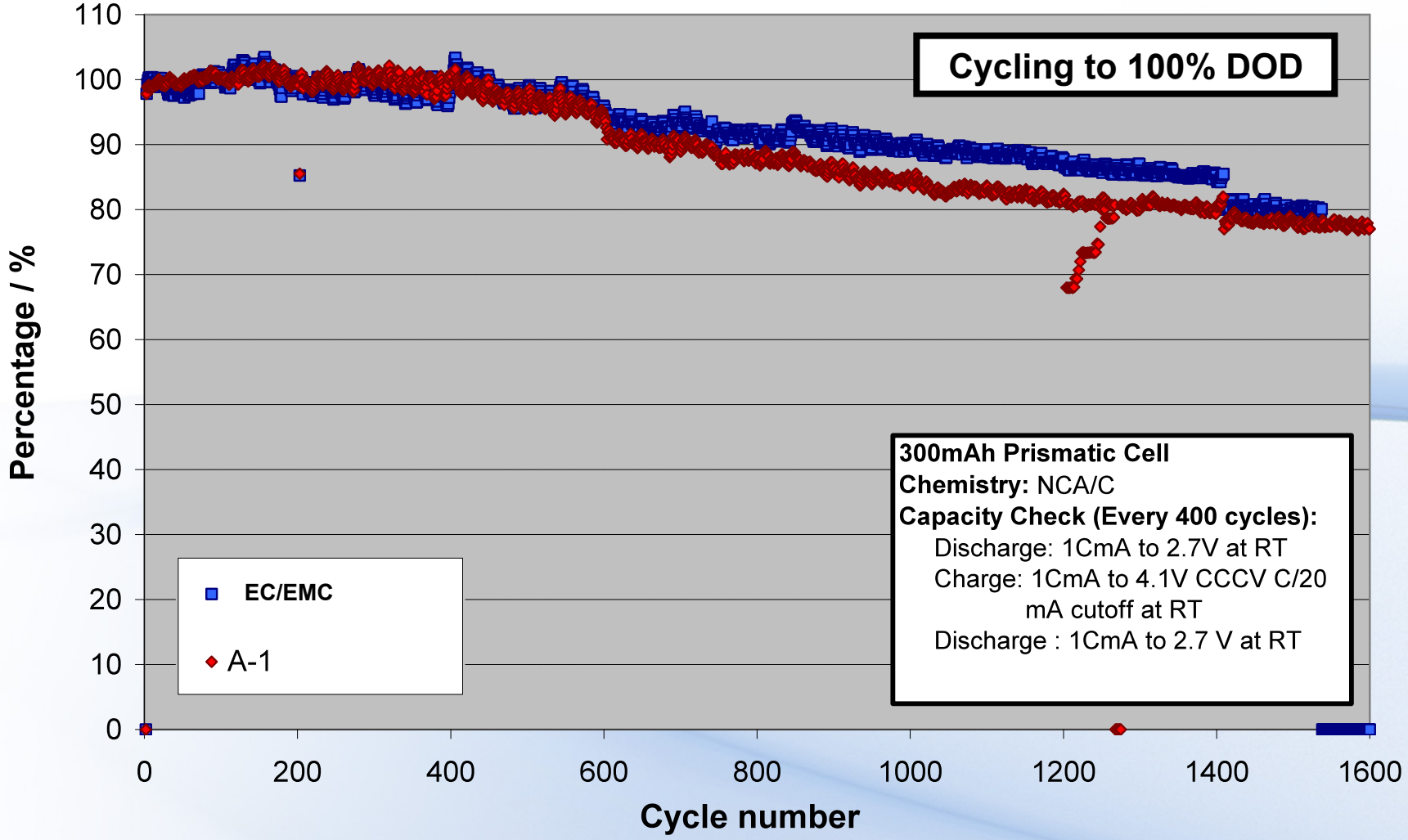
Powering Life.

Storage of BTE370-HP Cell with A-1 at +80°C/8 Weeks & 100% SOC



Powering Life.

1C/5C Charge-Discharge Rate Cycling of BTE370-HP at Room Temperature



Charge : 1.0 CmA, 4.1V CCCV C/20 mA cutoff at RT
Discharge : 5.0 CmA to 2.7 V at RT

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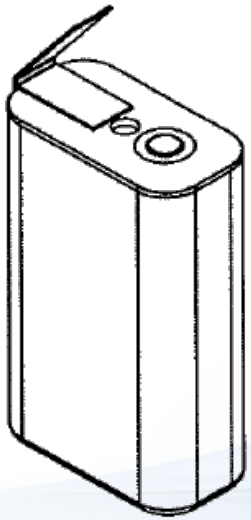
Power-Energy Balance Cell Design

- Same chemistry as baseline cell
- Improved energy density
- Rated up to 5C, with 10-15C possible at room temperature
- Low temperature electrolytes
  - EC/EMC (Control)
  - Quallion low temperature electrolyte A-1
  - Low temperature electrolyte M-1

BTE370-PE Mechanical Design



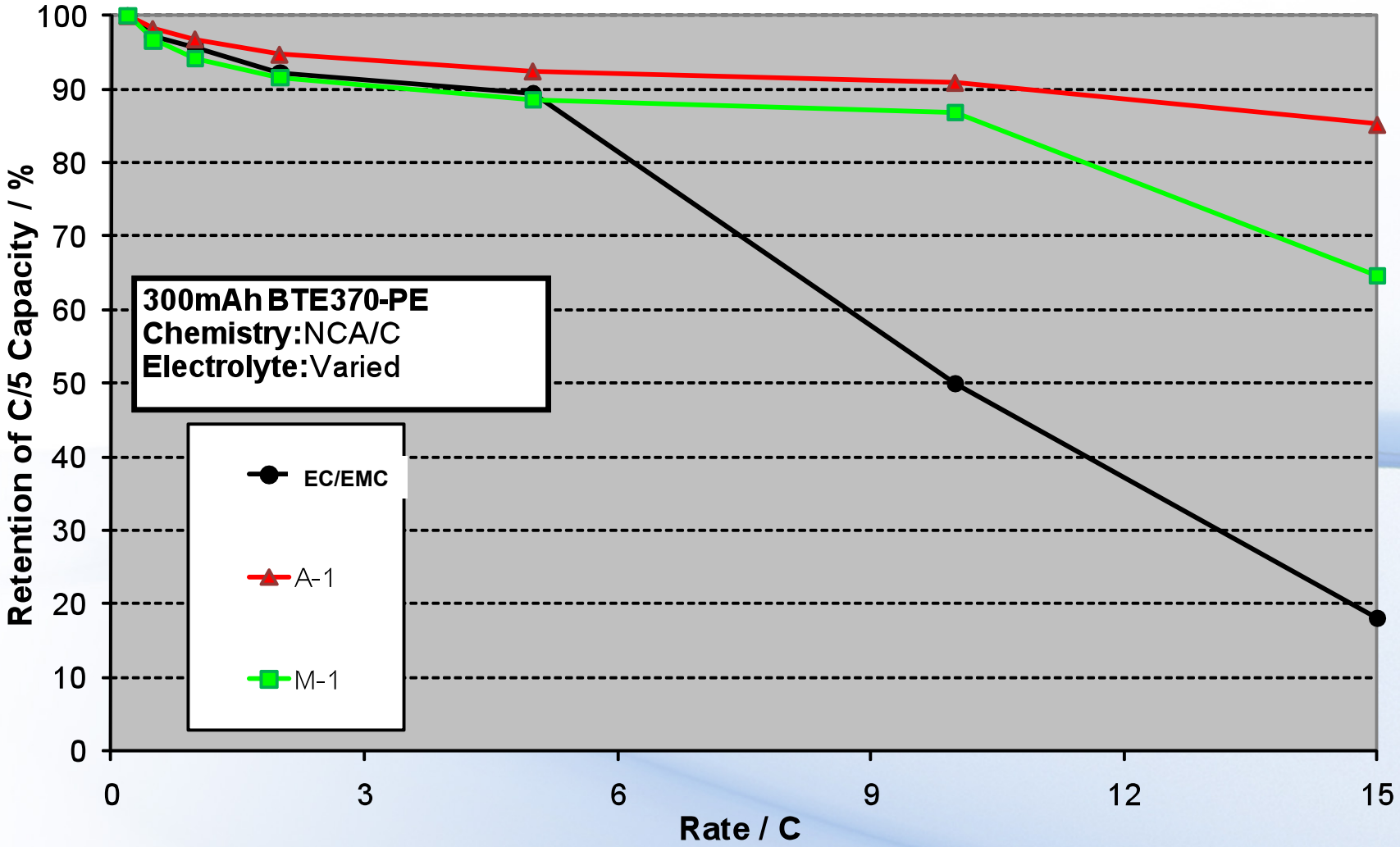
Cell Specifications	
True Capacity / mAh*	325
Energy Density / Wh/kg*	120
Energy Density / Wh/l*	210
Dimensions / mm*	30 x 18 x 10 (H x W x T)
Weight / g*	9.50 ± 0.75

- **Electrical Characteristics**
  - Nominal Capacity = 300 mAh
  - Target Operating Range = -70°C to +85°C
  - Rated for 5C discharge over entire temperature range (10C Possible)
- **Heritage Materials**
  - Active materials are the same as Quallion SATELLITE cells
  - USG T3 program enables Quallion to produce Cathode and Anode materials in-house by 2012

* Designed values

Powering Life.

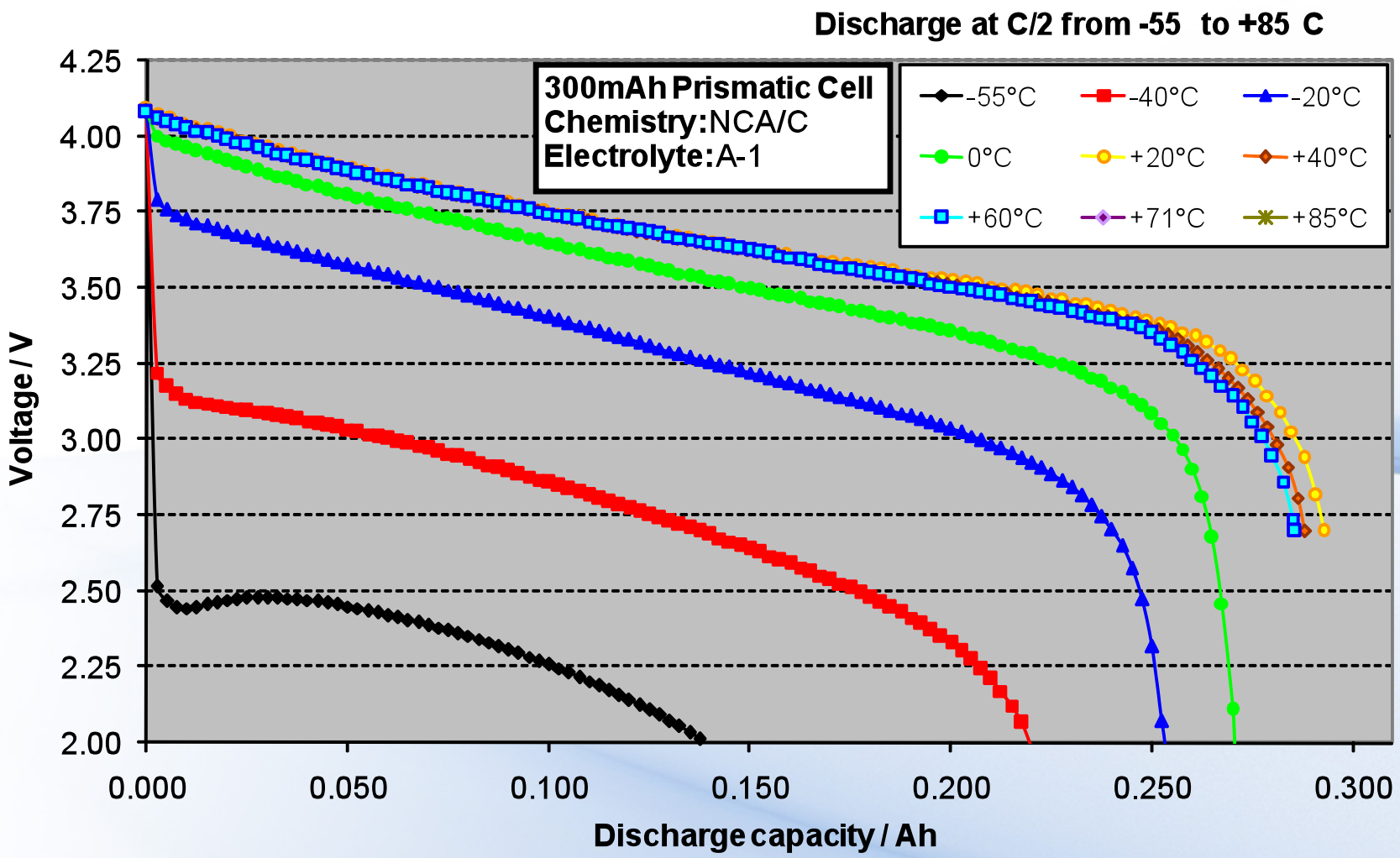
Rate Test Summary for BTE370-PE



Charge : 1.0C mA, 4.1V CCCV C/20 mA cutoff at RT
Discharge : 0.2, 0.5, 1, 2, 5, 10, 15C mA to 2.7 V at RT

Powering Life.

C/2 Discharge Summary for BTE370-PE with A-1 from -40° to +85°C



Charge : 1CmA, 4.1V CCCV C/20 mA cutoff at RT
Discharge : 0.5CmA to 2.0V at -55 , -40 , -20 , & 0 & to 2.7 V at +20 , +40 , +60 , +71 , & +85 C

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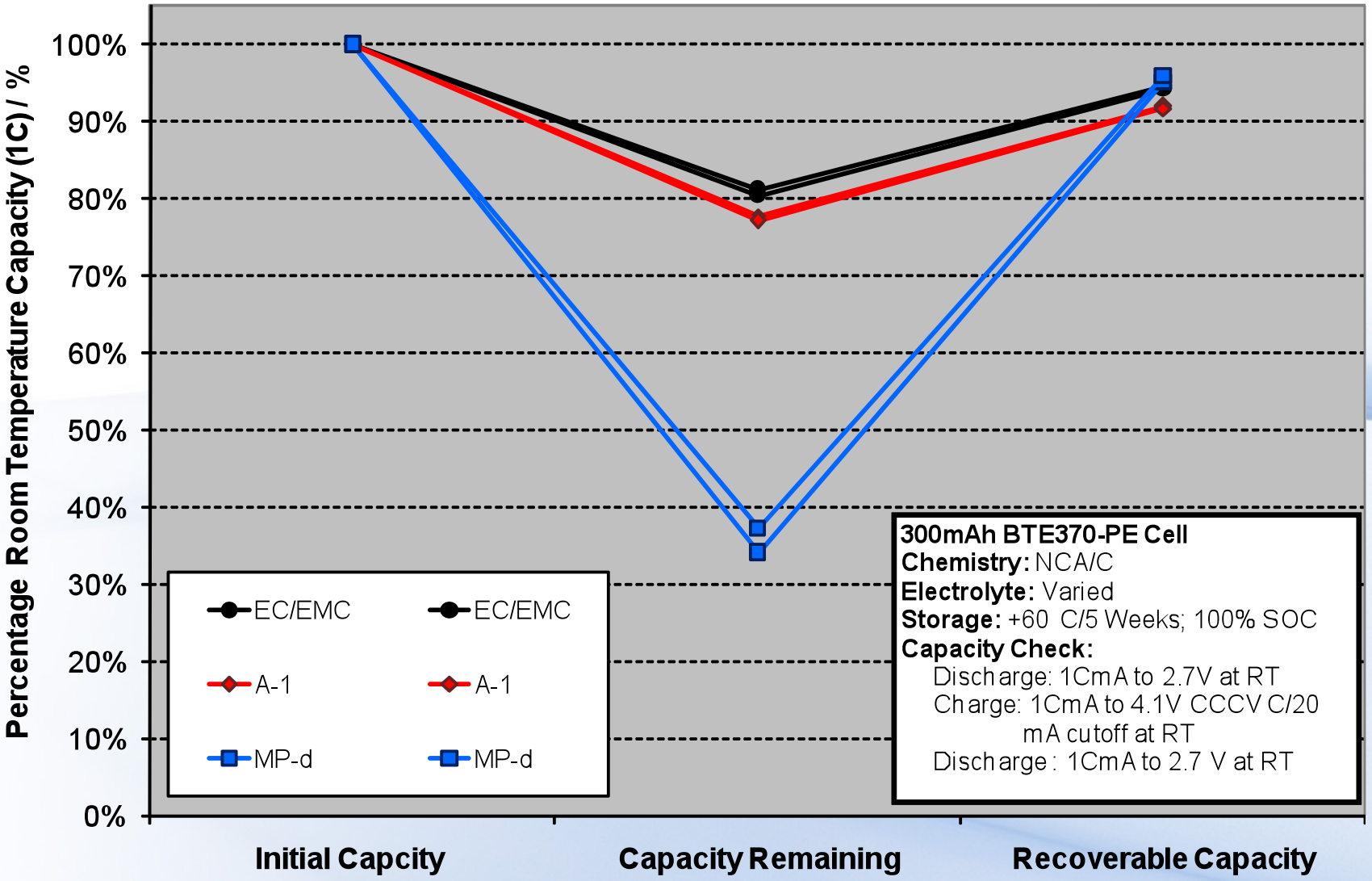
Storage of BTE370-PE Cell at +60°C/5 Weeks & 100% SOC



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18650 High Power Cell Design

- Same chemistry and mechanical parameters as baseline 300mAh cell
- Tunable rate capability based on design
- 30A discharge capability
- Uses Quallion A-1 electrolyte

Quallion Q18650-HP

At -40°C, 30C rate discharge capable

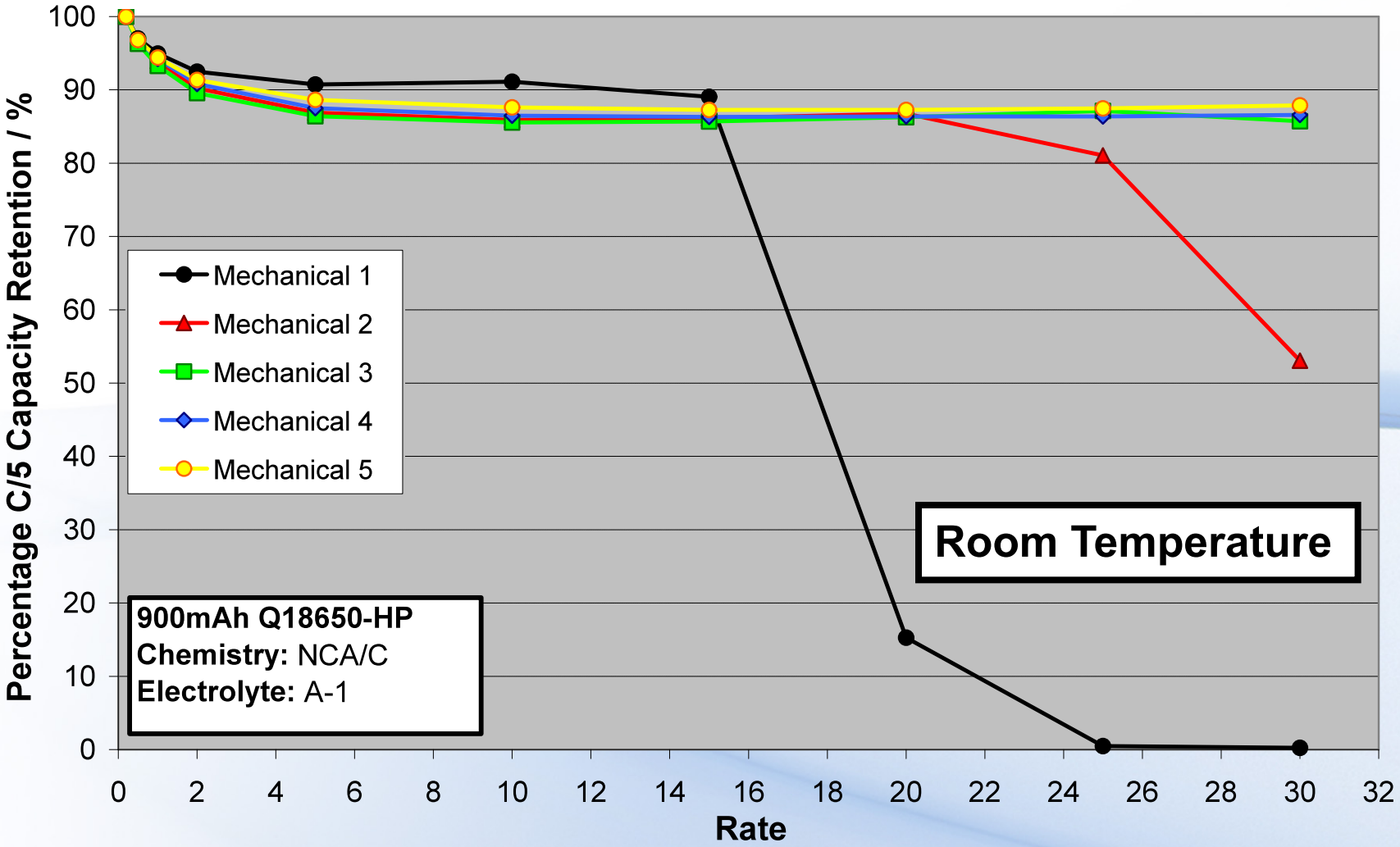
Cell Specifications	
True Capacity / mAh*	1000
Energy Density / Wh/kg*	92
Energy Density / Wh/l*	217
Dimensions / mm	65 x 18 (H x d)
Weight / g*	39 ± 0.75

- **Operating Range =** -40°C to +71°C
- **Heritage Materials**
  - Active materials are the same as Quallion SATELLITE cells

* Calculated values based on design

Powering Life.

Q-18650-HP Mechanical Design Evaluation



Charge : 1.0C A, 4.1V CCCV C/20 mA cutoff at RT
Discharge : 0.2, 0.5, 1, 2, 5, 10, 15, 20, 25, 30C A to 2.7 V at RT

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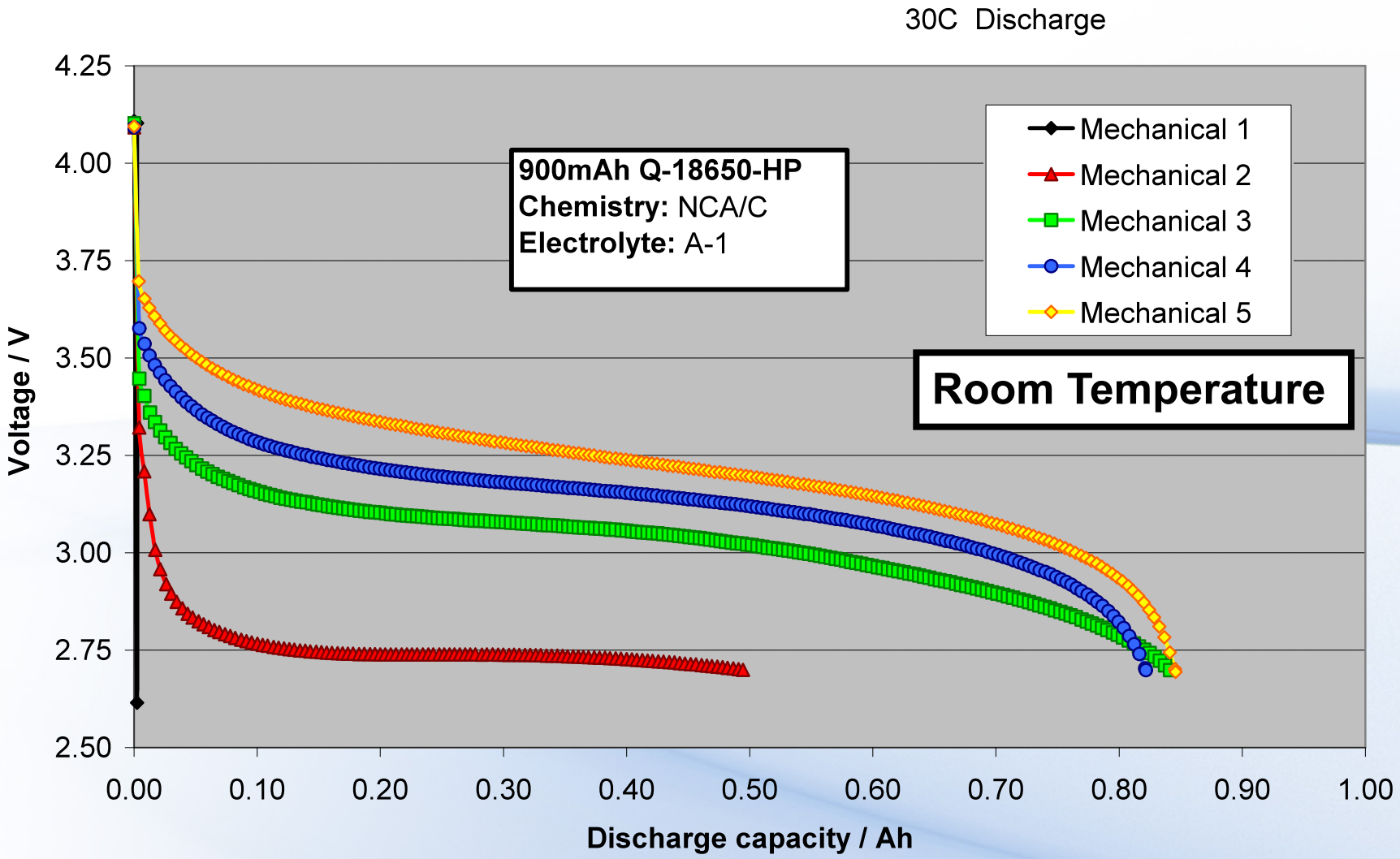
Q-18650-HP Mechanical Evaluation—30A Discharge



Charge : 1.0 CA, 4.1V CCCV C/20 mA cutoff at RT
Discharge : 30 CA to 2.7 V at RT

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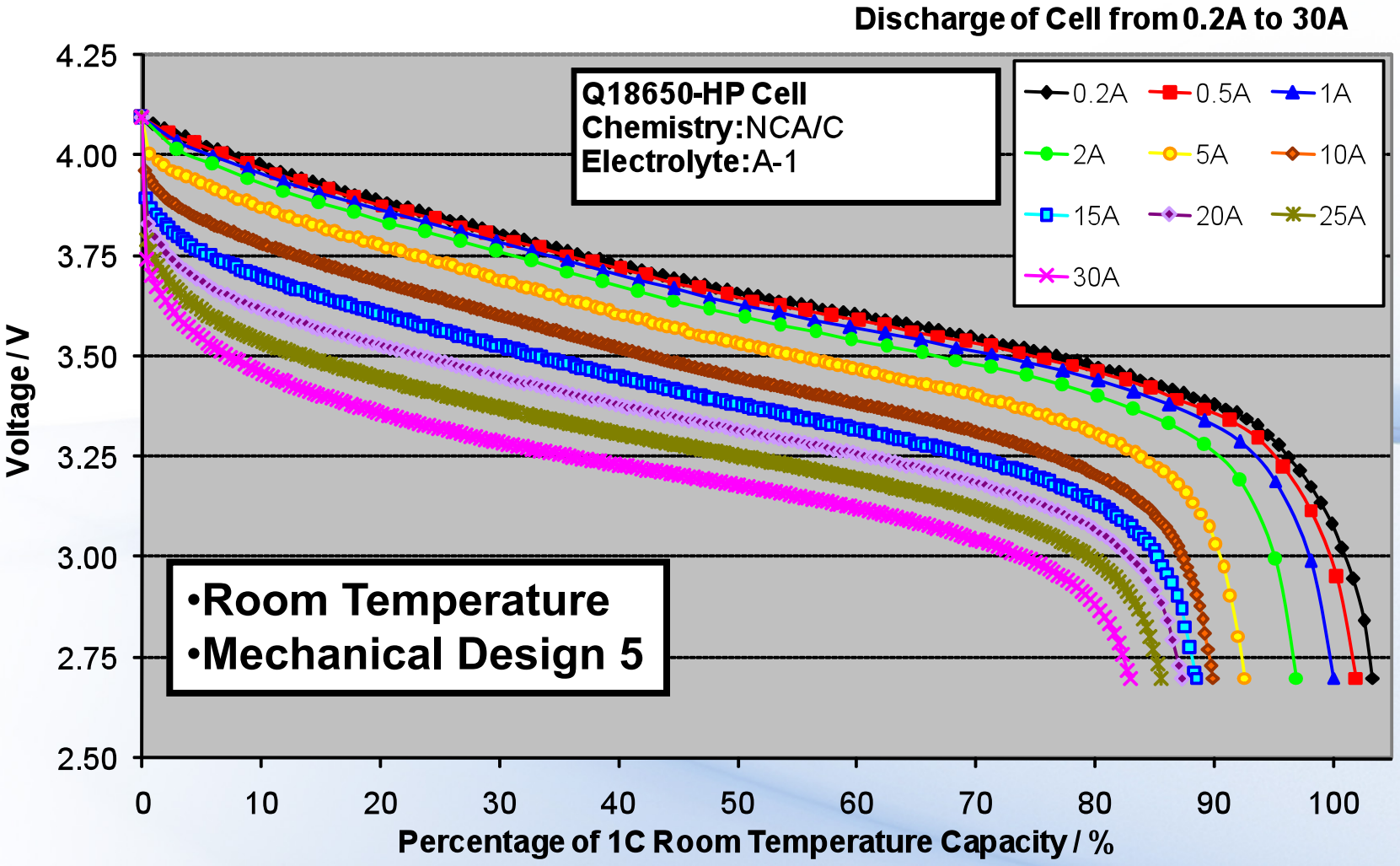
Discharge Rate Data of Quallion HP Cell



Charge : 1.0A, 4.1V CCCV C/20 mA cutoff at RT
Discharge : 0.2, 0.5, 1, 2, 5, 10, 15, 20, 25, 30A to 2.7 V at RT

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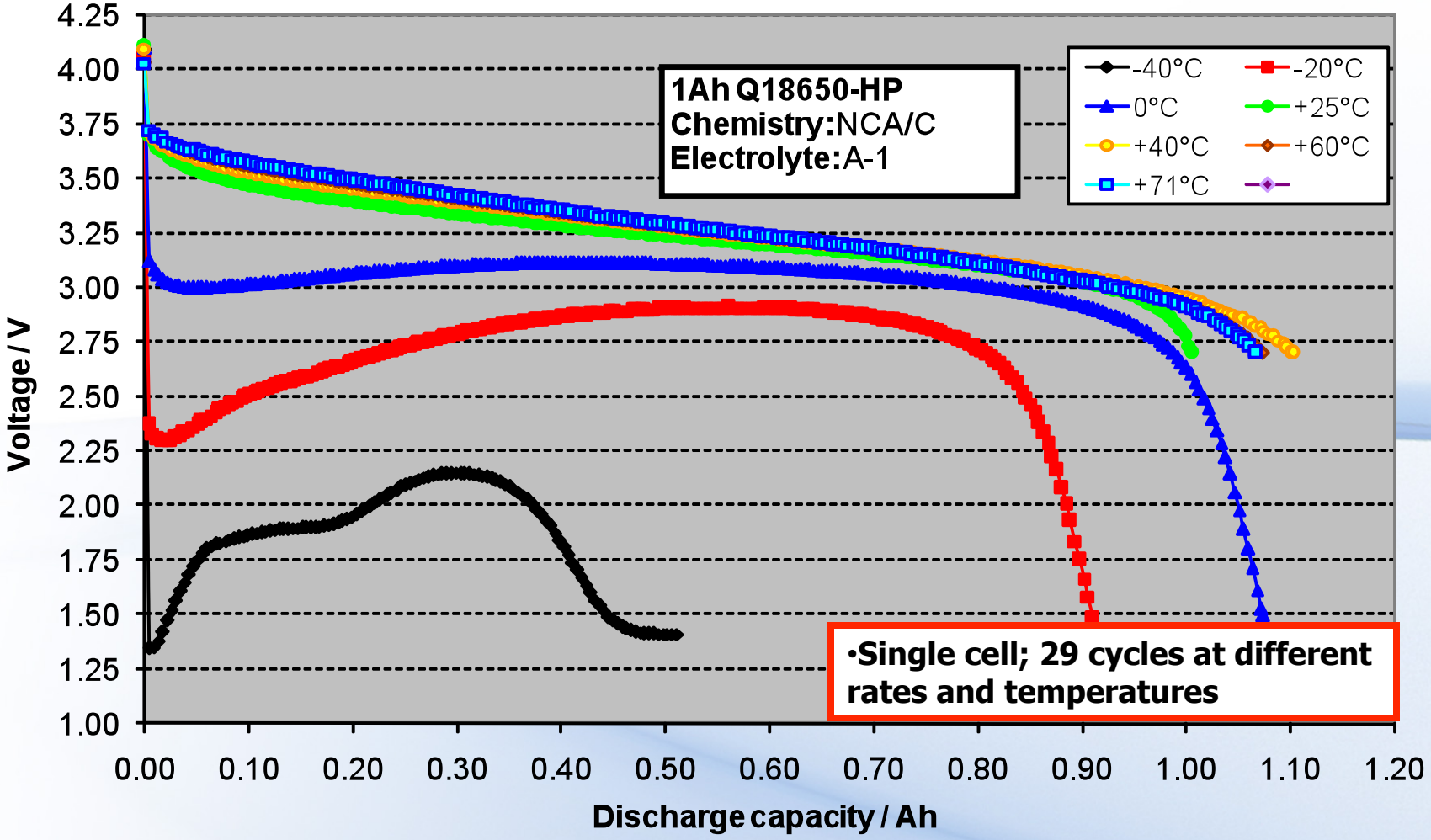
Discharge Temperature Data of Quallion HP Cell at 30C Rate



Charge : 1.0A, 4.1V CCCV C/20 mA cutoff at RT
Discharge : 30CA to 1.5V at -40 , -20 , 0 C or 2.7V at RT, +40 , +60 , and +71 C

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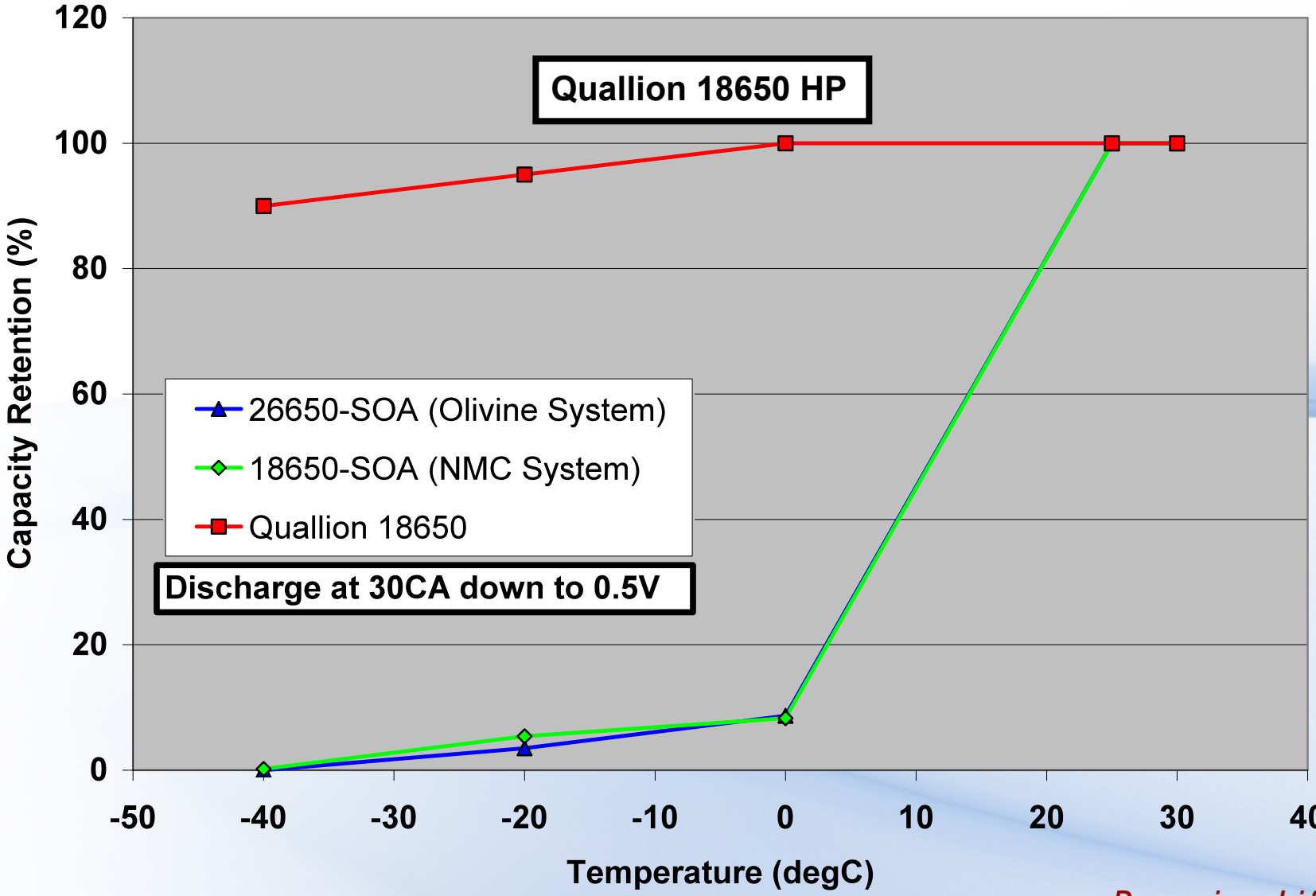
30C Discharge Data Comparison



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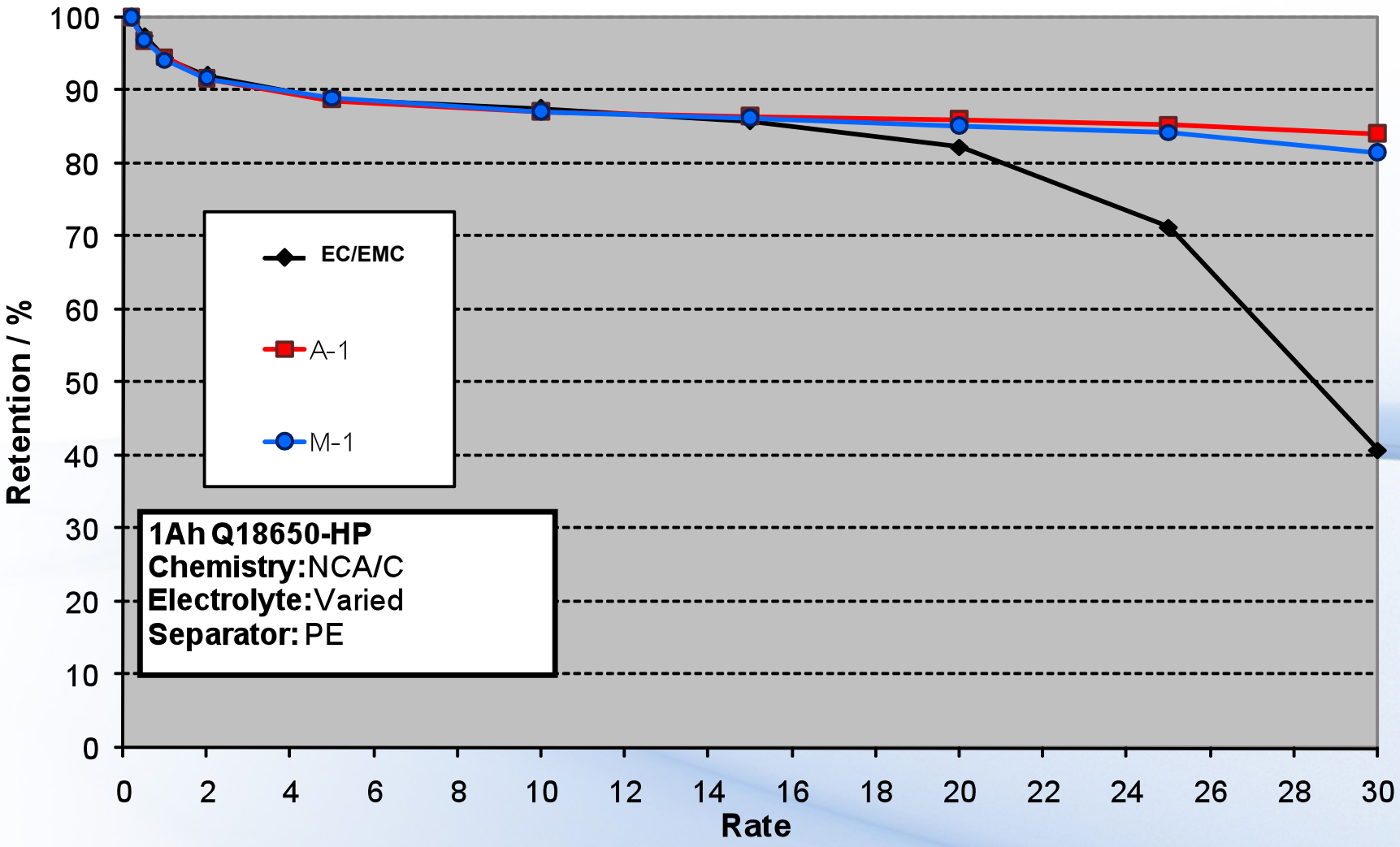
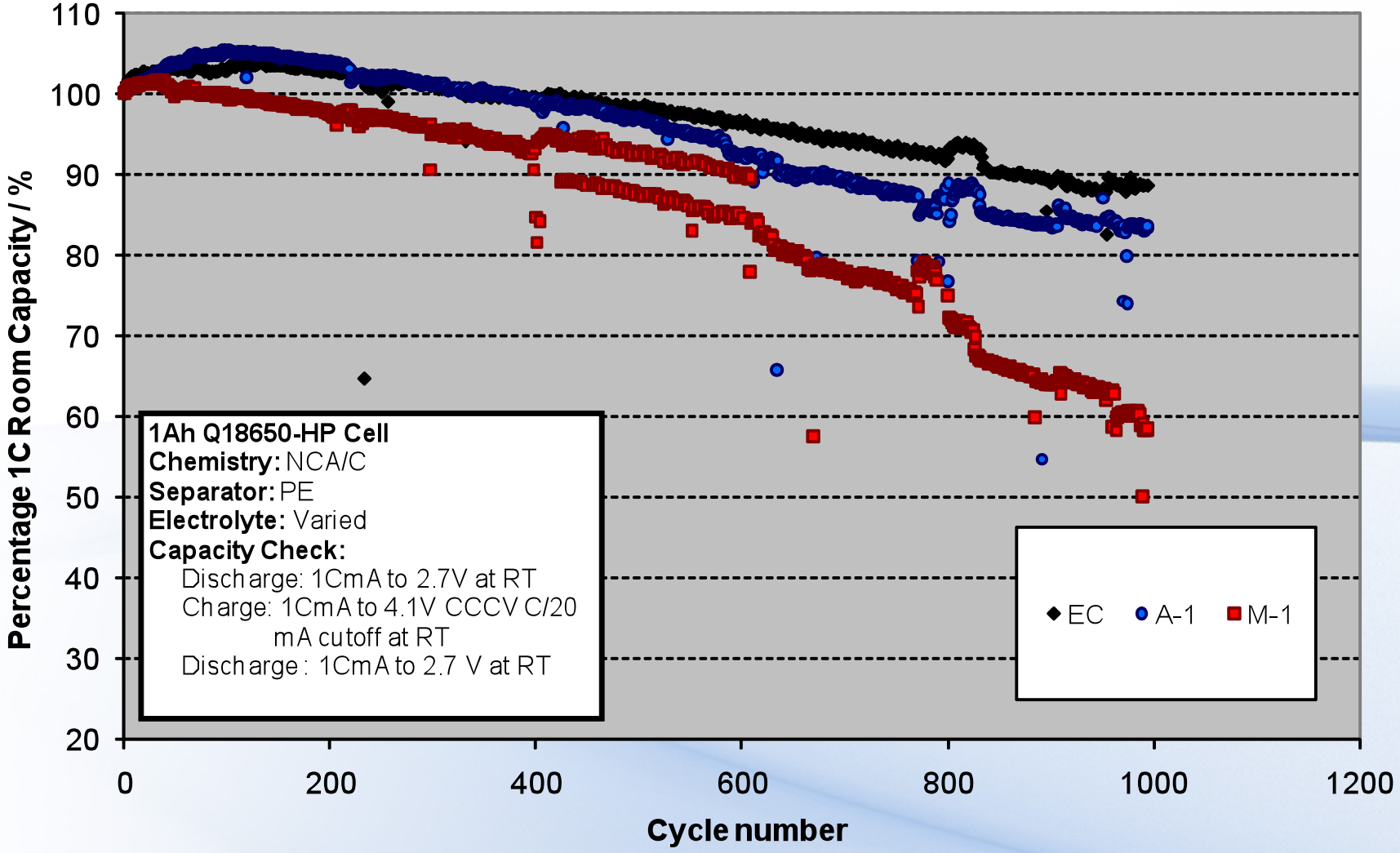
Q18650-HP Electrolyte Evaluation



Charge : 1.0C A, 4.1V CCCV C/20 mA cutoff at RT
Discharge : 0.2, 0.5, 1, 2, 5, 10, 15, 20, 25, 30C A to 2.7 V at RT

Powering Life.

Preliminary 1C-1C Charge-Discharge Cycling of Q18650-HP



Charge: 1 CmA, 4.1V CCCV C/20 mA cutoff at RT
Discharge: 1 CmA to 2.7 V at RT

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Prismatic Cell Design

- Same chemistry as baseline 300mAh cells
- 30C capable discharge
  - 55C possible
- Uses M-1 electrolyte
- Excellent low temperature cycling performance

Prototype Prismatic Cell*

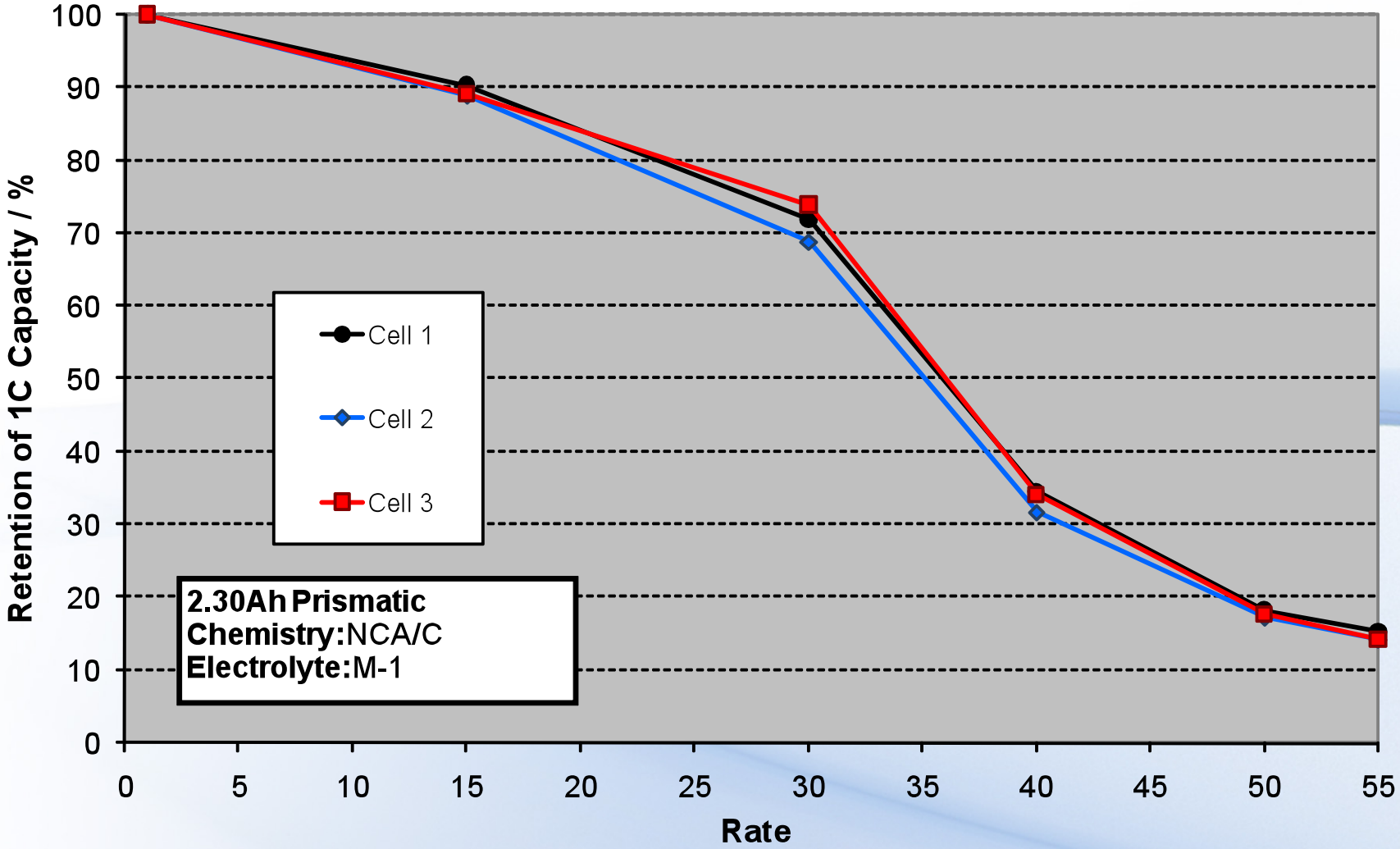
Cell Specifications	
Rated Capacity / mAh*	2300
Energy Density / Wh/kg*	110
Energy Density / Wh/l*	205
Dimensions	5.3 x 2.1 x 0.25 (H x W x T)
Weight / g	75 ± 0.75

- **Operating Range =** -40°C to +70°C
- **Heritage Materials**
  - Active materials are the same as Quallion SATELLITE cells
  - USG T3 program enables Quallion to produce Cathode and Anode material in-house by 2012

* Calculated values based on design

Powering Life.

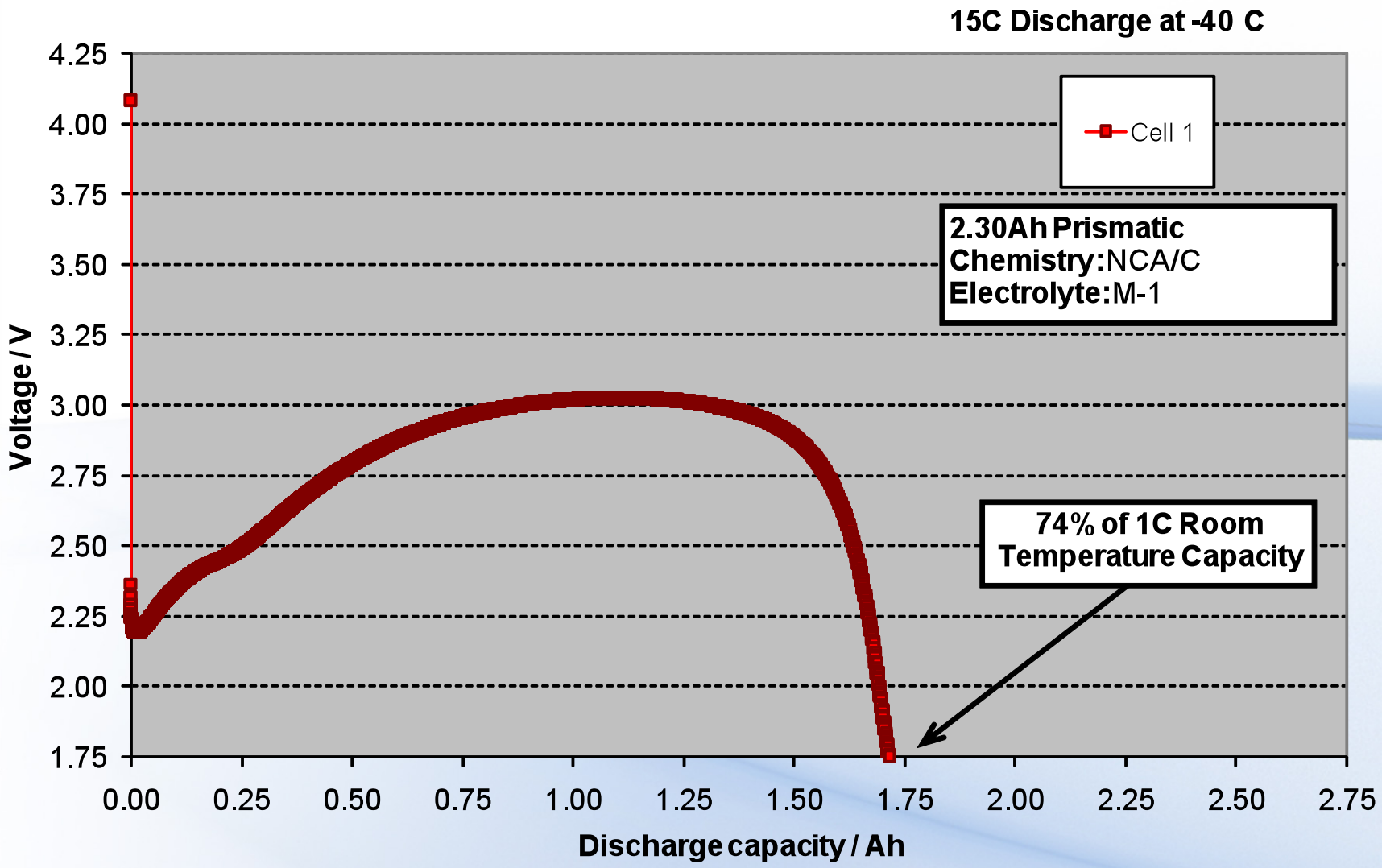
Discharge Rate Summary for Prismatic Cells



Charge : 1.0C A, 4.1V CCCV C/20 mA cutoff at RT
Discharge : 1, 15, 30C A to 2.7 V at RT

Powering Life.

15C Rate Discharge of Prismatic Cell at -40°C



Charge : 1.0C A, 4.1V CCCV C/20 mA cutoff at RT
Discharge : 15C A (32.25A) to 1.0 V at -40 C

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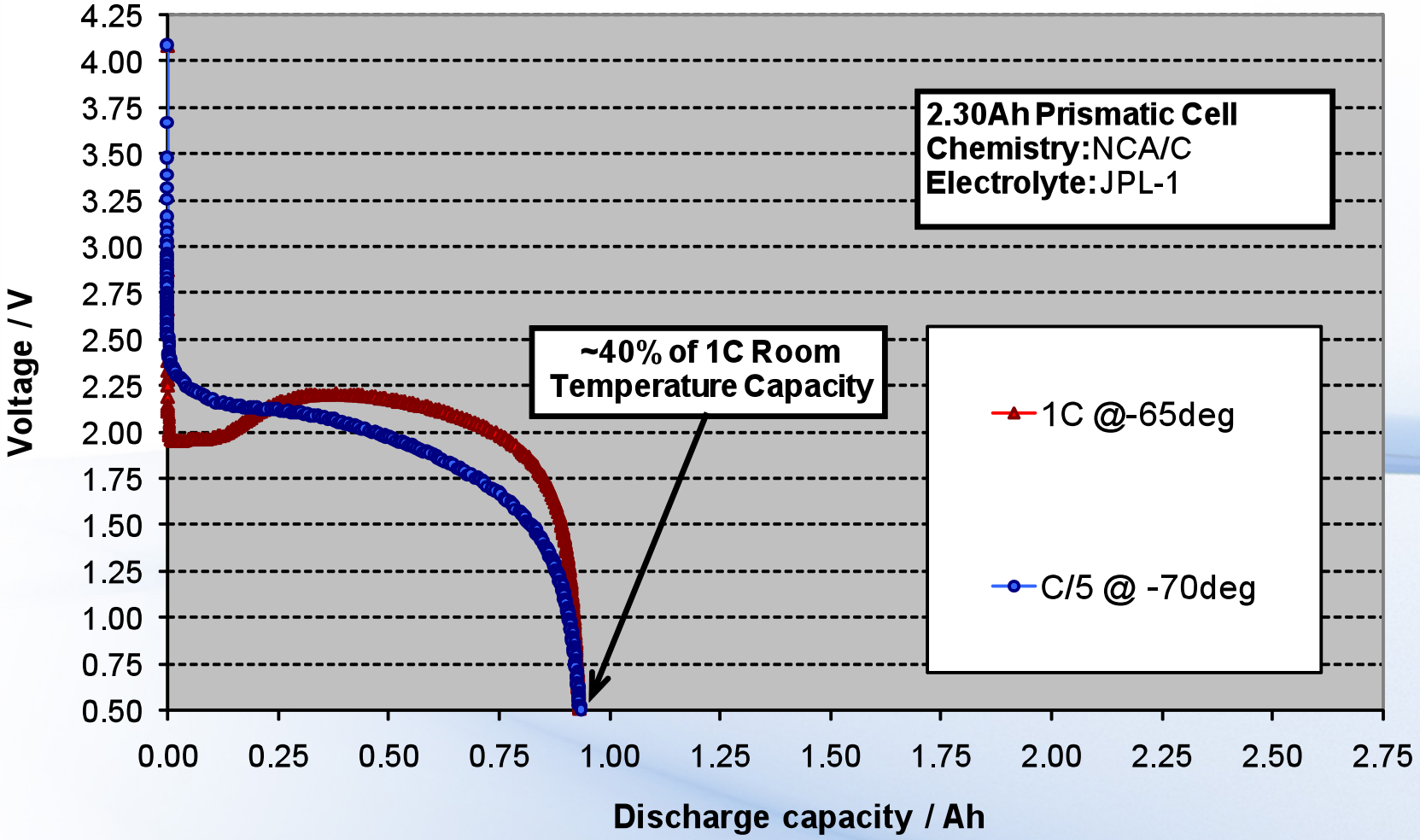
Low Rate Discharge of Prismatic Cell at -65°C & -70°C

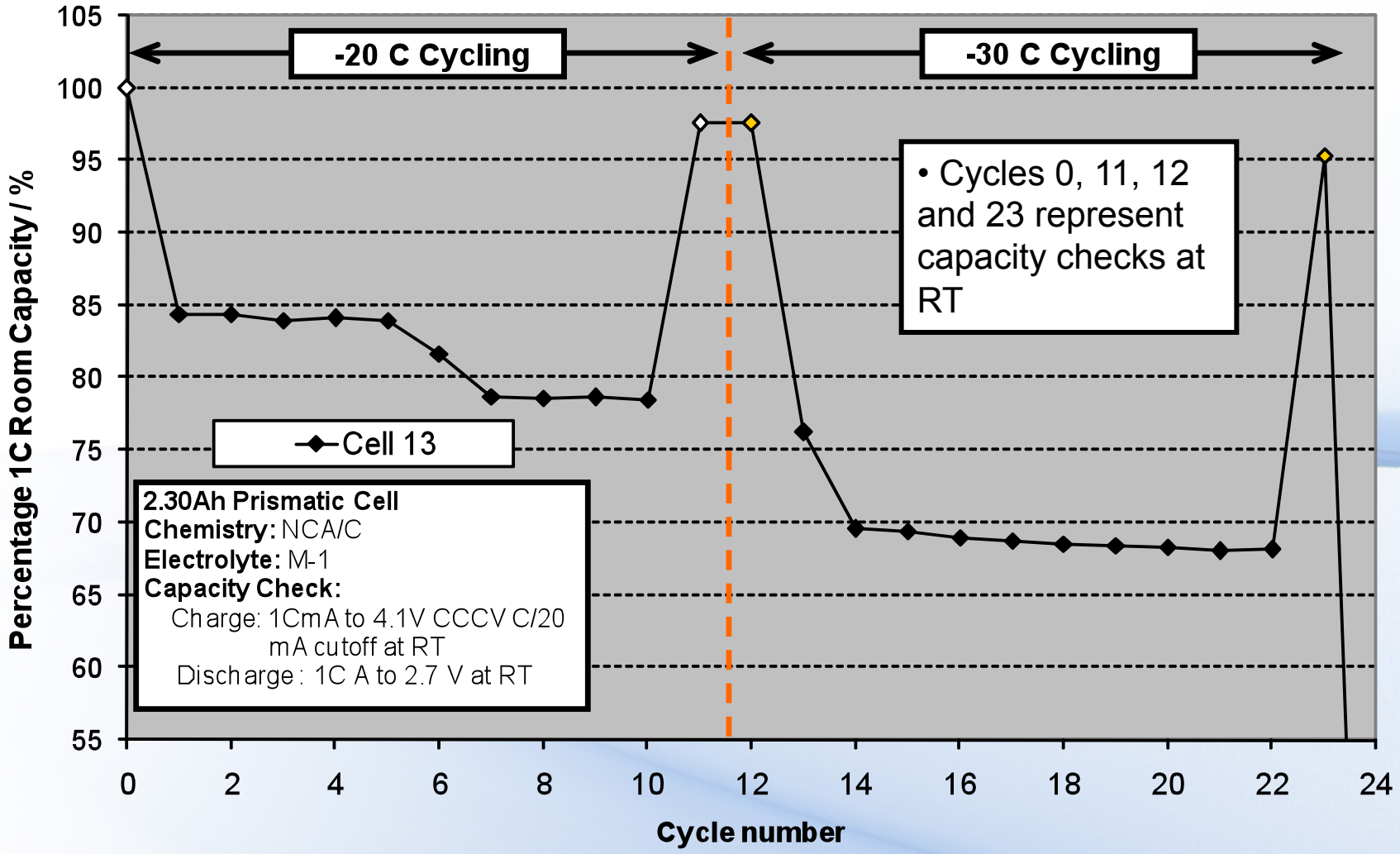


Charge : 1.0C A, 4.1V CCCV C/20 cutoff at RT
Discharge : 1C A to 0.5V at -65 C; C/5 A to 0.5V at -70 C

- **Same cell for both tests; no capacity loss seen**

Powering Life.

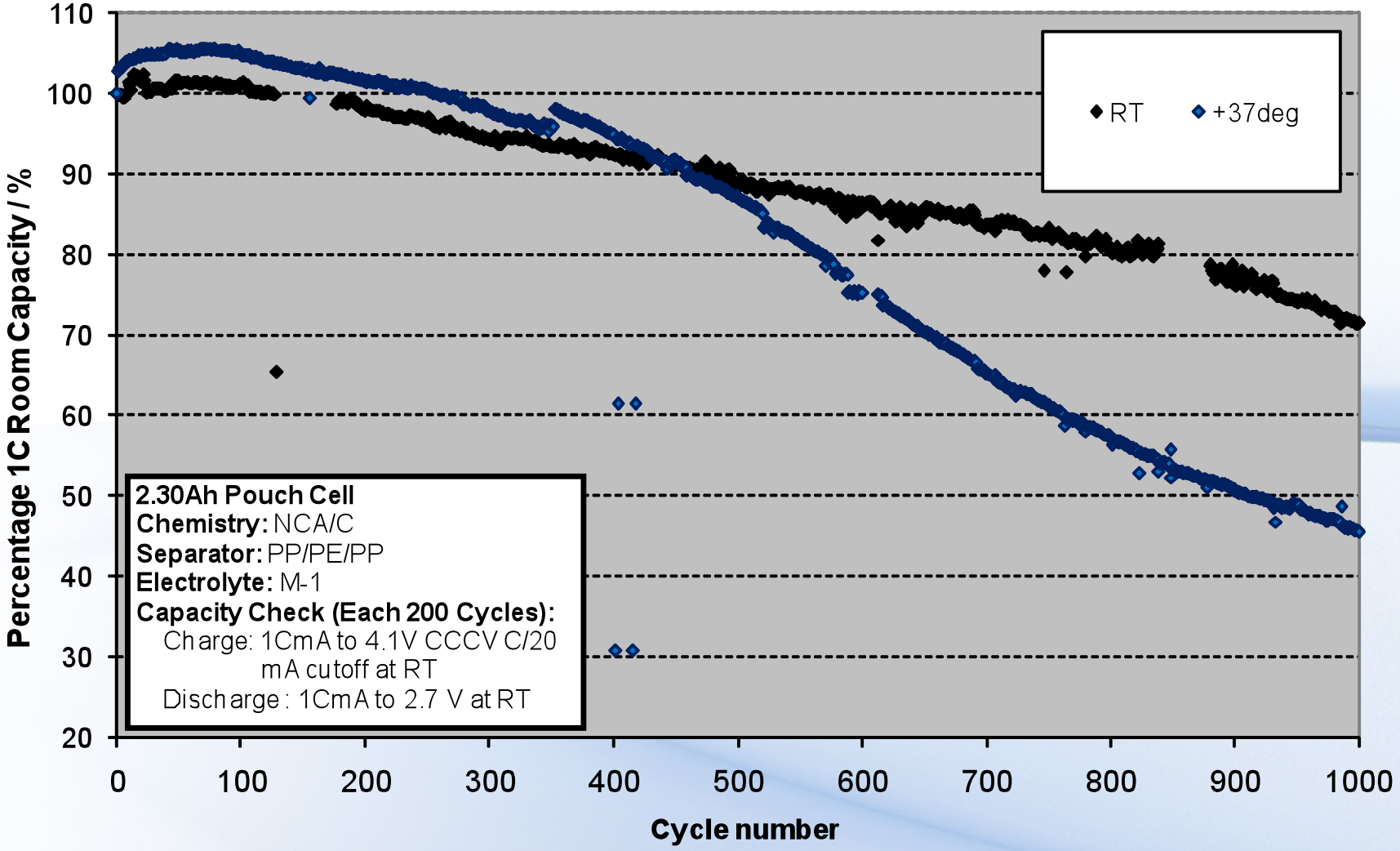
C/2 Charge/Discharge Cycling of Prismatic Cell at -20° & -30°C



Charge : C/2 A, 4.1V CCCV C/50 mA cutoff at -20 & -30 C
Discharge : C/2 A to 2.5 V at -20 & -30 C

Powering Life.

Preliminary 1C-1C Charge-Discharge Cycling Data



Charge : 1 CmA, 4.1V CCCV C/20 mA cutoff at RT
Discharge : 5 CmA to 2.7 V at RT

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Preliminary 15Ah Cell Design

- Same chemistry as baseline cell
- Improved energy density
- Rated up to 5C, with 10-15C possible at room temperature
- Low temperature electrolyte

Quallion 10Ah Cell with Wide Operating Temperature

Cell Specifications	
Theoretical Capacity / mAh*	10000
Energy Density / Wh/kg*	82
Weight / g*	450

- **Operating Range =** -40°C to +71°C
- **Heritage Materials**
  - Active materials are the same as Quallion SATELLITE cells
  - Wide temperature electrolyte
- **5000 DOD 60% to 80% Cycling over Wide Temp Temperature Spectrum**
- **Cell to undergo life testing February 2011**

* Calculated values based on design

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Summary and Future Work

- **Summary**
  - High power 300mAh test cells show wide temperature operating capabilities at high rate, excellent high temperature stability, and excellent cycle life
  - Power-energy hybrid 300mAh test cells show wide temperature operating range and improved high temperature stability while retaining some high rate ability
  - Q18650-HP cells can be “tuned” mechanically to get desired rate and show wide operating temperature ranges at high rate
  - 2.3Ah Prismatic cells show high rate capability and excellent low temperature stability
- **Future Work**
  - Improve high temperature storage performance through additives and alternative co-solvents
  - Analyze 300mAh test cells with improved anode and cathode chemistries
  - Design and preparation of larger form factor cells

Electrolyte Development and Testing Acknowledgements

- NASA Phase II SBIR Contract No. NNX09CA85C
  - NASA/JPL-TPOC's
    - Ratnakumar Bugga
    - Marshall Smart

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