Moli Li-ion Performance & Safety Evaluation

Test Facility: JSC Energy Systems Test Area (ESTA)

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Outline

- Cell Information
- Test Program Details
- Performance Test Results and Observations
- Safety Test Results and Observations
- Conclusions

Background

- Cell Information
  - Moli Energy 2.9Ah 26700 Li-Ion Cylindrical Cell
  - Energy Density of 285Wh/l (110Wh/kg)
  - High Rate Cells (over 5C rating)
- Objective
  - Assess Performance and Safety Characteristics of the Cells
  - Assess the High Rate Capability of the Cells

Moli Cell Test Program

- Performance Tests
  - **Rate Capability**
  - **Effective Internal Resistance**
  - Performance Capability at Various Temperatures
  - **Vacuum Leak Test**
  - Vent and Burst Pressure Test
- Safety Tests
  - **Overcharge Test**
  - **Over-discharge Test**
  - **High-Temperature Exposure and Heat-to-Vent Test**
  - **Internal Short-Circuit Test**
  - **External Short-Circuit Test**
- Electrolyte and Electrode Analysis Tests
  - Gas chromatography (GC) and Inductively Coupled Plasma (ICP)
  - Scanning Electron Microscopy (SEM)

BOLD: Tests which have been performed

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Rate Capability

- Test Objectives:
  - To observe how cells perform at various rates of charge and discharge
  - To determine the maximum rate of discharge and assess performance at this rate

Reduction in Capacity vs. Nominal Rates

Rate Number and Current Rates	Average Initial Capacity (Ah)	Ending average Capacity (200)	Reduction of Capacity (Ah)	% Reduction in Capacity
1 – 2.9 A Chg, 2.9 A Discharge	2.62	2.46	0.16	6.11
2 – 2.9 A Chg, 2.175 A Discharge	2.63	2.49	0.14	5.32
3 – 2.9 A Chg, 1.45 A Discharge	2.62	2.48	0.14	5.34
4 – 2.175 A Chg, 2.9 A Discharge	2.61	2.47	0.14	5.36
5 – 2.175 A Chg, 2.175 A Discharge	2.60	2.47	0.13	5.0
6 – 2.175 A Chg, 1.45 A Discharge	2.57	2.46	0.11	4.28
7 – 1.45 A Chg, 2.9 A Discharge	2.61	2.46	0.15	5.75
8 – 1.45 A Chg, 2.175 A Discharge	2.60	2.55	0.05	1.92

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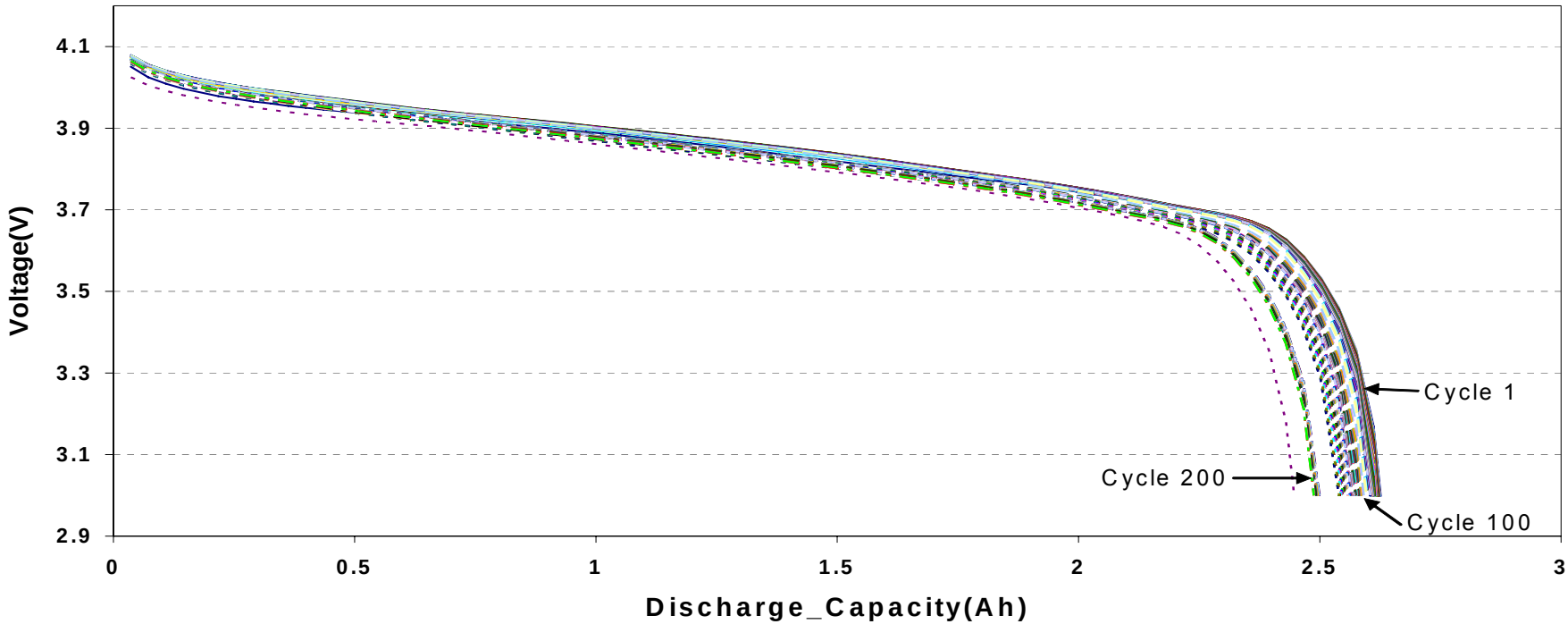
Rate Capability

Rate 2 (2.9A Charge/ 2.175A Discharge)
Voltage vs. Discharge Capacity



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Performance at High Rates of Discharge

- Discharge Rates: 30A, 25A, 23A, and 22A
  - The cell exceeded 45°C for all rates
- 1 Cell was cycled 2 times using a discharge rate of 30A with no safety cut-off
  - Average Discharge Capacity: 2.33Ah
  - Temperature reached 52.77°C
- 20A Rate:
  - Cell was cycled 104 times w/o exceeding 45°C
  - Average discharge capacity: 2.44Ah
  - Average reduction in capacity: 0.12Ah
- 15A Rate:
  - Cell was cycled 105 times w/o exceeding 45°C
  - Average discharge capacity: 2.49Ah
  - Average reduction in capacity: 0.13Ah

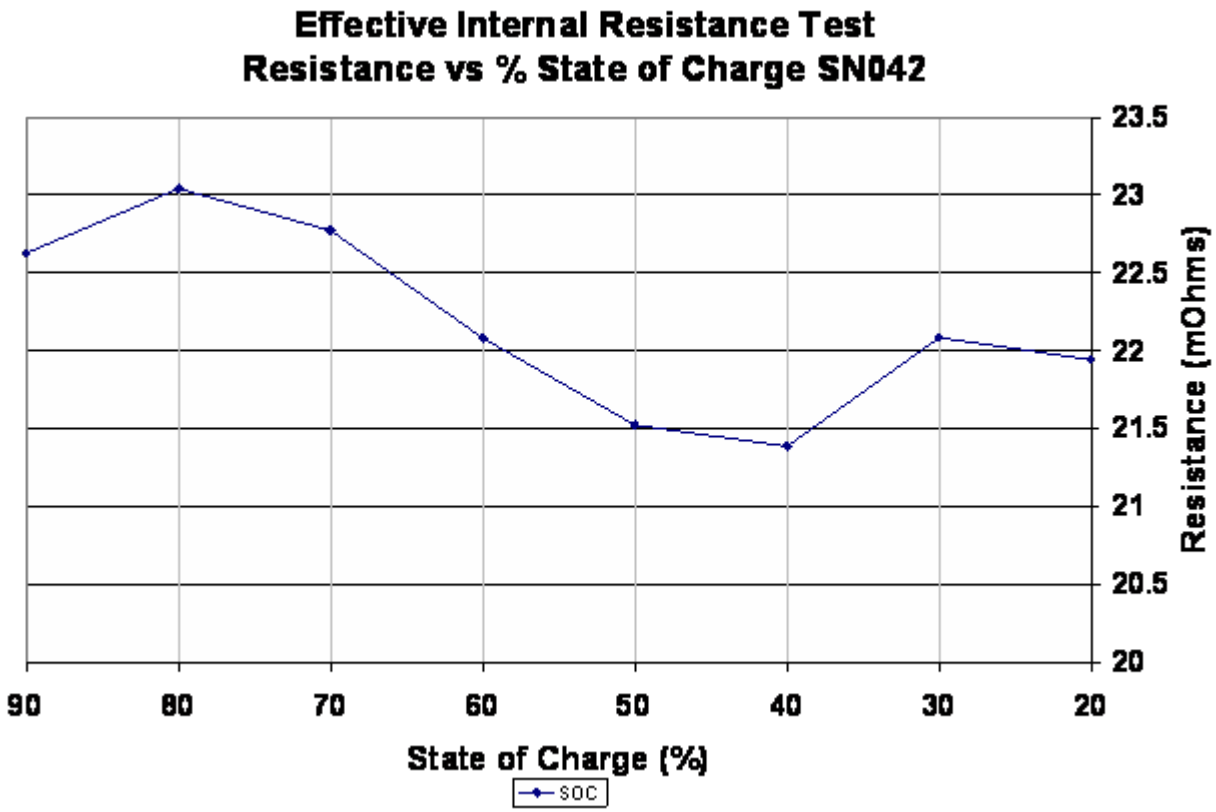
Effective Internal Resistance

- Test Objectives:
  - To determine the effective internal resistance of the cells at various SOC

Overall Effective Internal Resistance Observations

- Highest R_e observed: 23mΩ
- Lowest R_e observed: 20.75mΩ
- 2 cells behaved unexpectedly
  - Intervals of R_e spikes and decrements
- 2 cells have somewhat of a bowl shape

Effective Internal Resistance at Various SOC



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Vacuum Leak

- Test Objectives:
  - To observe how cells behave under vacuum conditions
  - To assess capacity or electrolyte loss after exposure to vacuum testing
- Cell Reaction: NONE
- Average Weight Loss: 0.075g
- Average Capacity Loss: 0.0575Ah

Overcharge

- Test Objectives:
  - To observe how tolerant cells are to overcharge and high rates of charge

Overcharge Test Profiles

Profile Number	Charge Profile
1	C/2 to 4.5V; CV for 2hours; C/2 to 5V; CV for 12hours
2	C/2 to 12V for 4hours
3	C/4 to 12V for 4hours
4	1C to 12V for 2hours
5	2C to 12V for 50minutes
6	3C to 4.2V then CV until I=50mA

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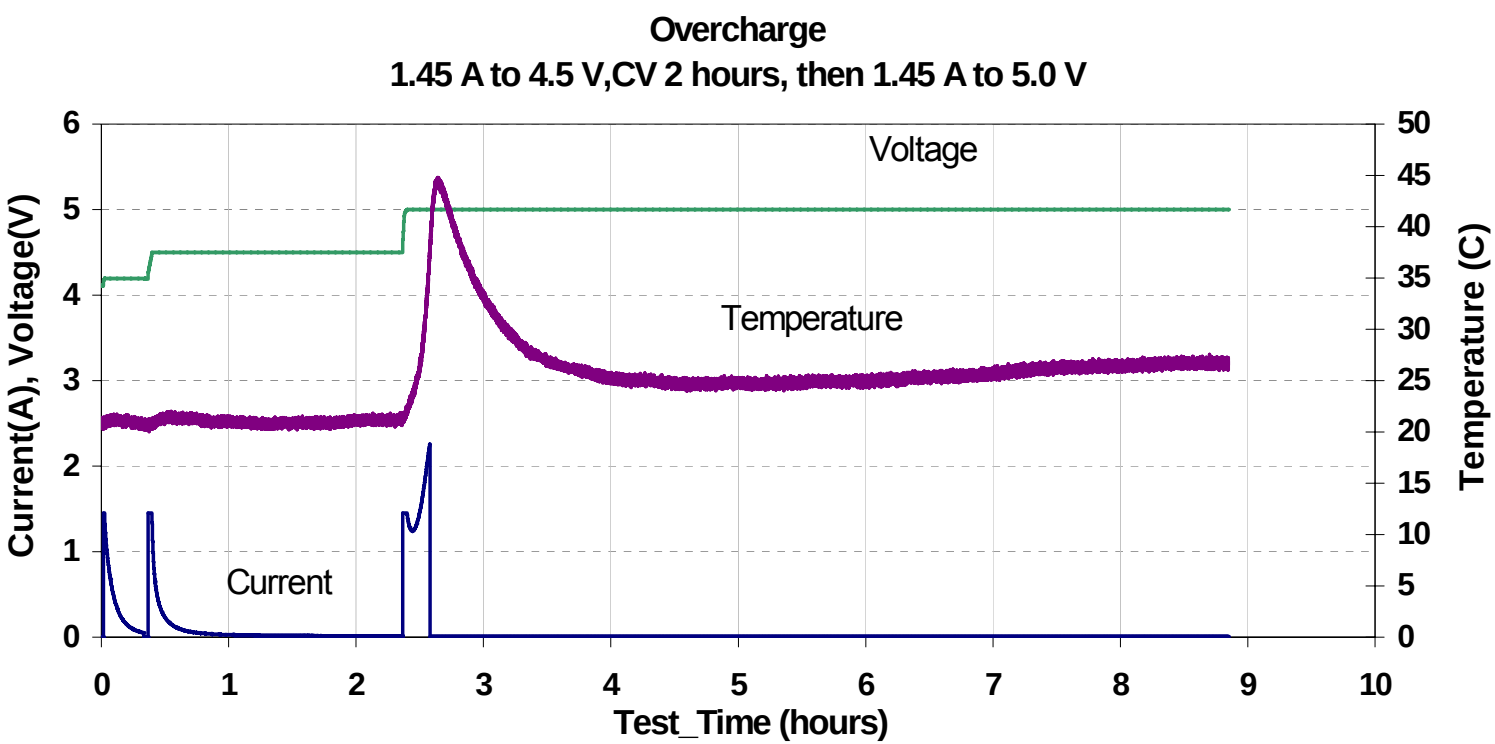
Overcharge Profile 1 (hold at 5V)



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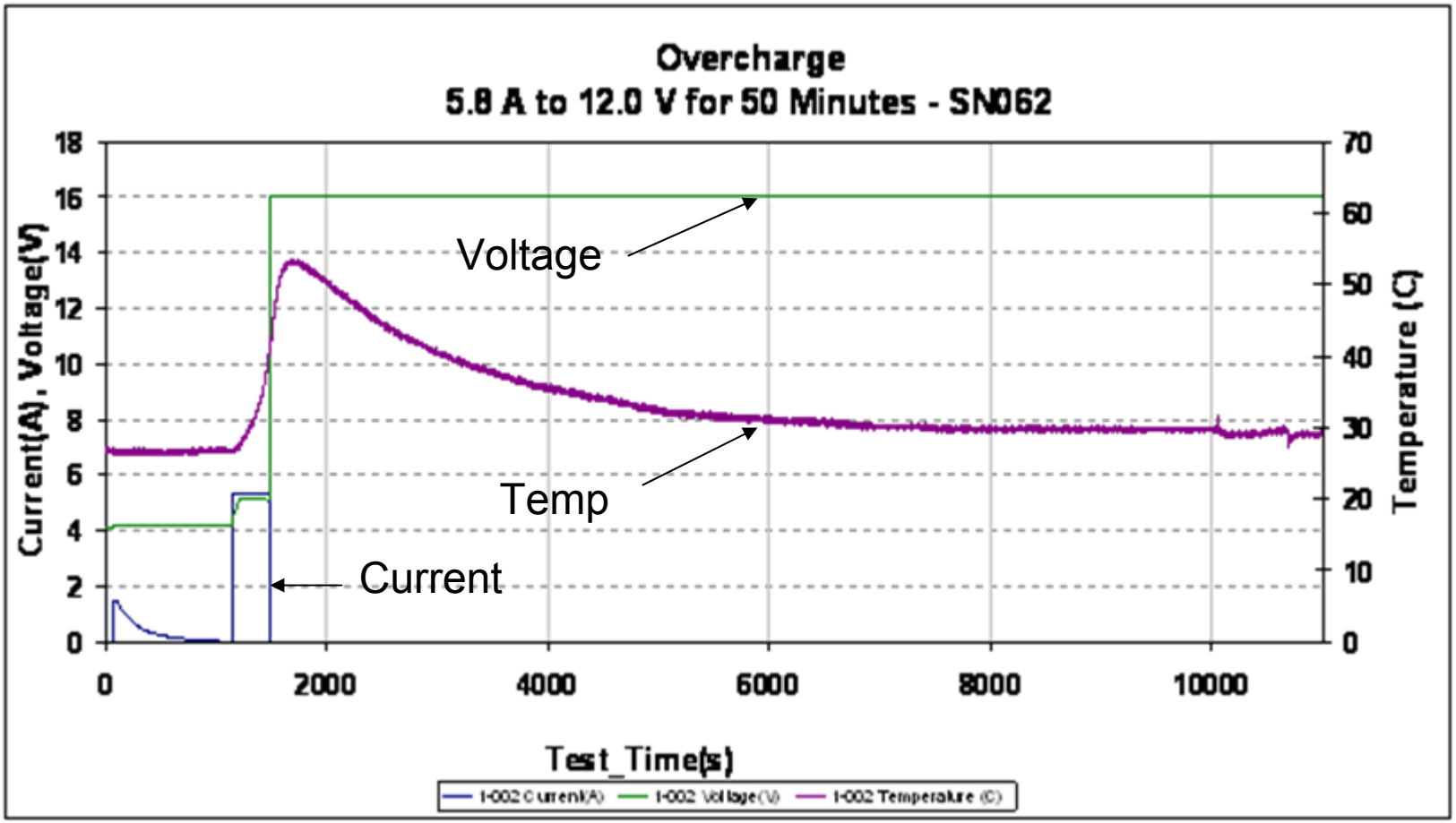
Overcharge Profile 4 (Charge to 12V)



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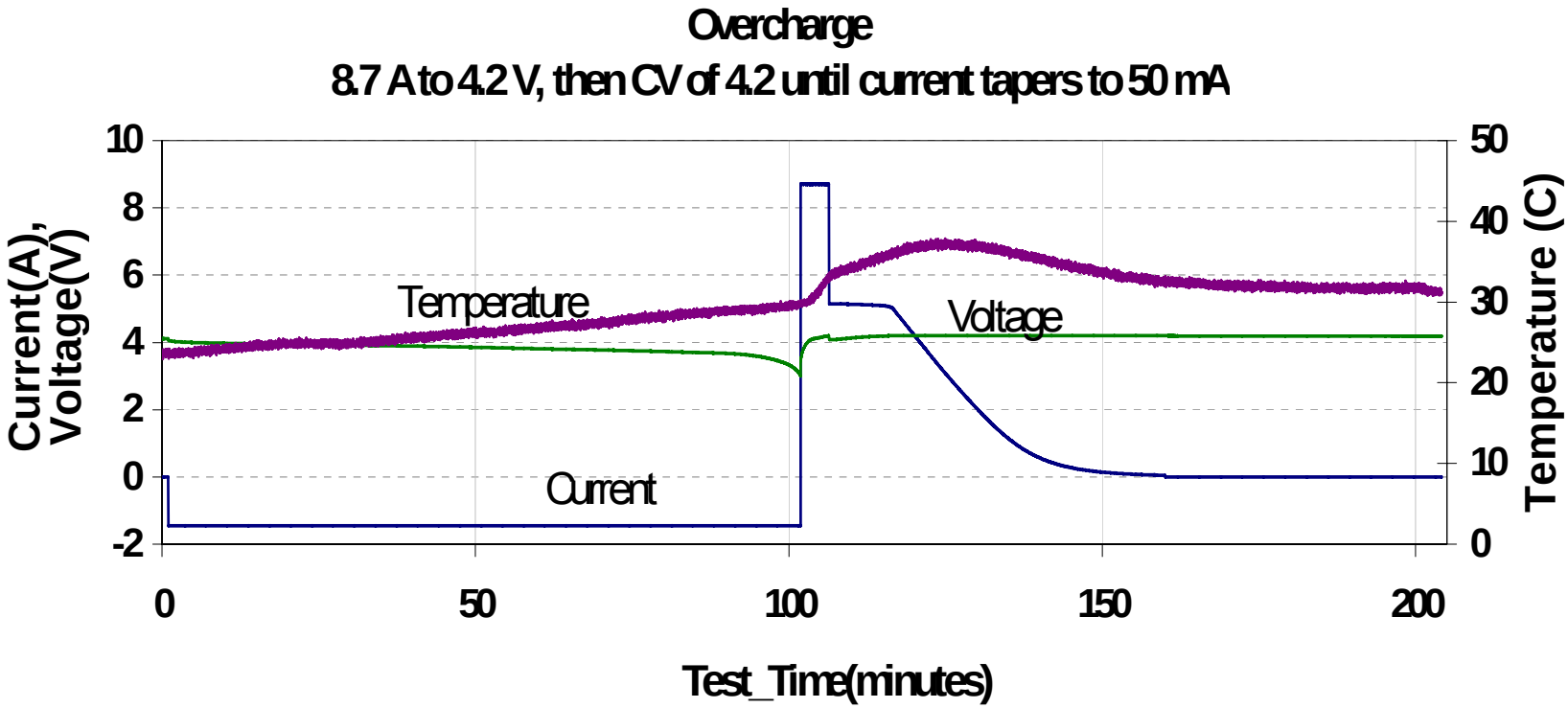
Overcharge Profile 6 (3C to 4.2V)



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Overcharge Profile 3 (cont.)

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Over-discharge

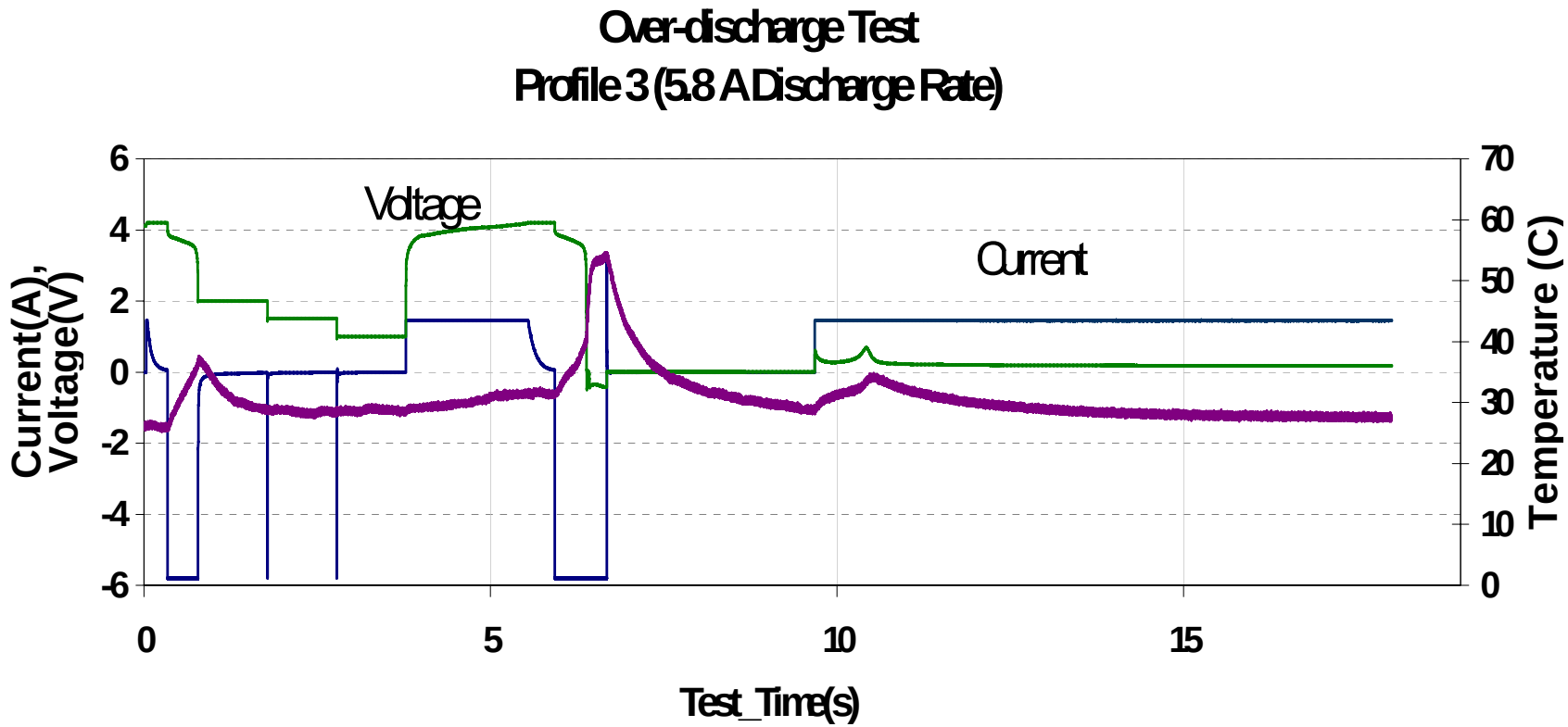
- Test Objectives:
  - To assess the behavior of the cells upon being over-discharged
  - To determine whether the cells could perform cycles after being over-discharged

Over-discharge Profiles

- Test Profiles:
  - Profile 1:
    a) Discharge: C/2 to 2.0V
    b) CV for 1hour
    c) Discharge: C/2 to 1.5V
    d) CV for 1hr
    e) Discharge: C/2 to 1.0V
    f) CV for 1hr
    g) C/2 Charge/Discharge/Charge
    h) Discharge: C/2 until 4.35Ah is achieved
  - Profile 2: Profile 1 using 1C rate
  - Profile 3: Profile 1 using 2C rate
  - Profile 4: 3C discharge to 2.7V

- A post-test charge/discharge cycle was attempted on all cells

Over-discharge



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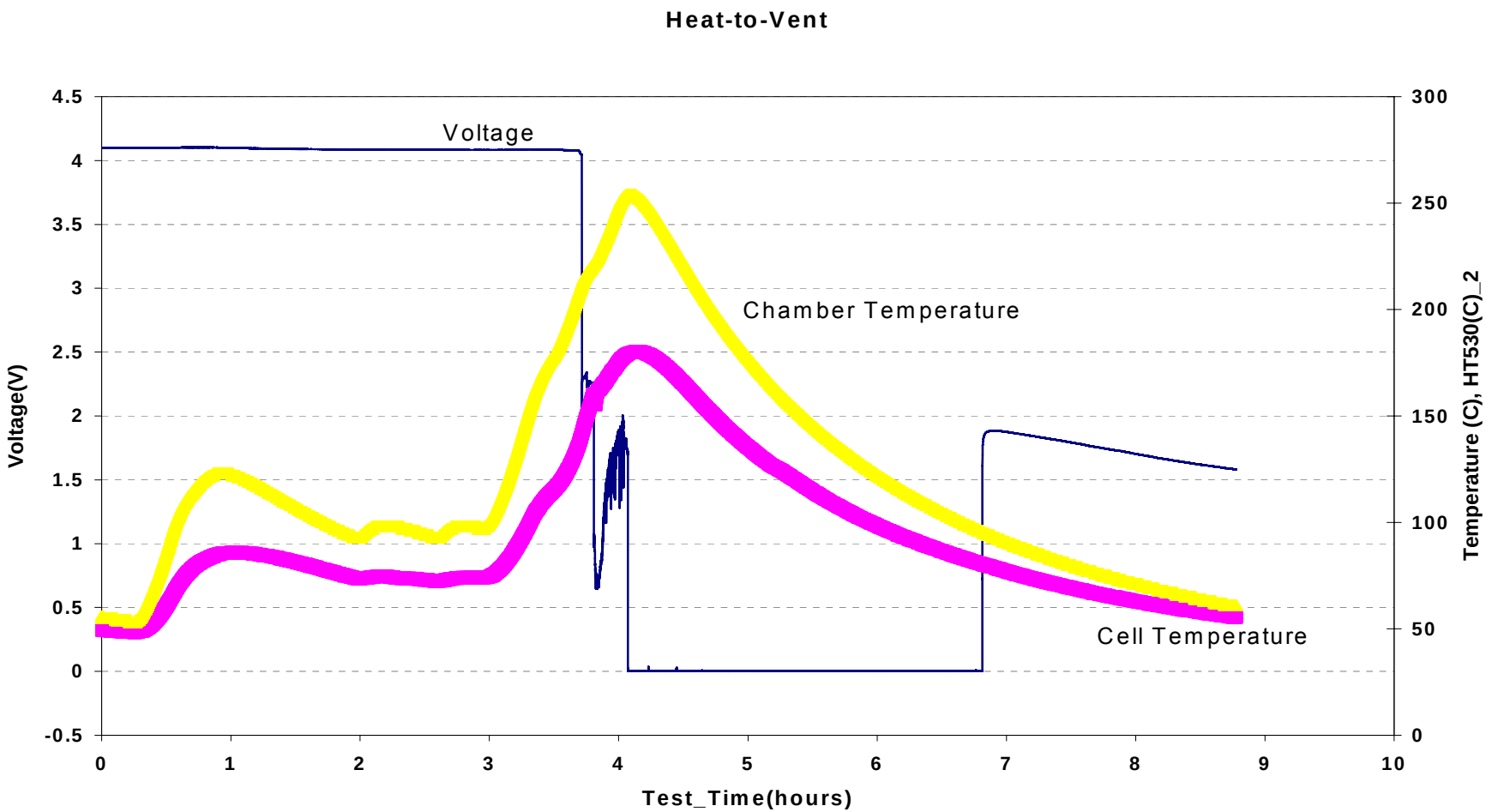
Over-discharge Test Results

- Profile 1, 2 and 3:
  - No cells were discharged below -0.4V upon reaching a discharge capacity of 1.5Ah Below 0V (a total of 4.35Ah)
  - No cells were able to be cycled
- Profile 4:
  - All cells were able to undergo a charge/discharge/charge cycle
    - Average discharge capacity: 2.53Ah
    - Average post-cycle discharge capacity: 2.54Ah

High-Temperature Exposure/Heat-to-Vent Test

- Test Objectives:
  - To determine the temperature tolerance of the cell

High Temperature Exposure/Heat-to-Vent



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High-Temperature Exposure/Heat-to-Vent Test Results

Pre OCV	Post OCV	Difference in Weight	Maximum Temperature
4.14 V	2.2 V	2.50 g	175°C
4.14 V	0 V	2.00 g	180°C

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Internal Short Circuit/Crush Test

- Test Objectives:
  - –To observe how tolerant the cells are to internal short
  - –To determine whether SOC affects the cell's response to an internal short
- Test Observations:
  - –100%SOC: No Venting or Flame
  - –50%SOC: No Venting or Flame

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External Short Circuit

- Test Objective:
  - To assess how the cell's response to an external short varies with respect to load or SOC

Highest Initial Current	Profile	Final Results
142.79	100%SOC (10mΩ)	NONE
83.22	100%SOC (50mΩ)	Leaked
84.26	100%SOC (50mΩ)	Leaked
86.88	100%SOC (50mΩ)	Outside cover burned
132.32	50%SOC (10mΩ)	Outside cover burned
123.47	50%SOC (10mΩ)	Leaked

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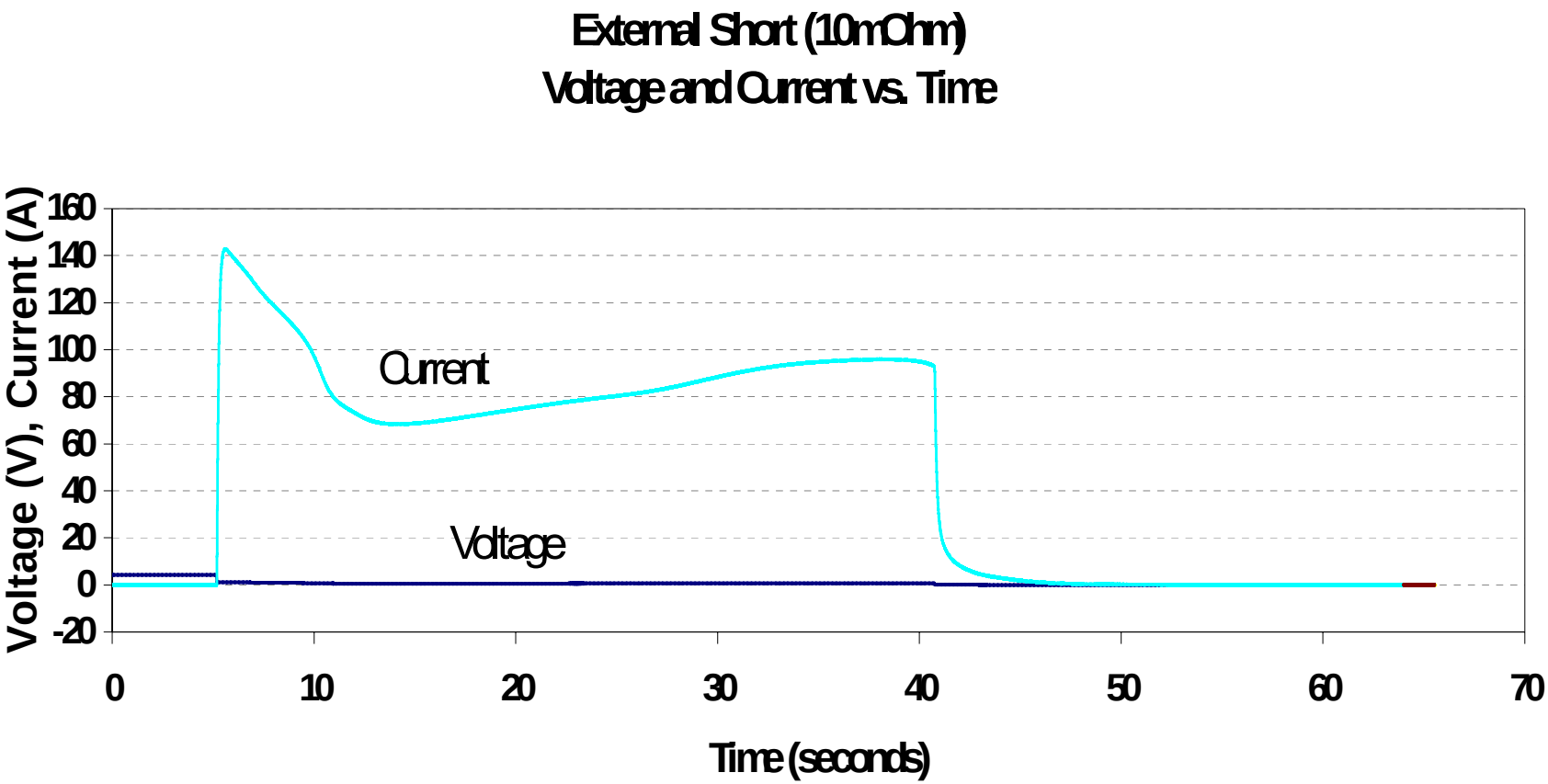
External Short Circuit (10mΩ)



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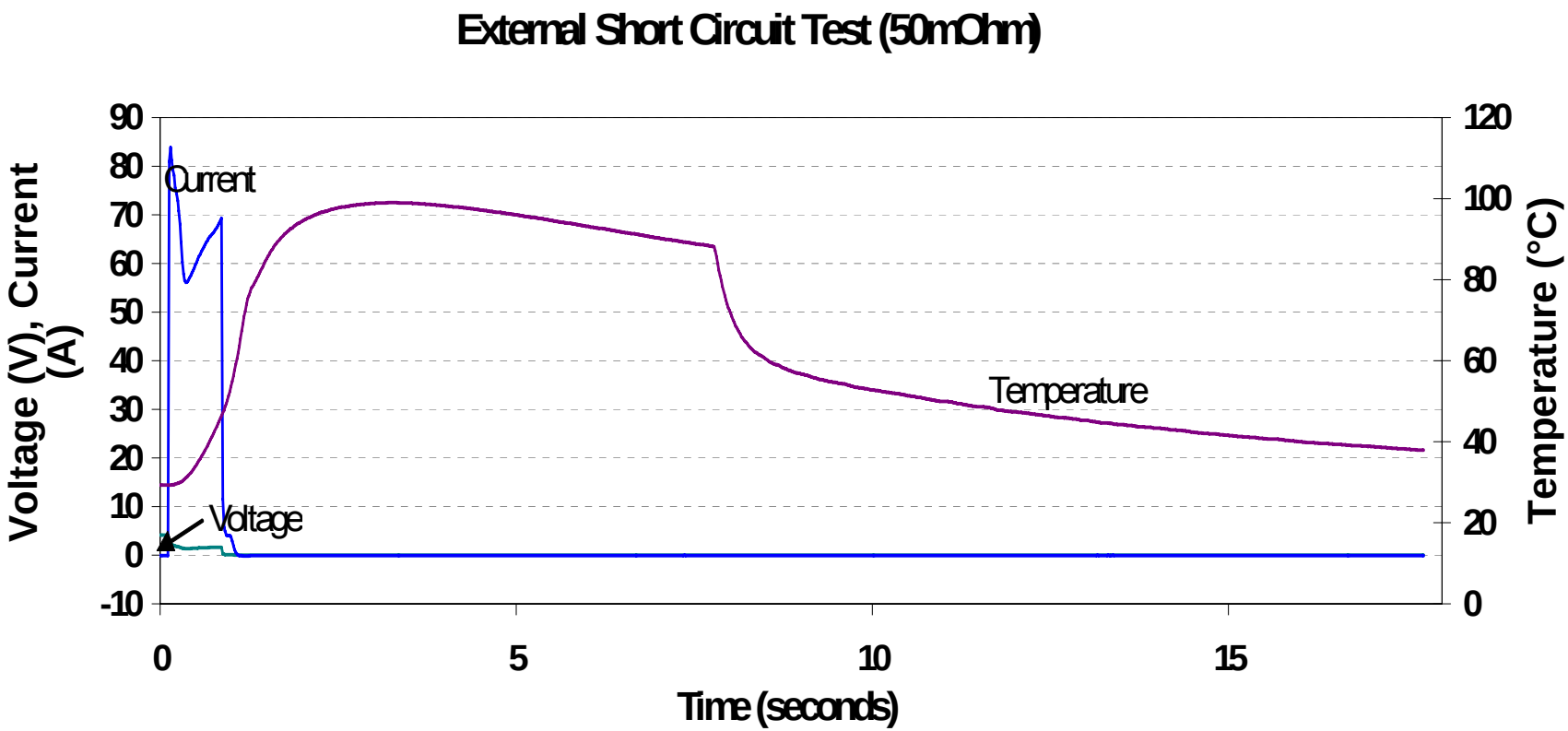
External Short Circuit (50mΩ)



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Conclusions

- Performance Tests
  - Optimum Charge/Discharge Rates: Charge 2.9A/Discharge 2.175A
  - Highest Discharge Rate at which cells remain below 45°C: 20A
  - Average R_e: ~22mΩ
  - Cells do not leak in a 0.1psi environment
- Safety Tests
  - Cells are not tolerant to overcharge > 5V but failed in a fail-safe mode
  - Cells are tolerant to higher rates of charge (3C)
  - Cells cannot be cycled after being discharged below 0V
  - Cells vented at temperatures above ~140°C (environment temp: ~211°C)
  - No event upon internal short
  - Leakage or fire resulted for most cells upon external short regardless of SOC or load

Acknowledgements

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