Limitations of Internal Protective Devices in Cylindrical Lithium-ion Cells

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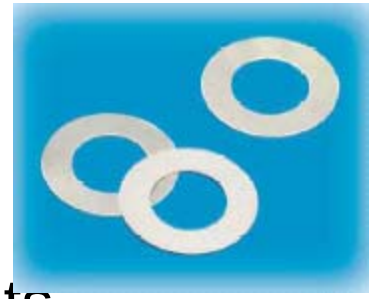
- Introduction and Background
- Sony Li-ion Cell Safety
- Other cell tests
- Present work

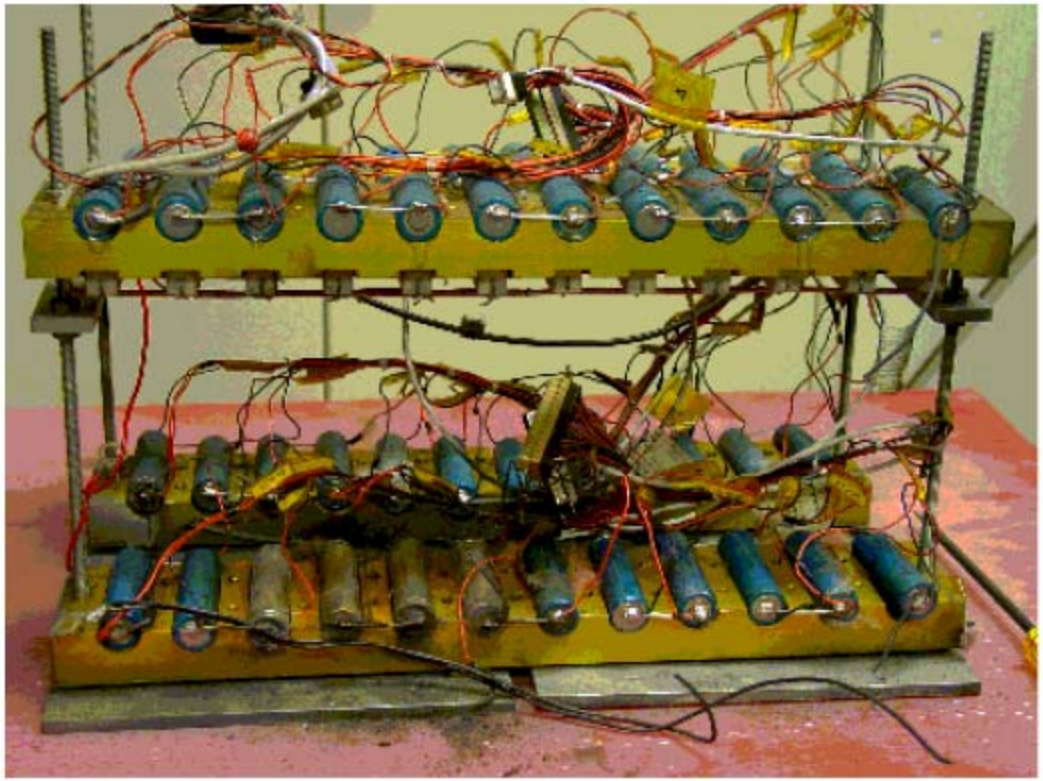
Introduction

- PTC devices are internal to most Lithium-ion cylindrical cells with cobaltate cathodes
- PTCs are resettable.
- PTCs have limitations.
- First experience with lab bench/ GC resistance measurements on PTCs
- Tests performed are of off-nominal nature to determine worst case events and limitations and design for off-nominal conditions;
  Two-fault tolerance to catastrophic failures is a requirement for crewed space applications.



External Short Test at ComDev

24S 2P



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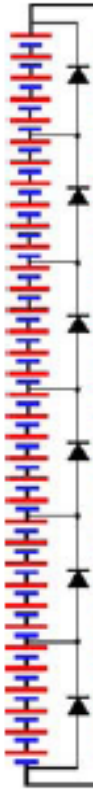
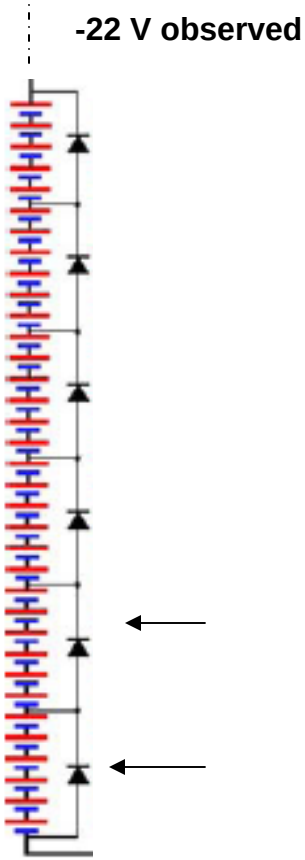
Suggested solution

Use of diodes



External Short Test with Removed Diodes

48S (210 V) with diodes for every six cells; two diodes at the low voltage end shorted; max current observed is 4 A (current used for charge is 130 mA before short circuit test.



If two diodes that were not next to each other had been removed; failure may not have occurred.

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Overcharge Test on Battery Module

41S 5P

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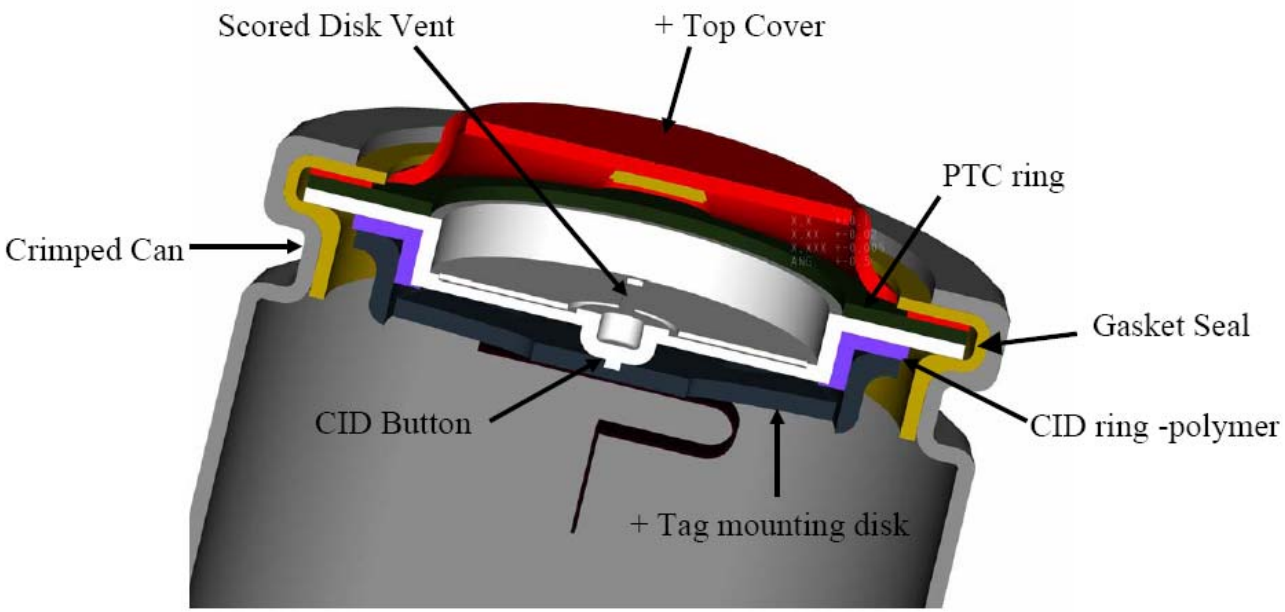
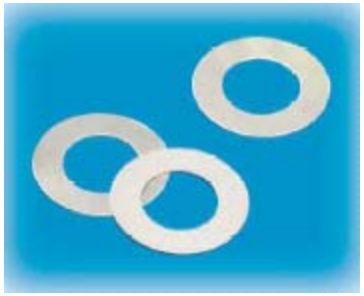
Cross-cut of Cell Showing Protective Features





PTC Withstanding Voltages

Moli: (SRI)

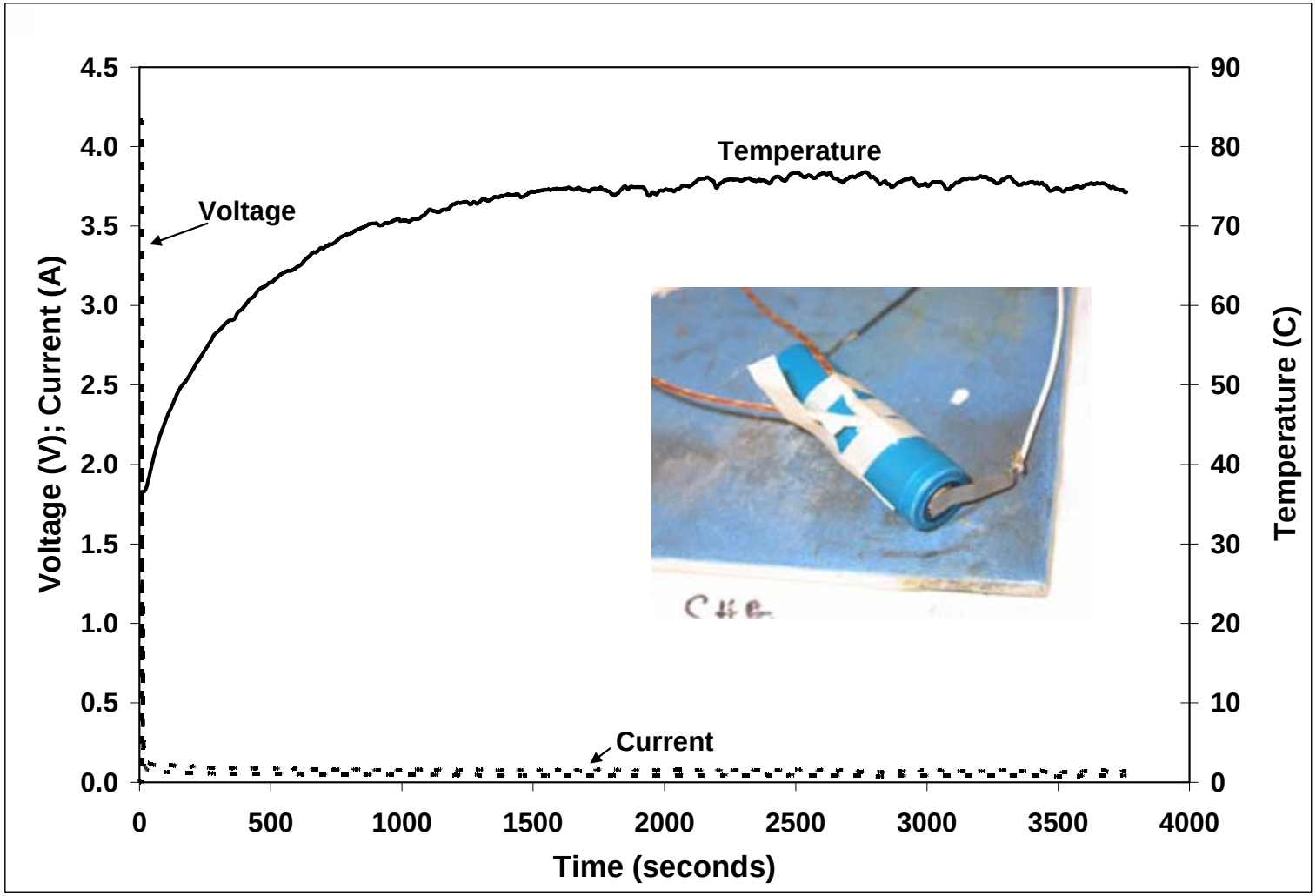
- **30 V (~ 32 V)**

Sanyo : Between 65 to 75 V (NASA-JSC / ESTA)

Panasonic : ~ 60 V (ABSL)

15 A used in all cases

External Short Circuit – Sony Li-ion Cell



Peak Current : 30 – 31 A

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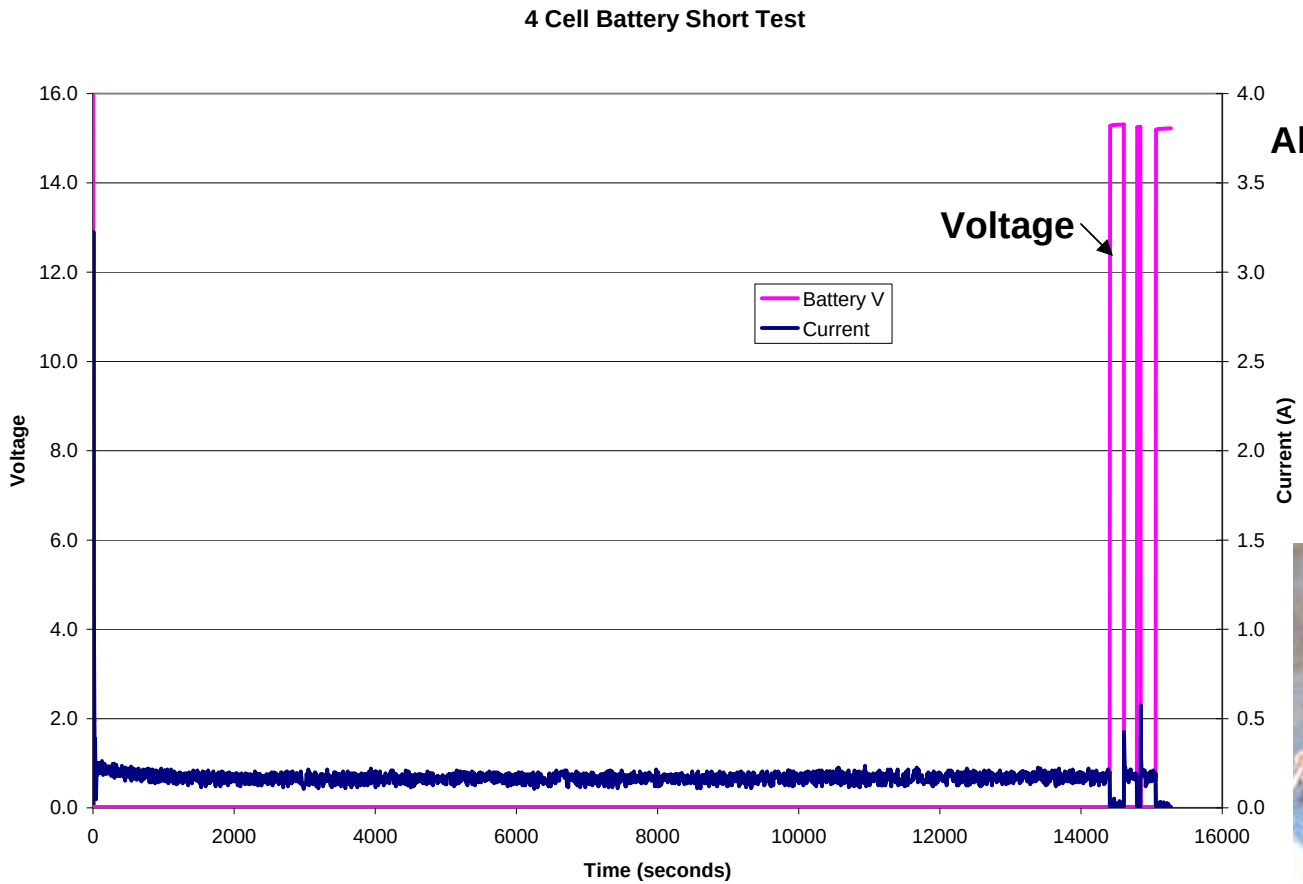
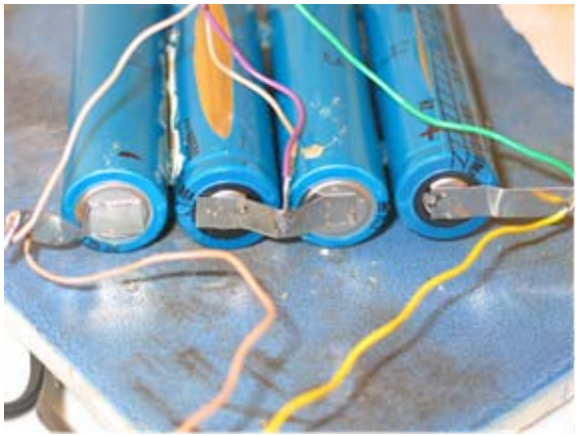
Battery Voltage During the 4-Cell External Short Test on Sony Li-ion Cells



All cells had voltage at recheck



Peak Current : 5 A for 200 ms

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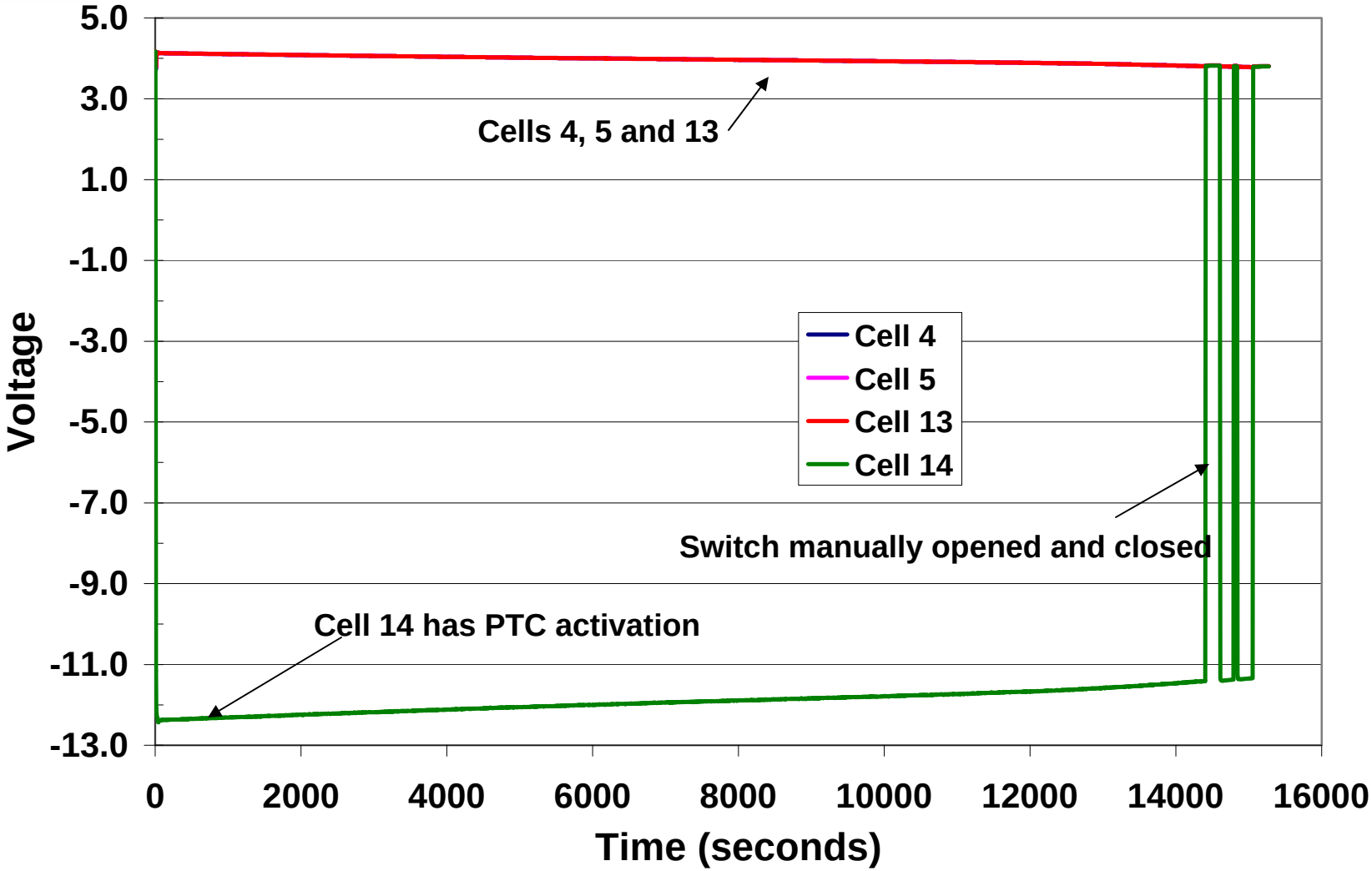
Cell Voltages During the 4-Cell External Short Test on Sony Li-ion Cells



Cells have nominal voltage after test;
No venting

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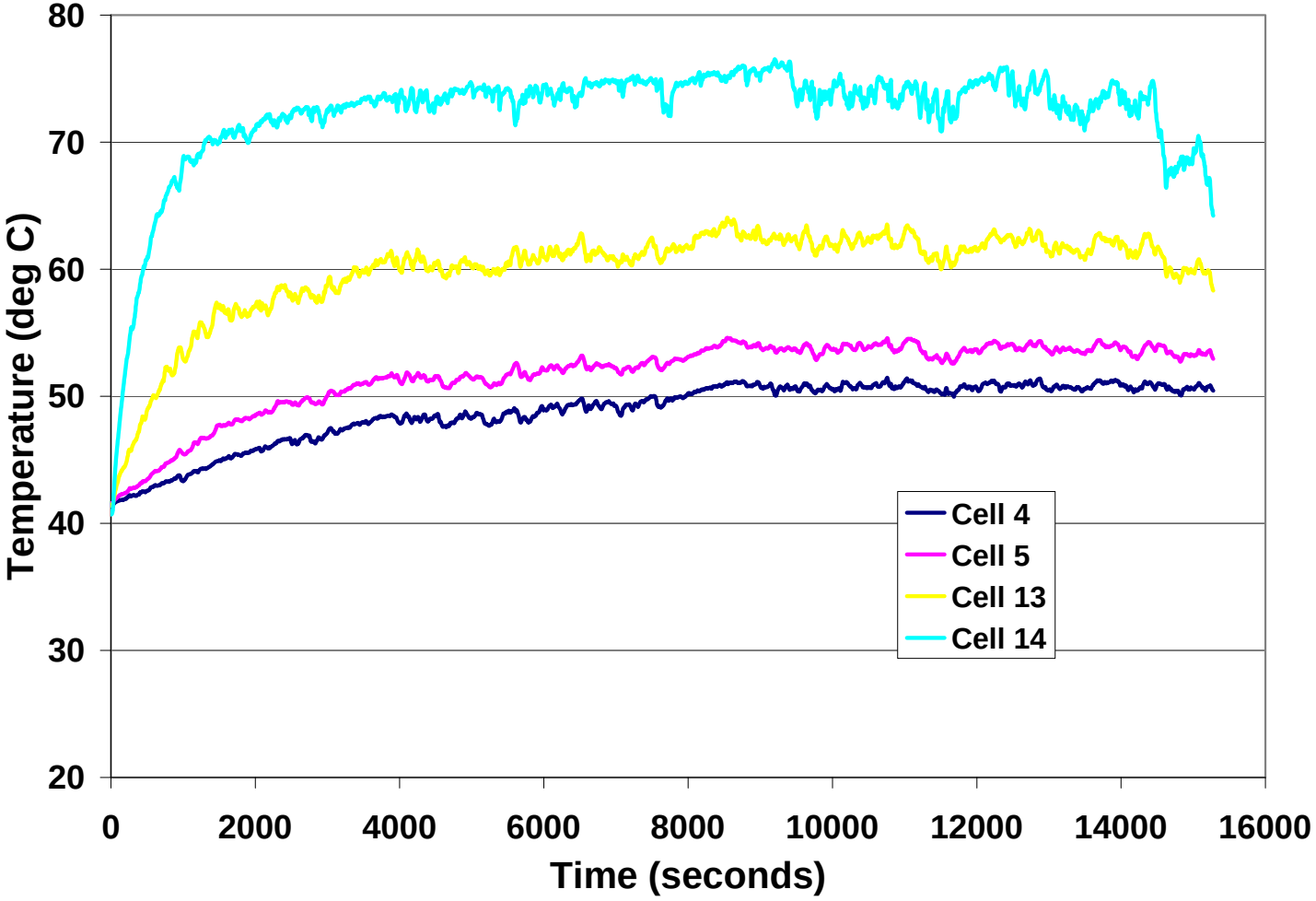
Cell Temperatures Recorded During the 4-Cell String External Short Test



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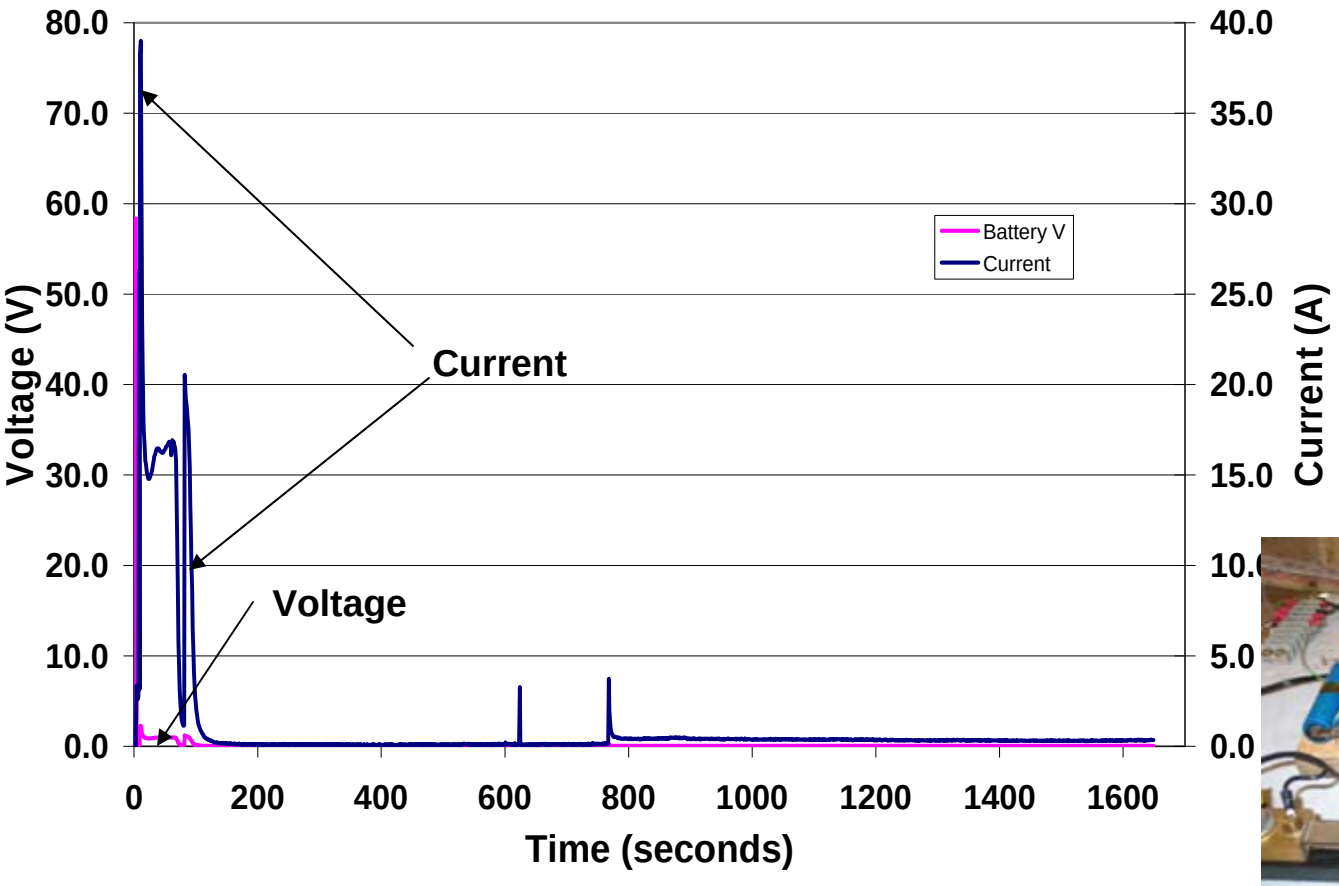
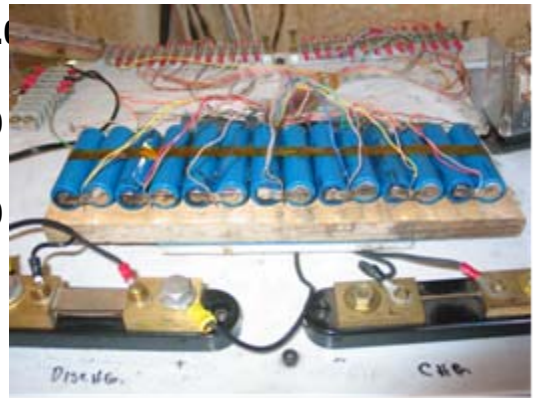
Battery Characteristics Under an External Short Test on a 14-Cell String of Sony Li-ion Cells





Peak Current: 39 A

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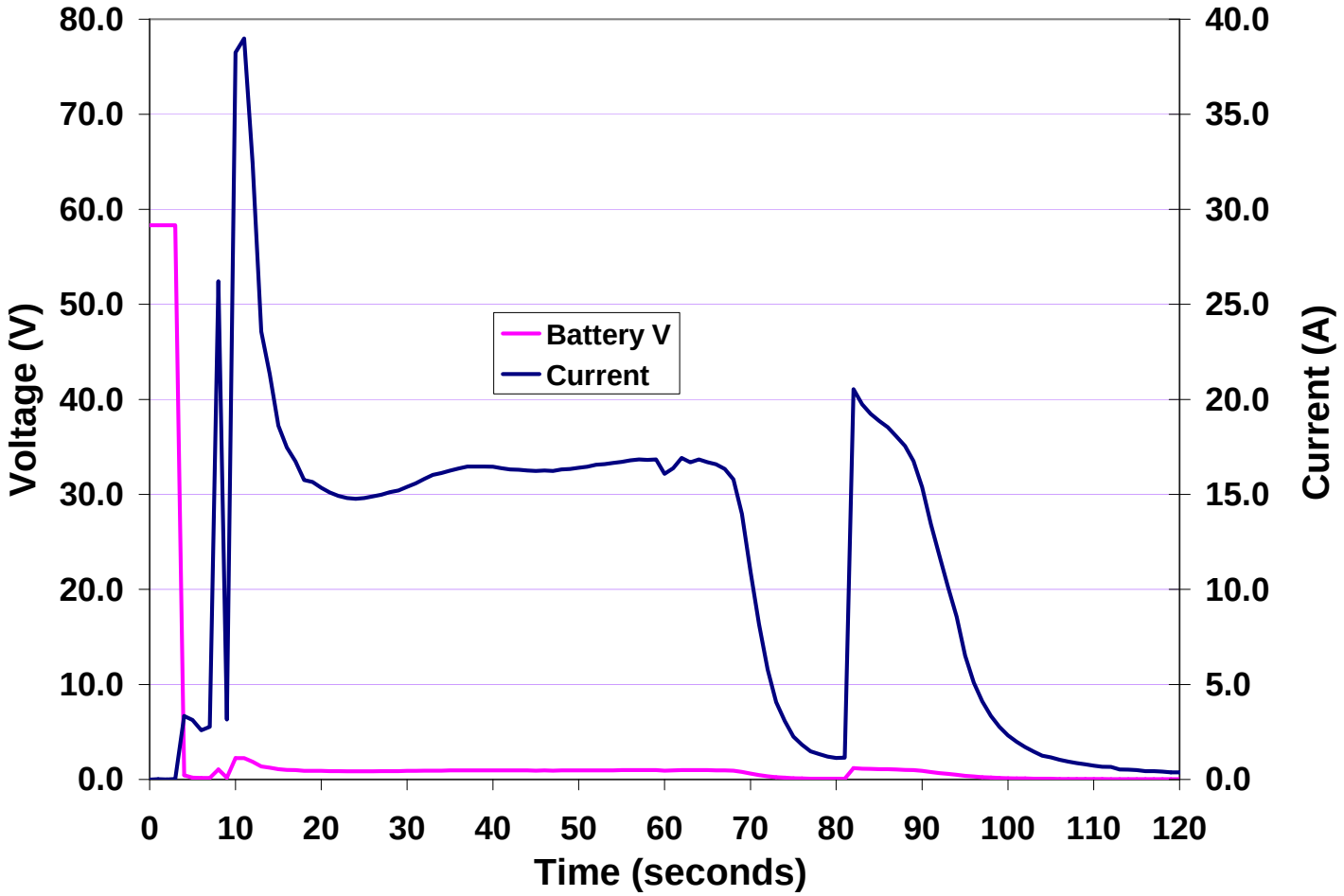
Battery Voltage and Current Expanded for the First Few Seconds Under the Short Circuit Test on Sony Li-ion Cells



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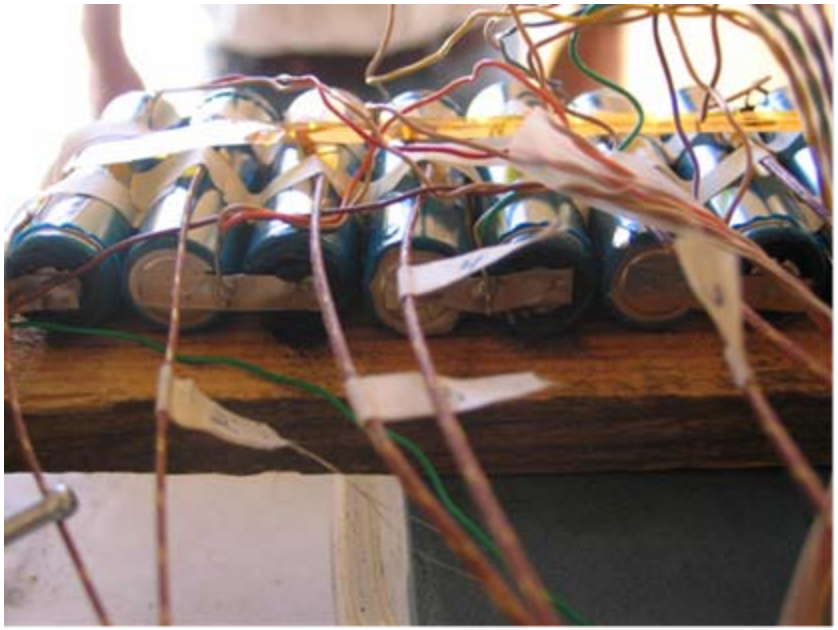
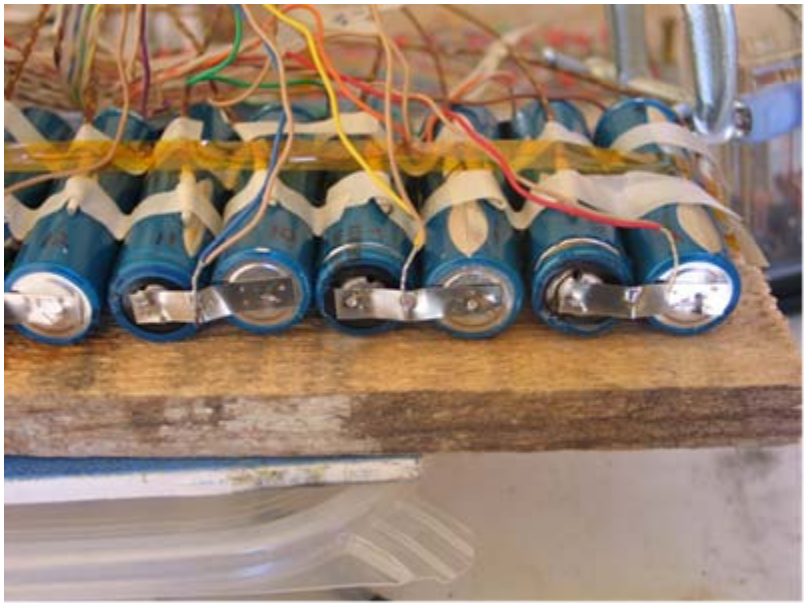
Sony Lithium-ion Cells Under a 14-cell String External Short Test



Cells 1 to 12

Opposite View of same cells



Rapid cell venting within the first 10 seconds but no fire

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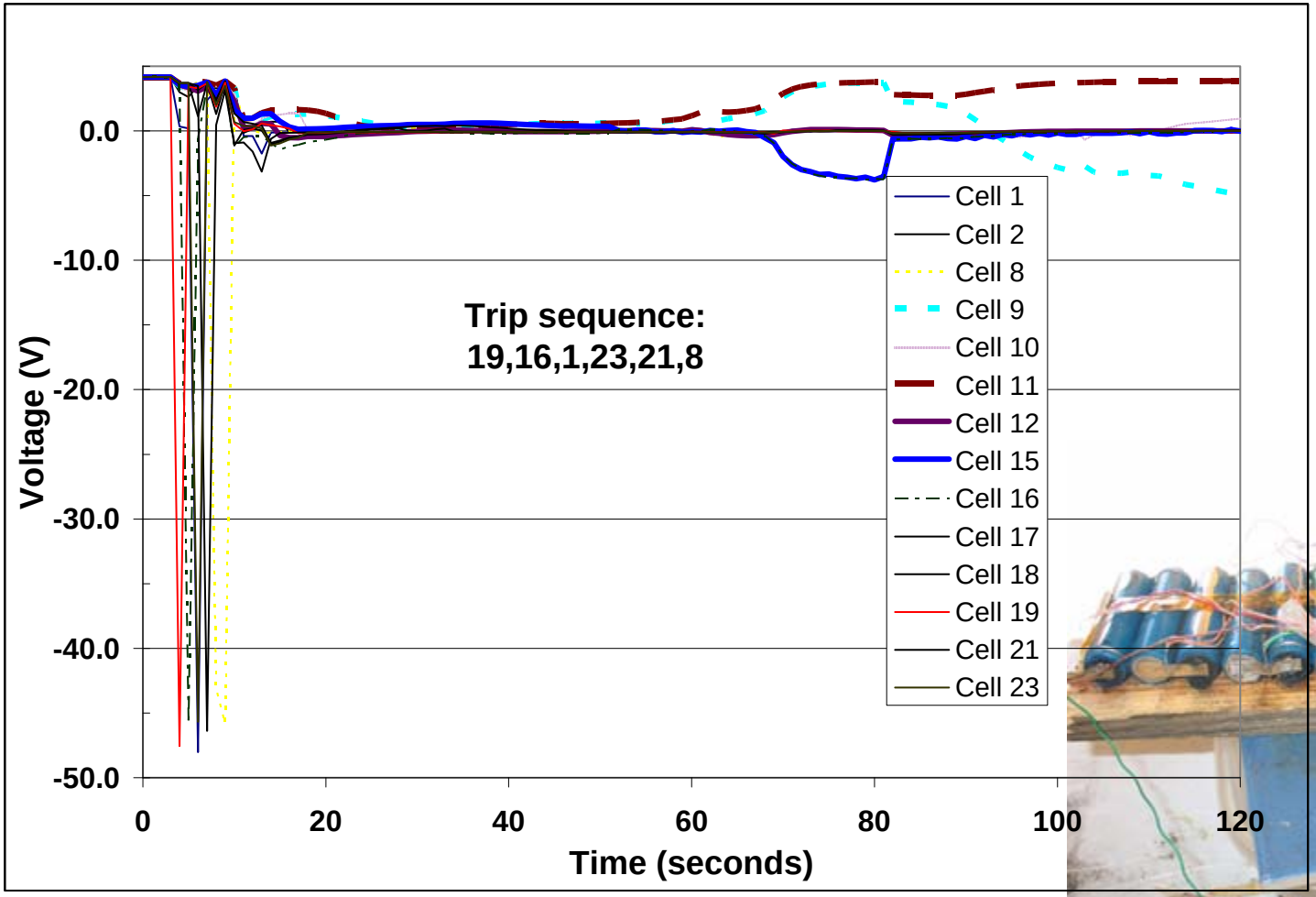
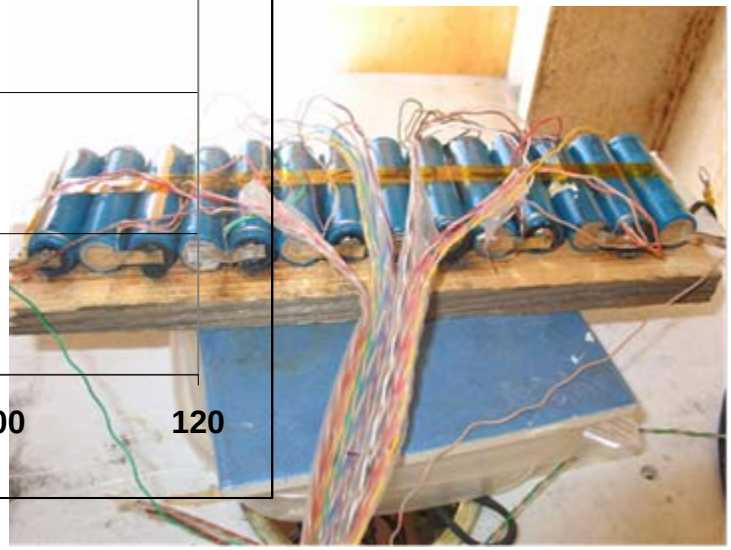
Cell Voltages During 14-Cell String Short Circuit Test on Sony Li-ion Cells



Only venting observed, no fire
Cell Voltages in bold – No visible signs of Venting or damage, but no voltage;
All others vented with Obvious leakage or discoloration



Rapid cell venting within the first 10 seconds

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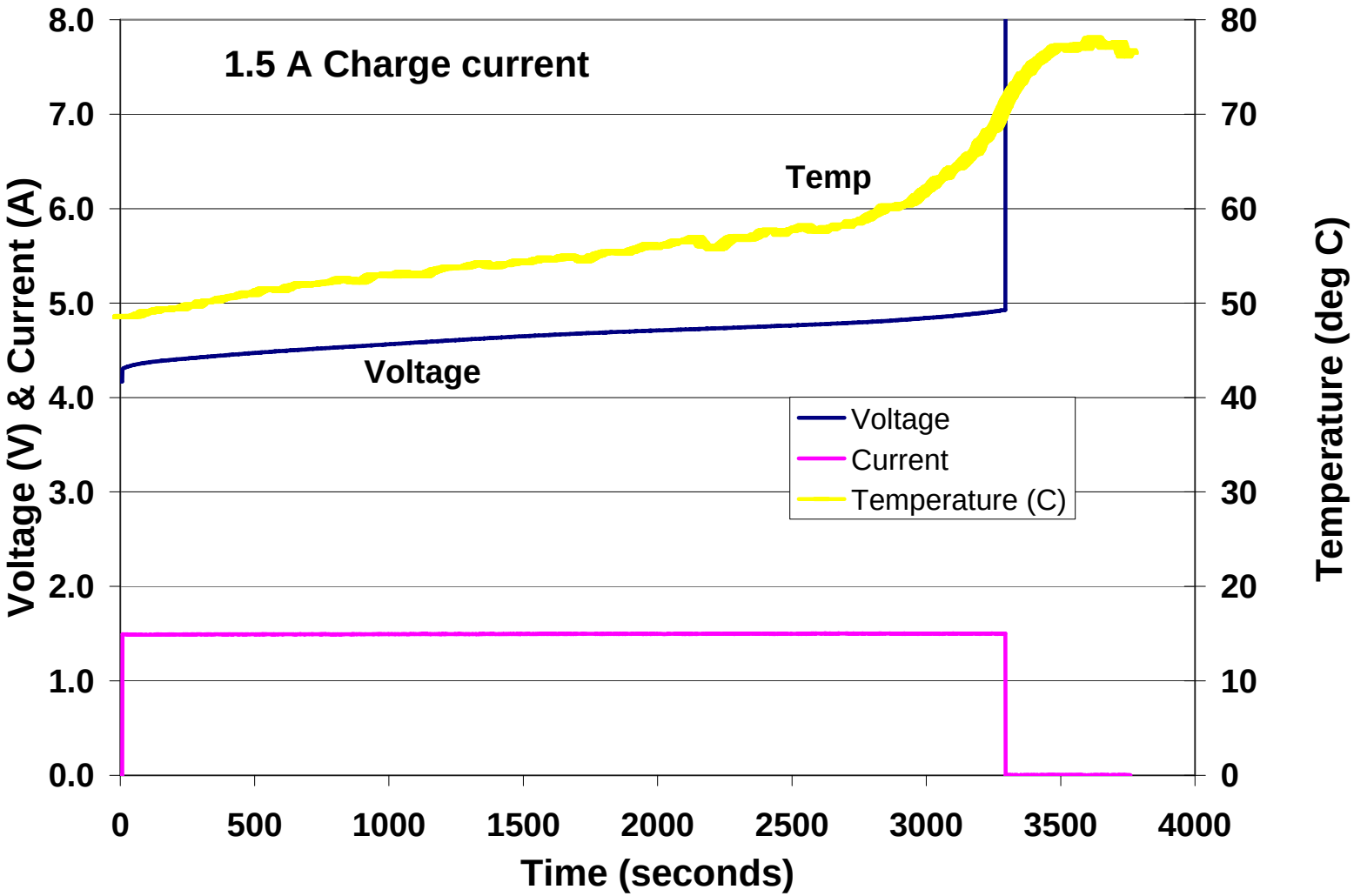
Overcharge Test on Single Sony Lithium-ion Cells



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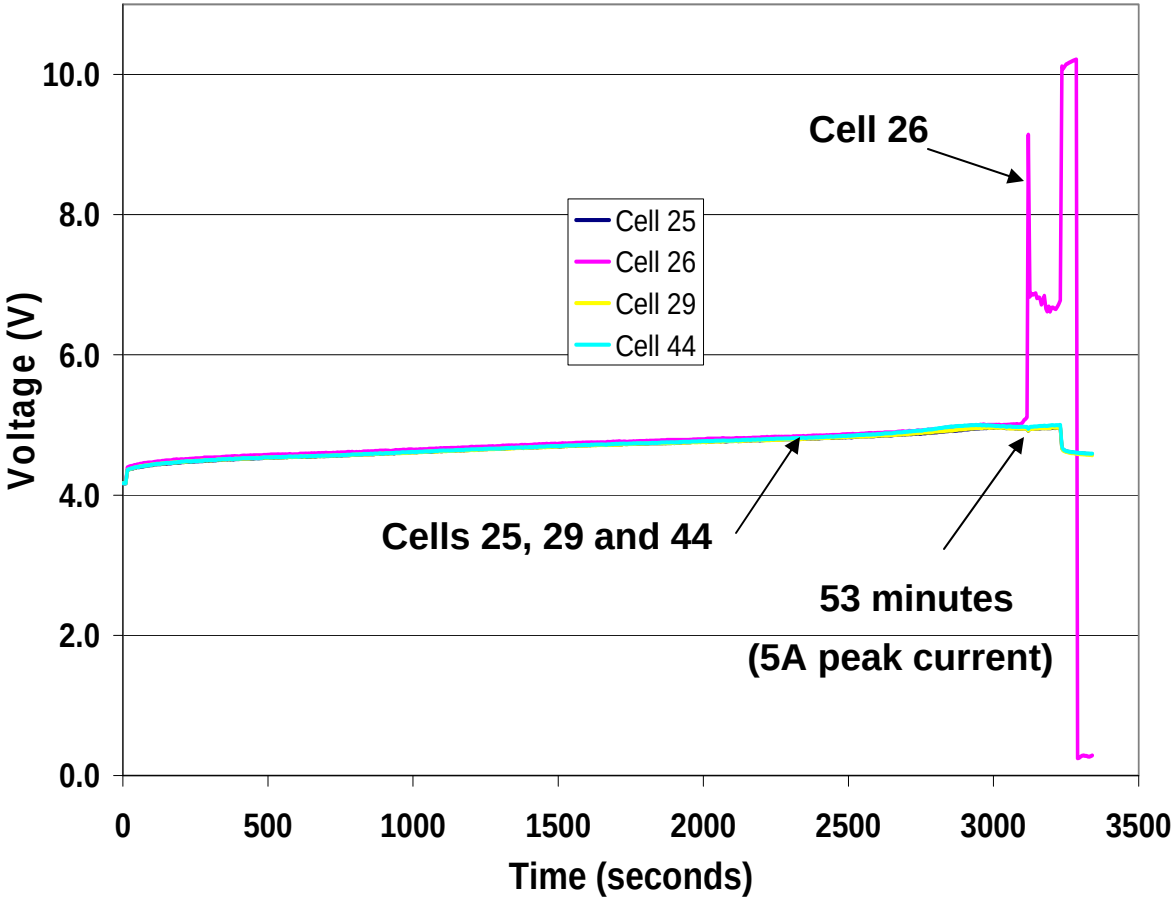
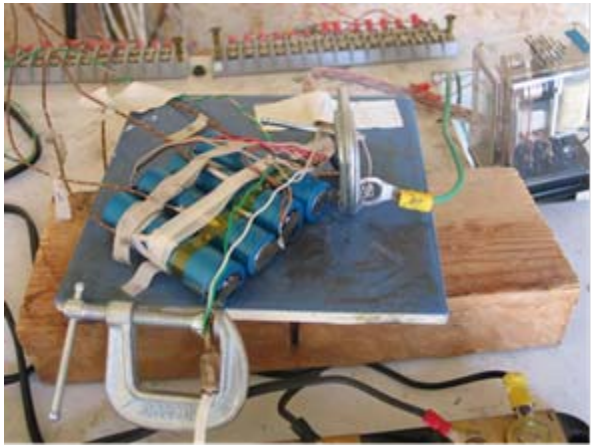
Overcharge Test on 4 -Cell String of Sony Lithium-ion Cells



Only 26 had opened up (no voltage);
all others had good voltage at recheck

Cells 25, 26, 29, 44 (bottom to top)
Before Test



Cells 25, 26, 29, 44 (bottom to top)
+
After Test

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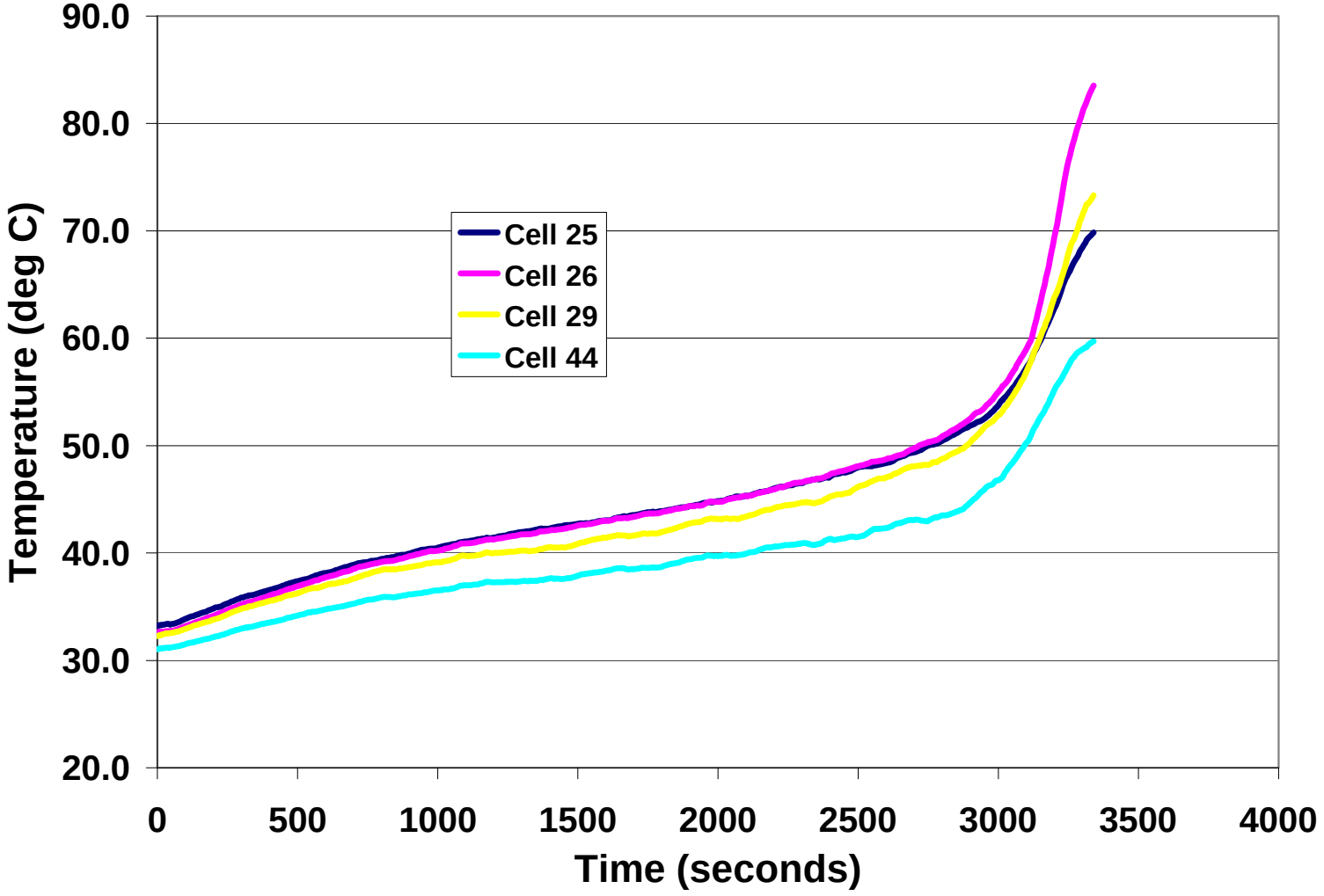
Overcharge Test Showing Temperatures on 4-Cell String of Sony Lithium-ion Cells



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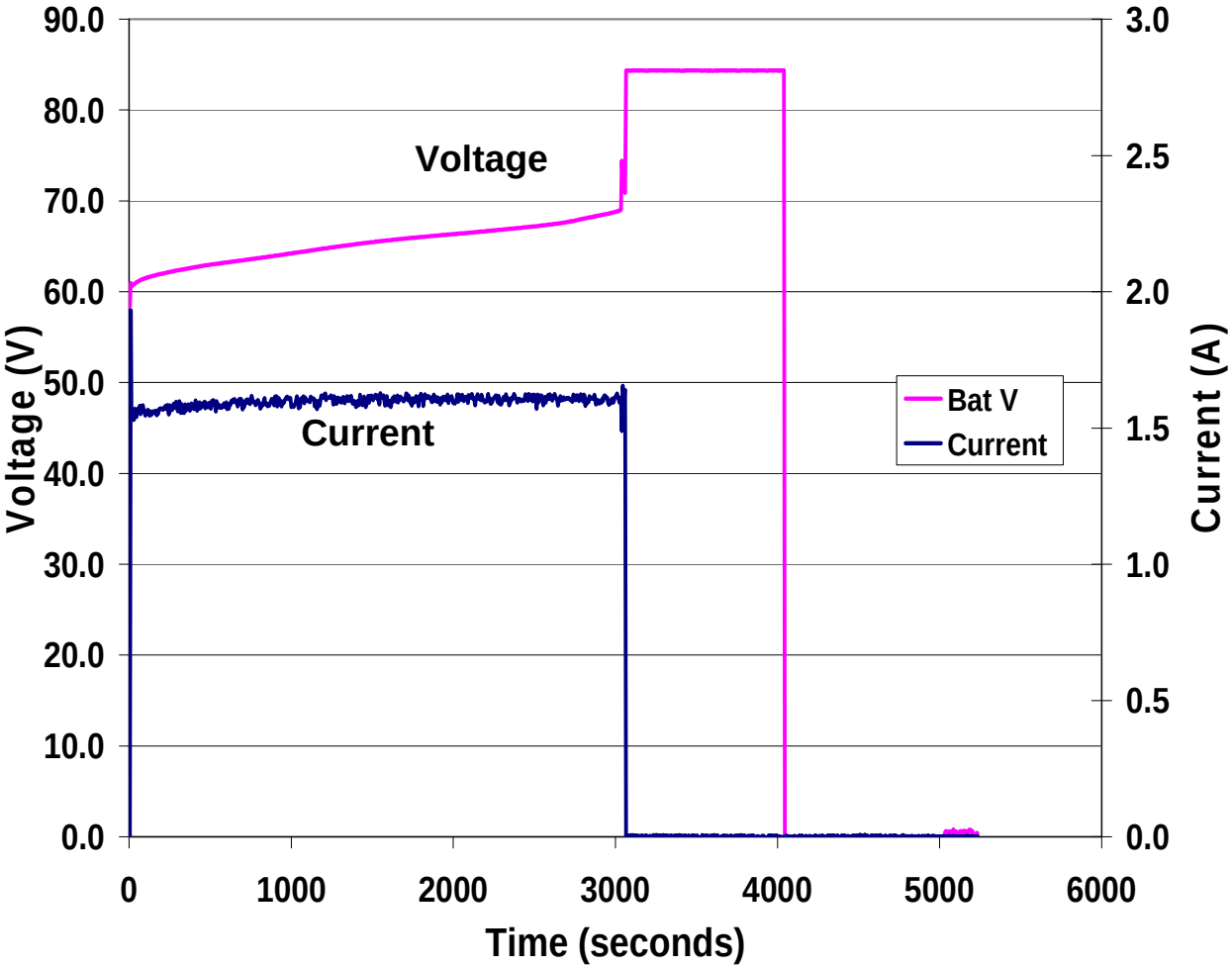
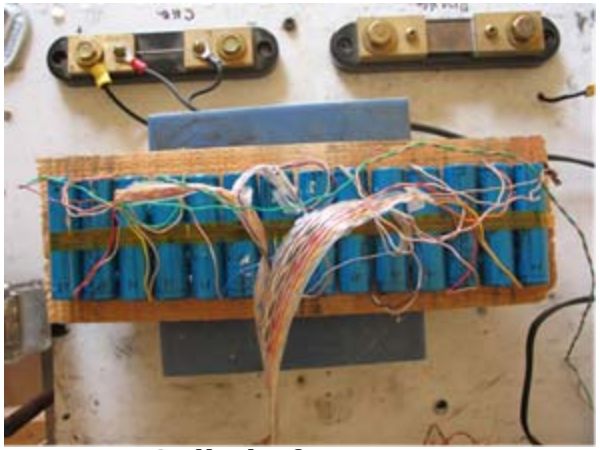
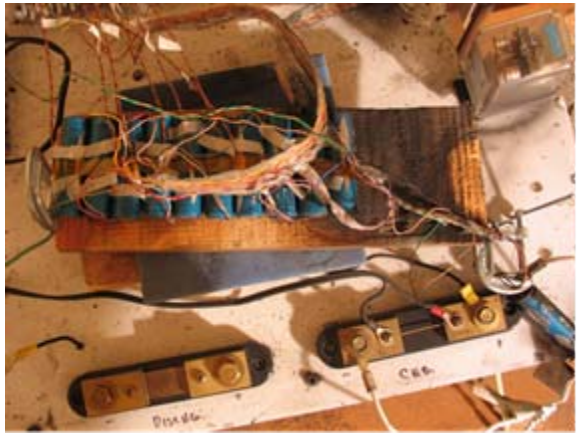
Overcharge Test on 14-Cell String of Sony Lithium-ion Cells





Cells before Test



Cells After Test

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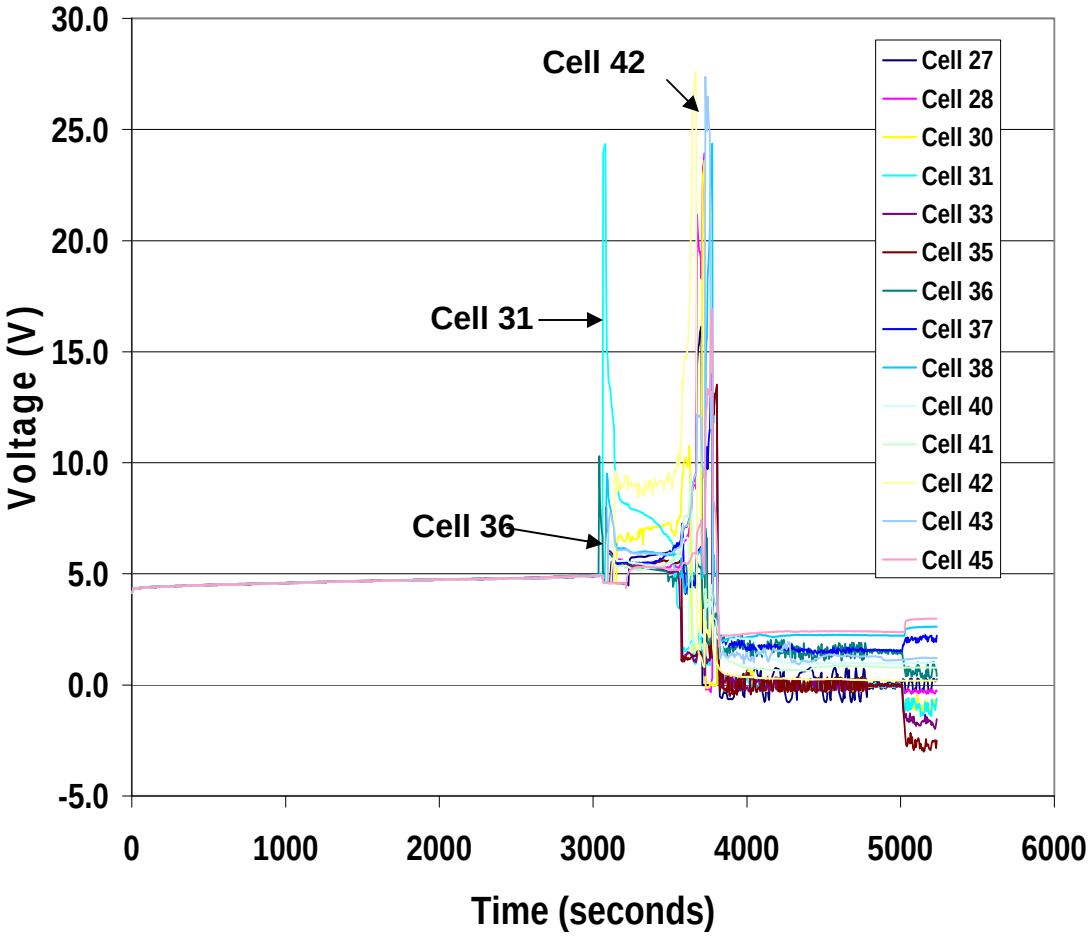
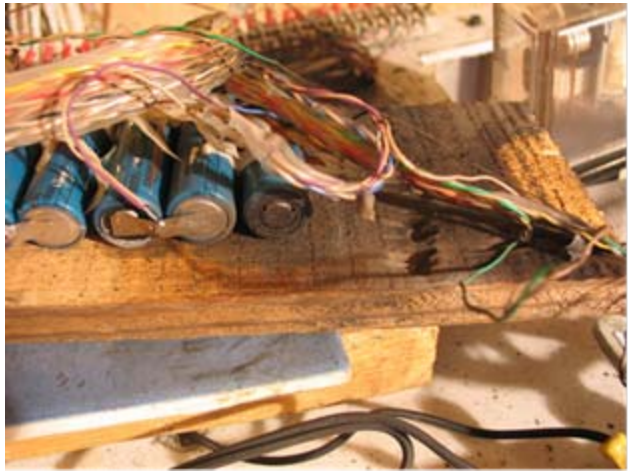
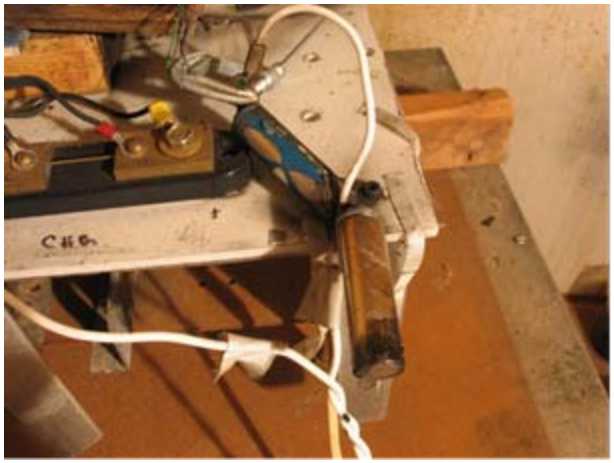
Overcharge Test on a 14-Cell String Showing Cell Voltages for the Sony Li-ion Cells





Group 27-37



Cells 27 and 28

Missing : 27, 28, 30 and 31

Cells 37, 38 and 45 showed no visible Signs of venting

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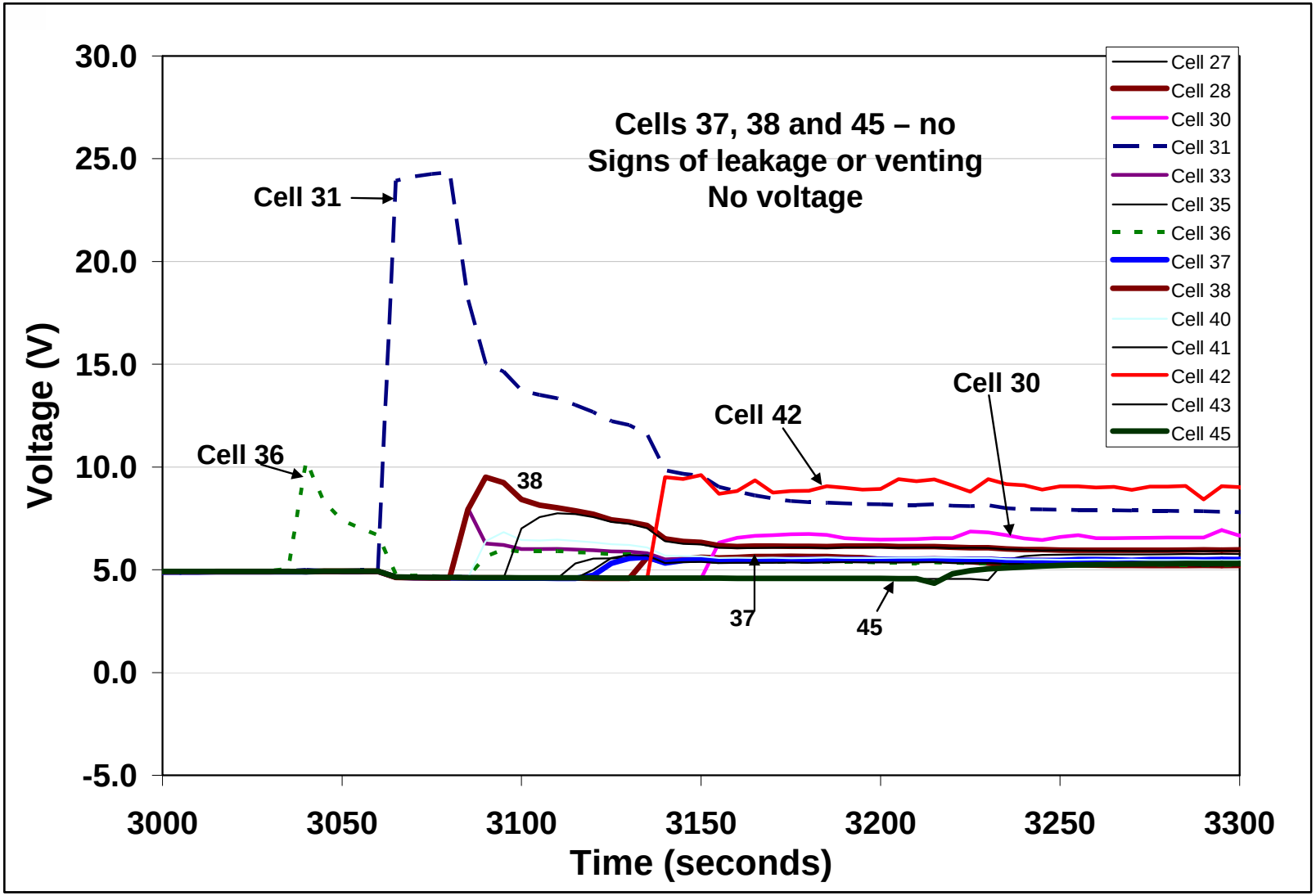
Expanded View of Cell Voltages During the 14-Cell Overcharge Test on the Sony Li-ion Cells



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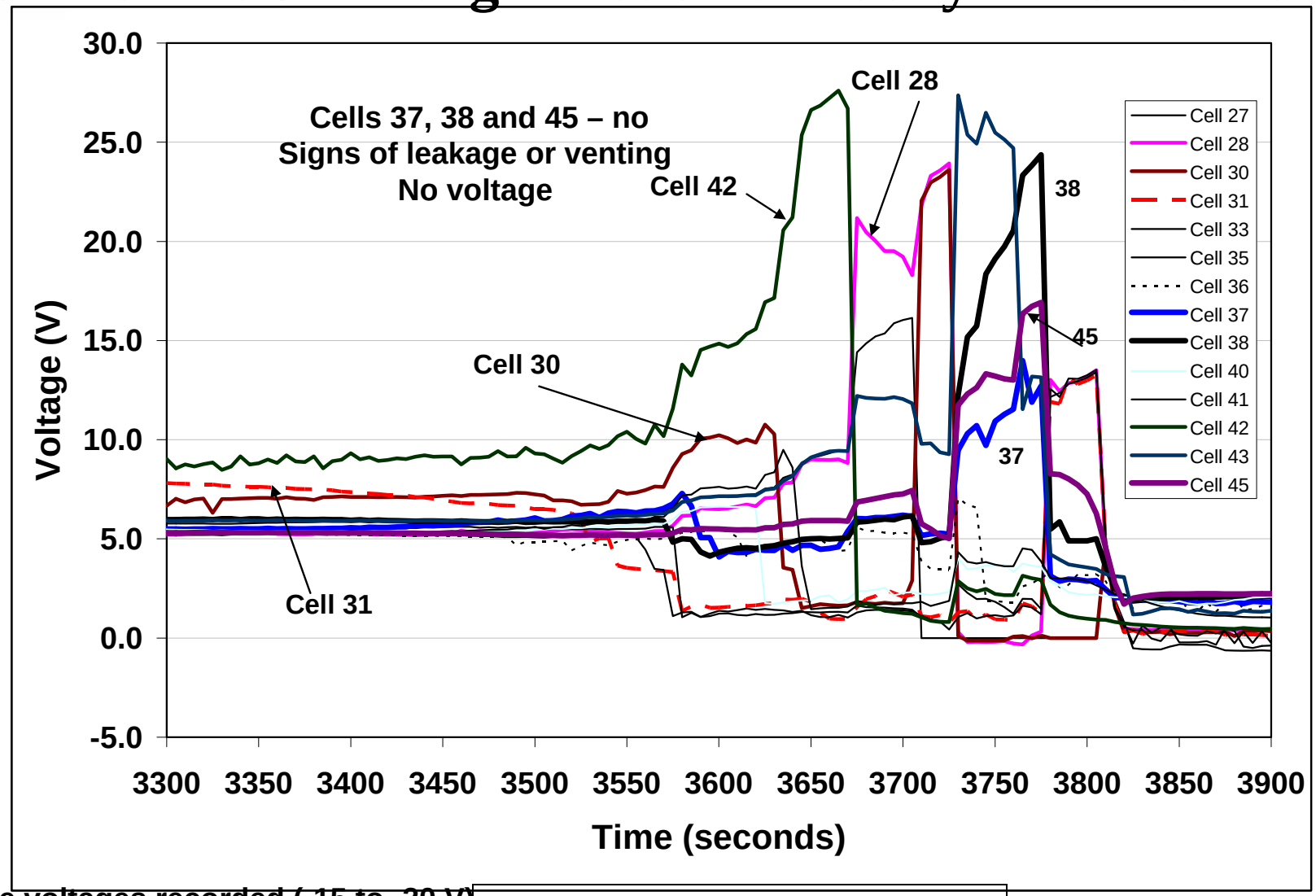
Expanded View of Cell Voltages During the 14-Cell Overcharge Test on the Sony Li-ion Cells



Negative voltages recorded (-15 to -20 V)
On at least three cells

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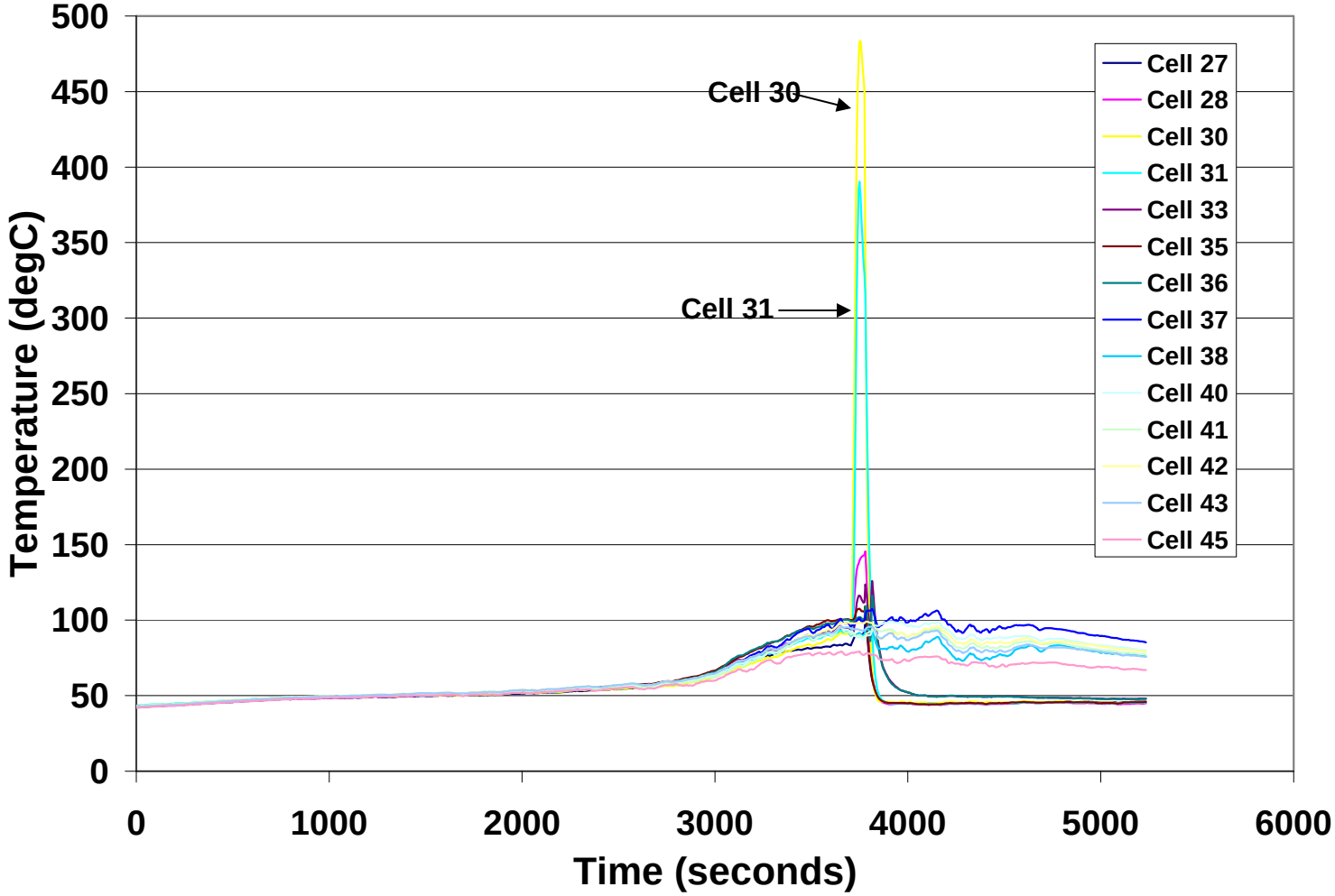
Overcharge Test on a 14-Cell String Showing Cell Temperatures for the Sony Li-ion Cells



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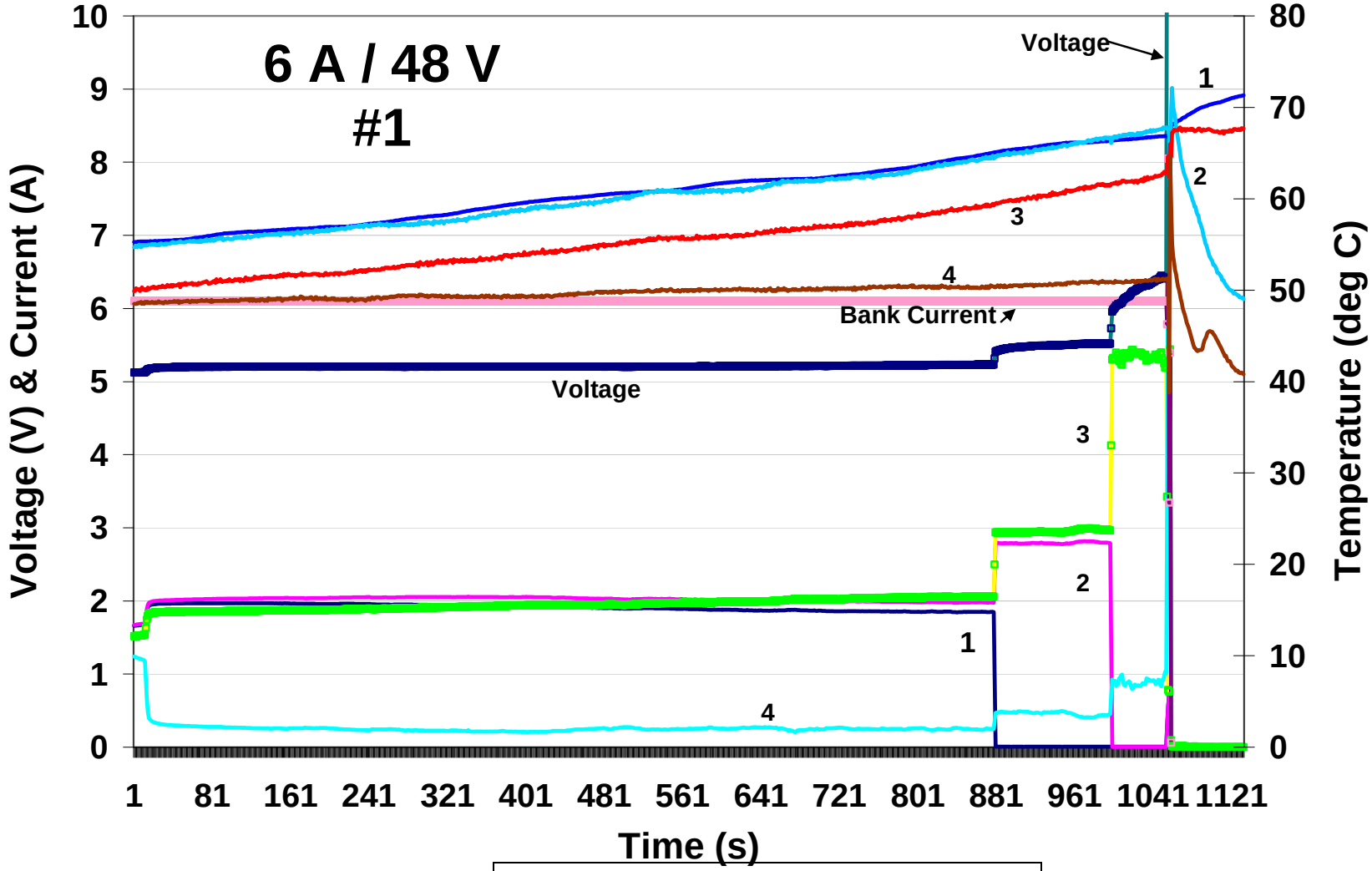
Cells Removed from String

Cell #31

Cell #30

Overcharge Test on 4 Cell Bank of Cylindrical Li-ion Cells



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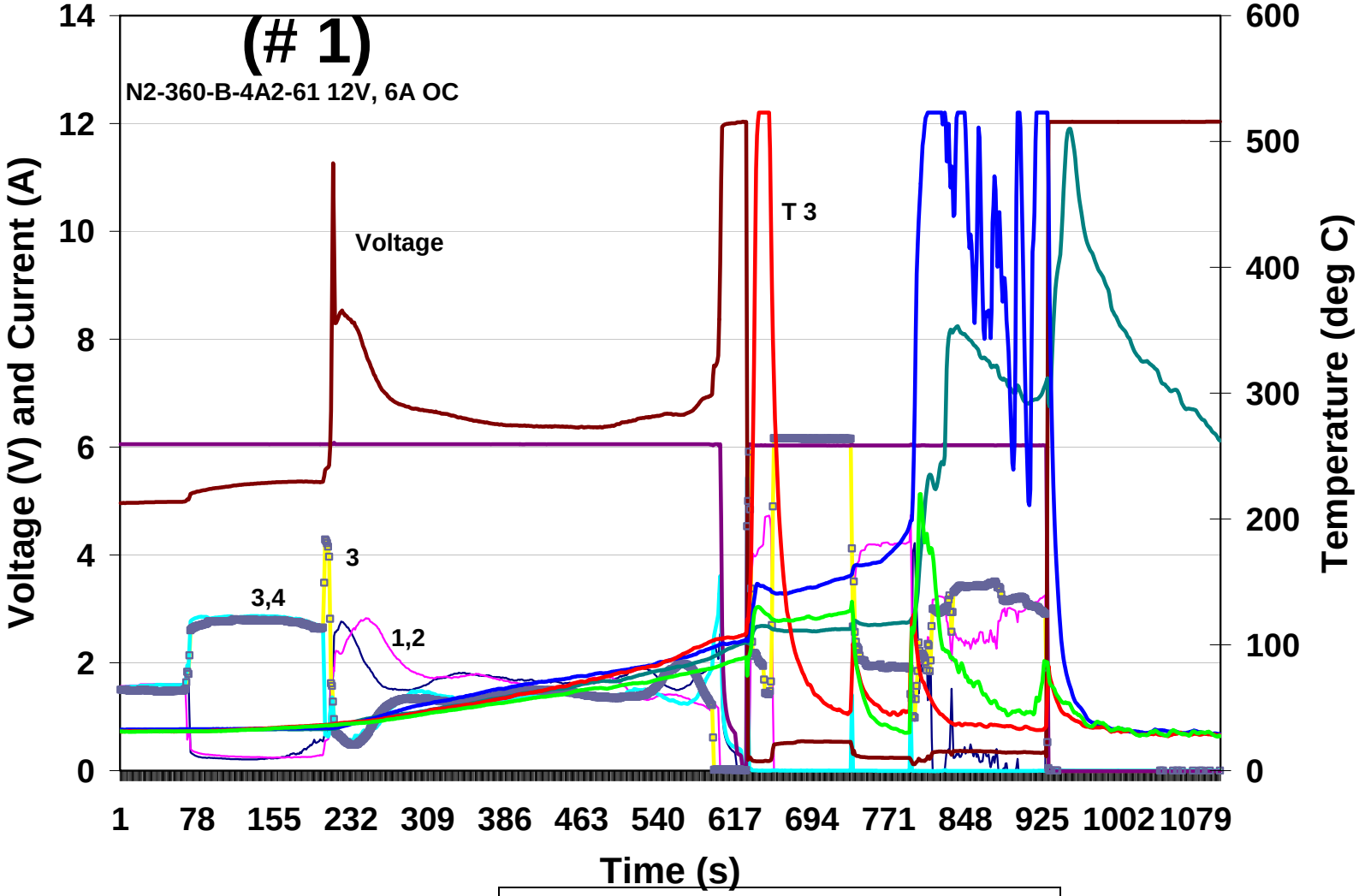
Overcharge Test on 4 Cell Bank of Cylindrical Li-ion Cells

6A / 12 V (# 1)



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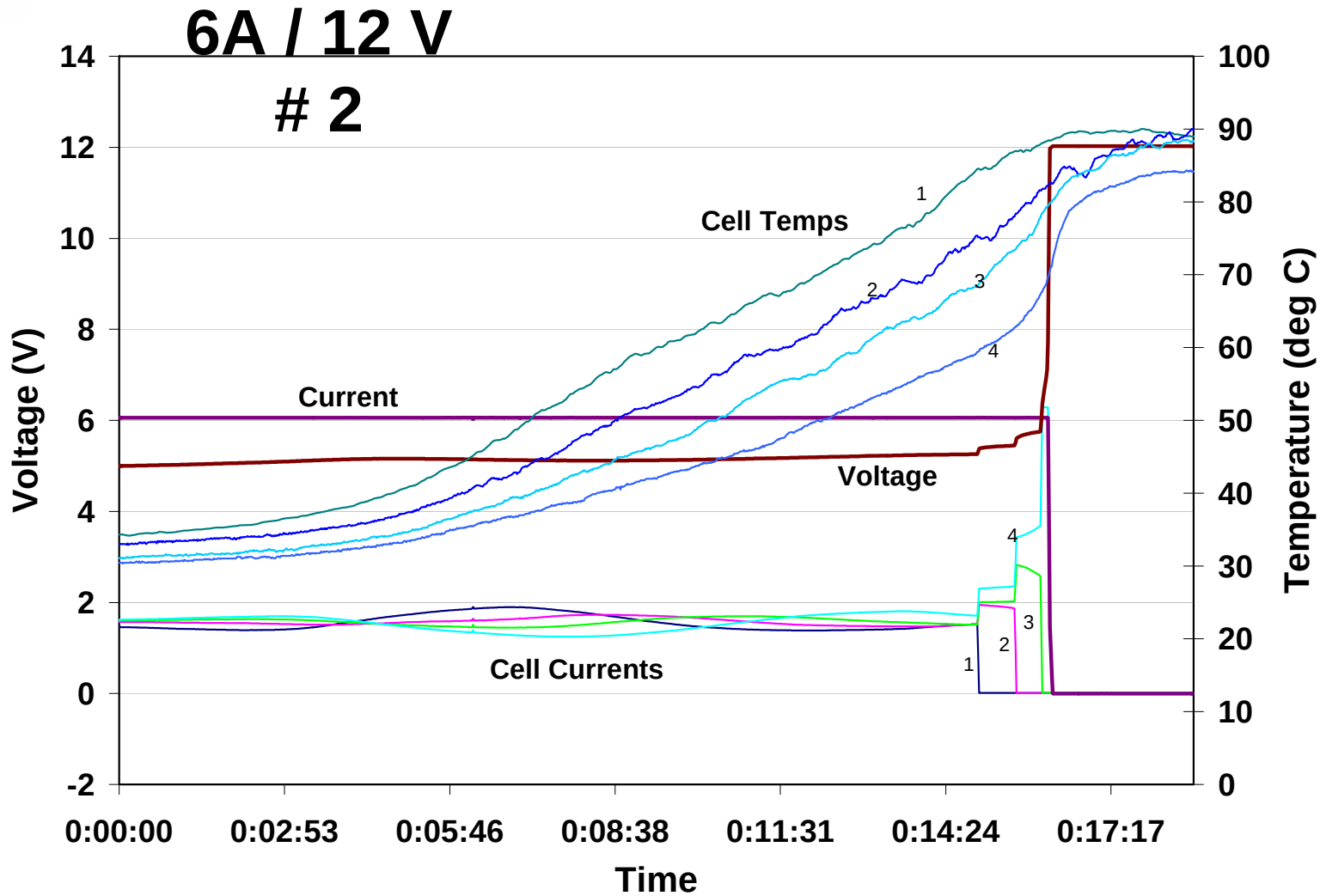
Overcharge Test on 4 Cell Bank of Cylindrical Li-ion Cells



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Overcharge Test on 4 Cell Bank of Cylindrical Li-ion Cells

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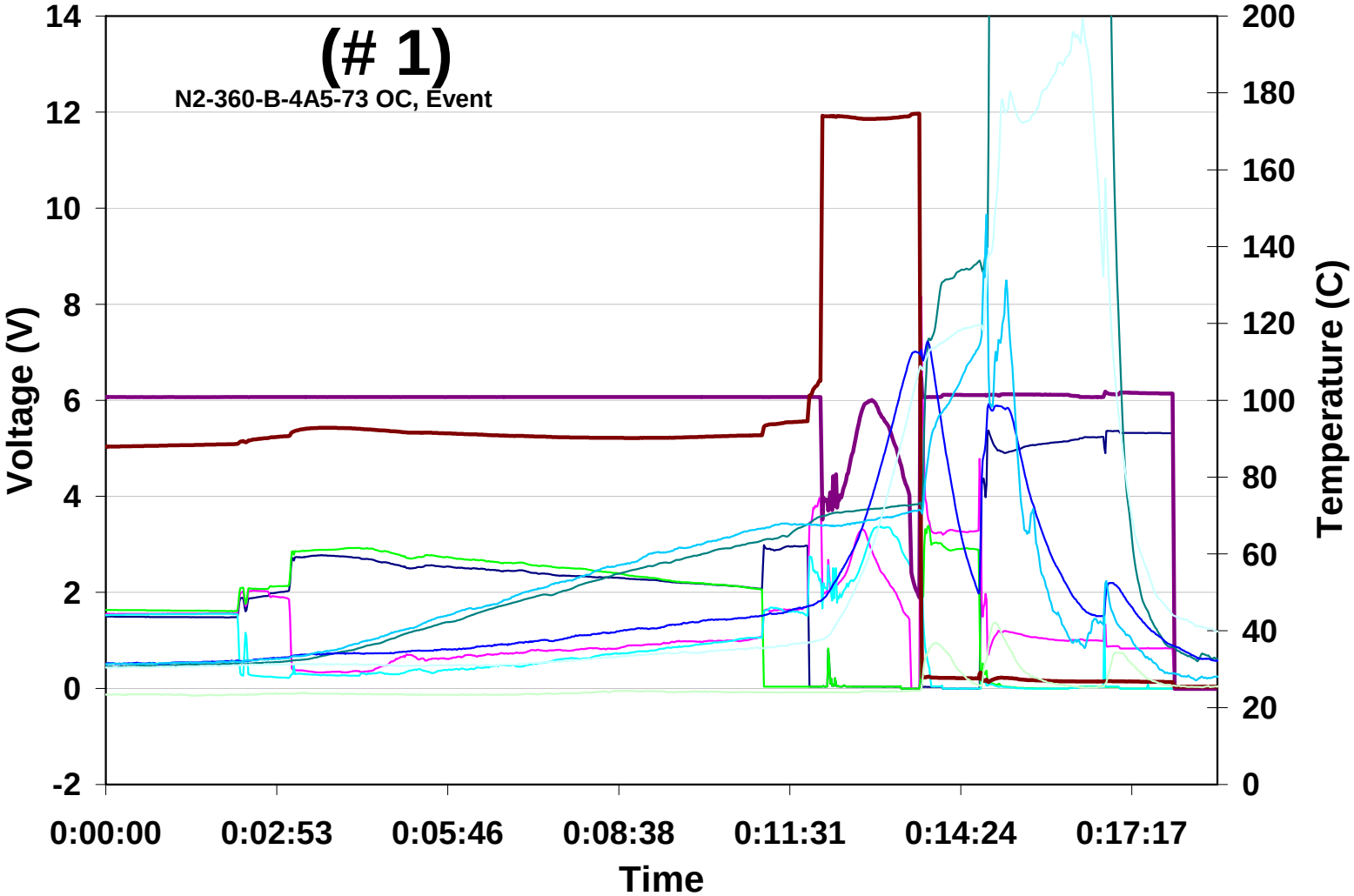

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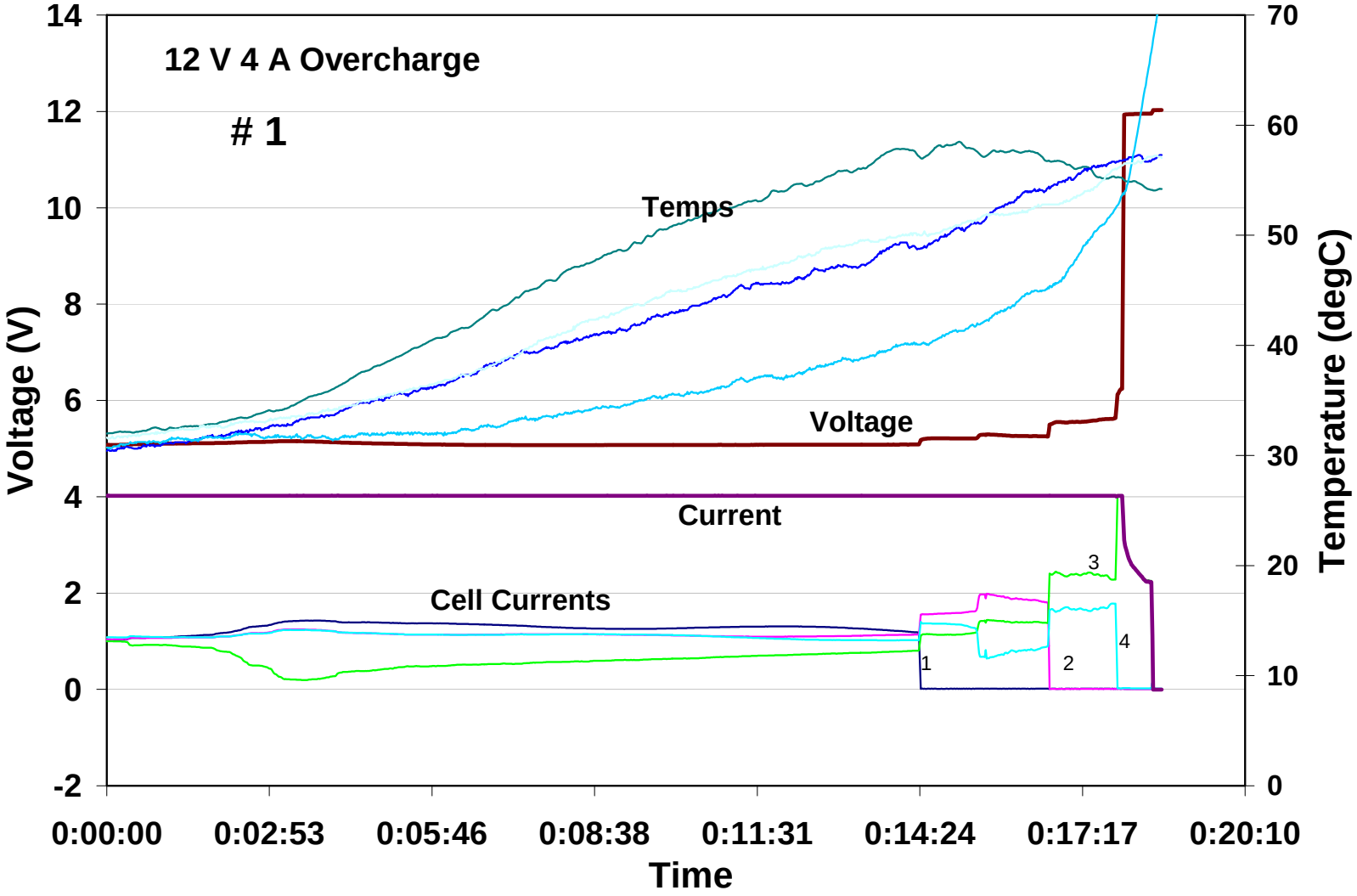
Overcharge Test on 4 Cell Bank of Cylindrical Li-ion Cells



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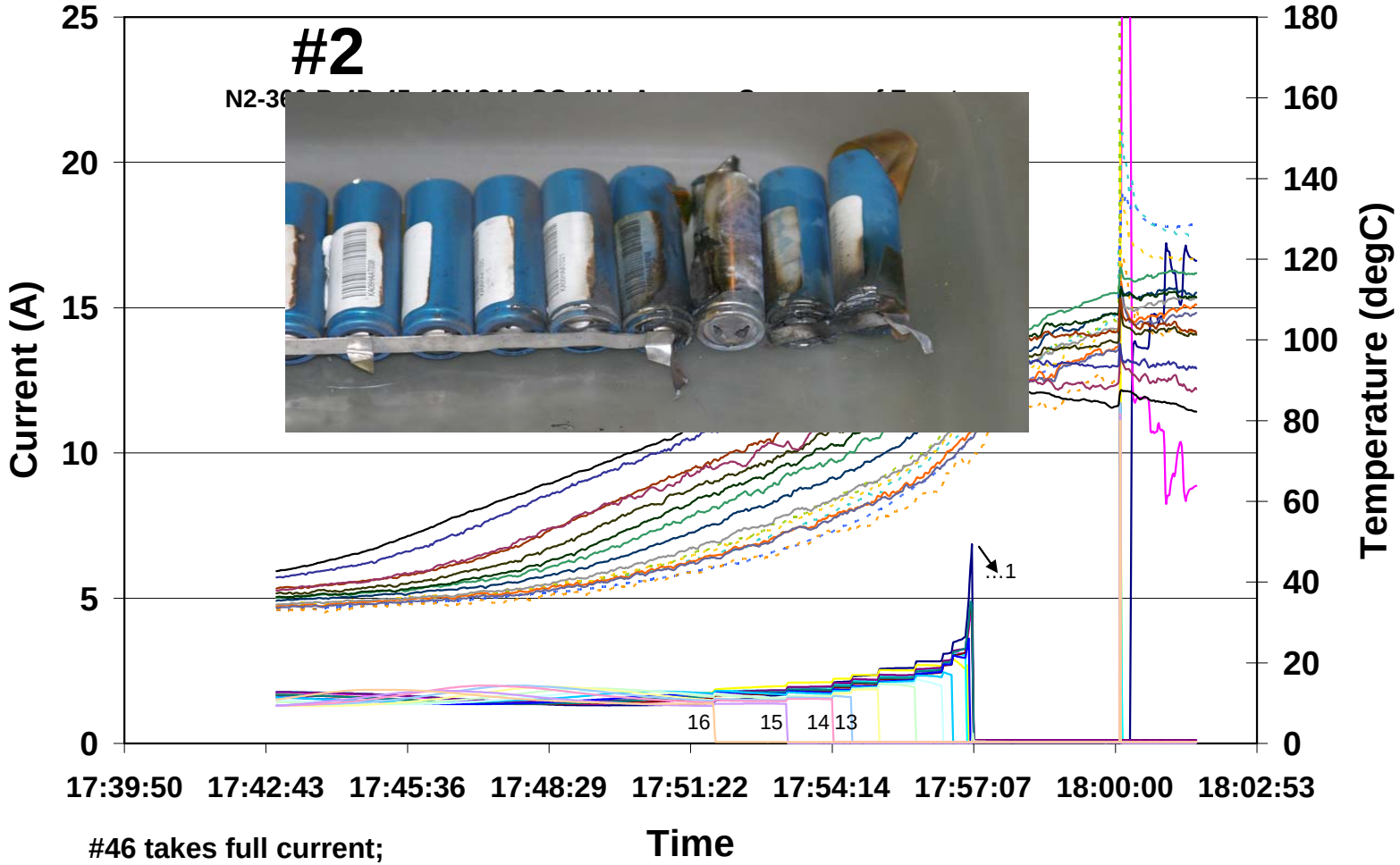
Summary of 4-cell Bank Overcharge Tests

- 4P: 6A 48 V -thermal runaway
- 4P: 6A 12 V – twice – cells vent with flames and go into thermal runaway (current fluctuations and current sharing seen; one cell vents which causes thermal propagation)
- 4P: 6A 12 V - no event (current wavers a lot; cell that shows high fluctuations was the cell that had its CID activated first; protects the rest of the cells; 39 minutes observed after CID activation; no event)
- 4P: 4A 12 V – no event (normal CID activation)

Overcharge Test on 16 Cell Bank of Cylindrical Li-ion Cells

24A / 48 V



#46 takes full current;
#45 shares that current;
Pack seemed to be in shorted state;
When Cells #46 and 45 were removed,
cells returned to normal voltage;
short gone from 46 and 45 also

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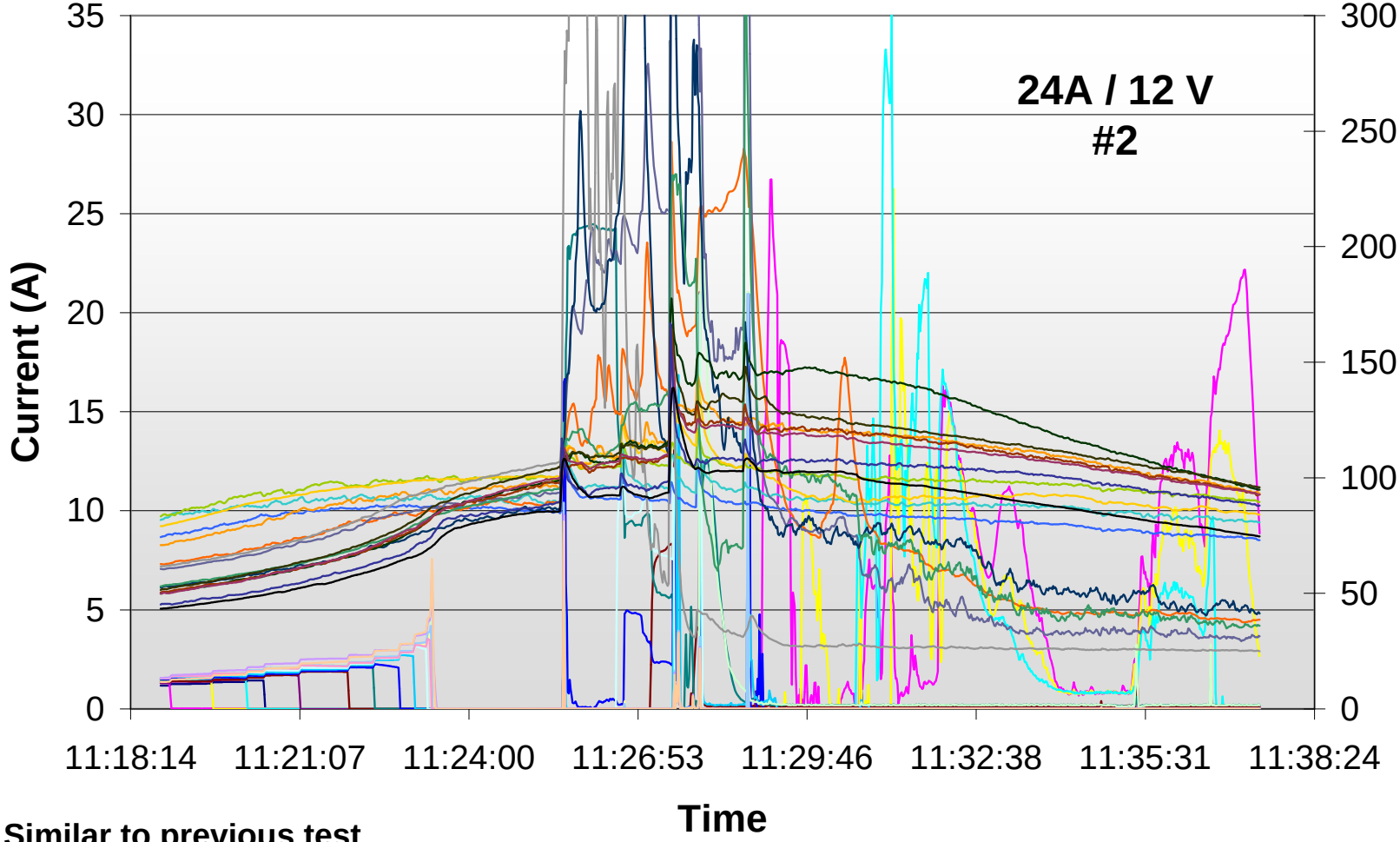
Overcharge Test on 16 Cell Bank of Cylindrical Li-ion Cells

N2-360-B-4B2-77, 12V 24A OC, 1Hz Average Summary of Event



Similar to previous test
1 cell confirmed to be in shorted condition

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Diode Research

- **ON Semi : P/N MR 754**

Summary

- Tests indicate that the cell internal protective devices have limitations similar to other electronic parts/devices; inconsistency even within same cell type seen; space-cells seem to have more tolerance to the off-nominal abuse conditions (?)
- Single cell protection or abuse tolerance need not translate to string or bank level; Cell level protective devices may not prove effective at a string or bank level.
- Design considerations should take into account the limitations of the cells and their protective components as well.
- The PTC has voltage limitations and the activation of the CID is not complete at a string or bank level leading to internal heating, which can in turn lead to short circuits due to internal heating and crimp seal meltdown; collateral damage also seen with cells due to heat transfer between cells through tabs.
- Lower current overcharges are not as catastrophic if the currents carried by the active cells in a bank are not high enough to trip the PTC or cause excessive internal heating.
- Not a big difference between the 12 V and 48 V tests for the 16P bank; shorts that are reset were observed in both tests.

Future Work

- Complete tests on at least two other commercial cells
- Carry out work on large capacity cells; Large cells have other safety features such as fusible link, composite switches, shut-down separators; inherent tolerance due to nature of cathode or anode
- Need to study if these features protect even in the presence of high voltage strings and large number of cells in banks

Acknowledgment

API: Walt Tracinski

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C. Keen
M. Piestrak

Team Members:
P. Patel
G. Varela
F. Davies
E. Darcy
J. Jeevarajan

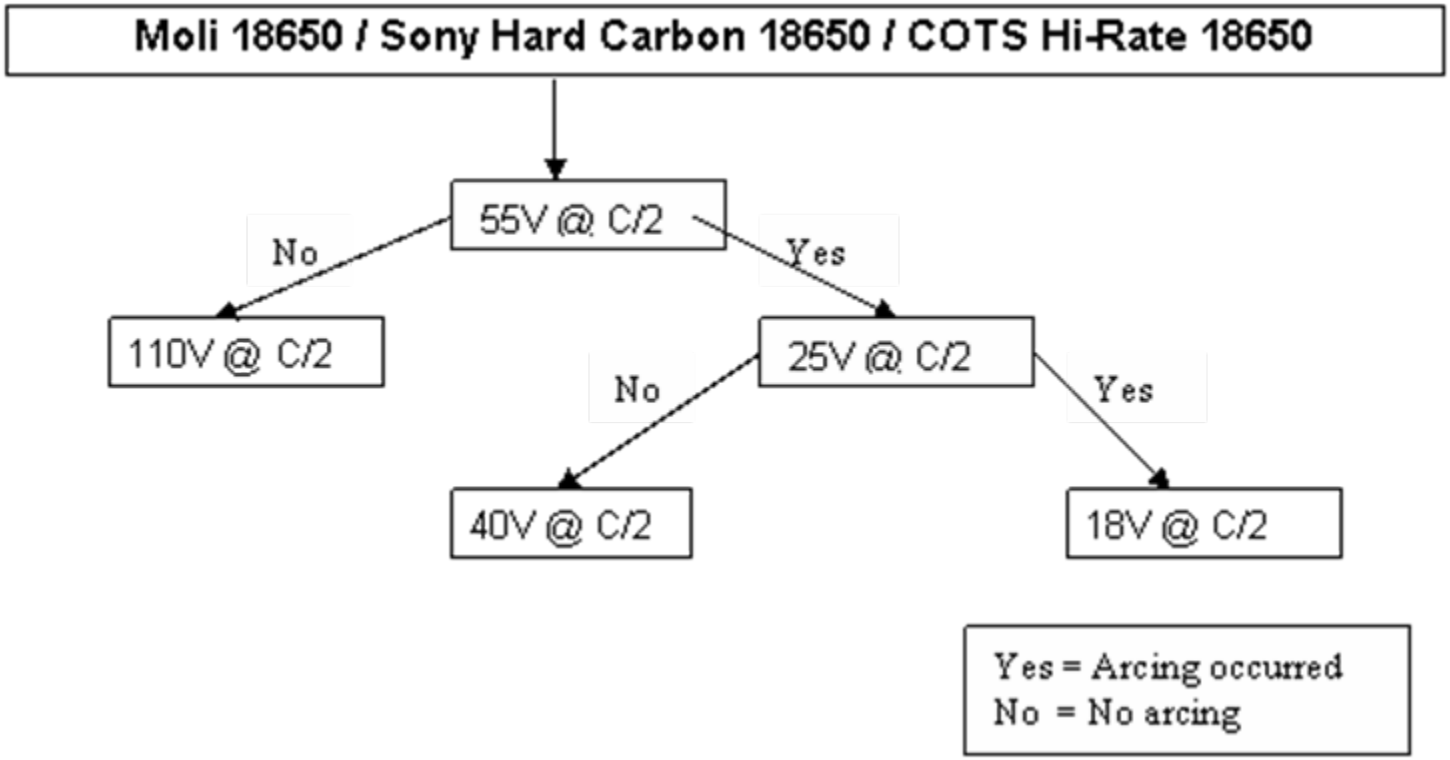
Effects of Arcing Induced by CID Activation on High Voltage Batteries

Purpose / Test Plan

- **Can CID activation induce arcing**
- **Can arcing cause large enough spark to create flame**
- **When is atmosphere in cell conducive to starting fire**
  - Amount of flammable gasses seen by CID activation site
- **Live Cell Test**
  - **Overcharge cells and observe current and voltage curves**
  - **Change power supply voltage based on occurrence of arcing**
- **Header assembly with Fixture Test**
  - **Remove header to isolate it from stack**
  - **Affix head to test fixture that will allow flow of CO2/O2 gas mixture and electrical connection**
  - **Pass current through CID while pressuring fixture**

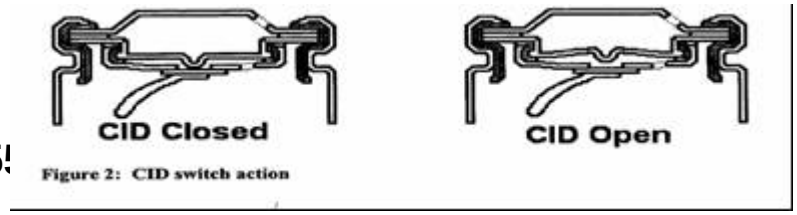
CID Test Plan

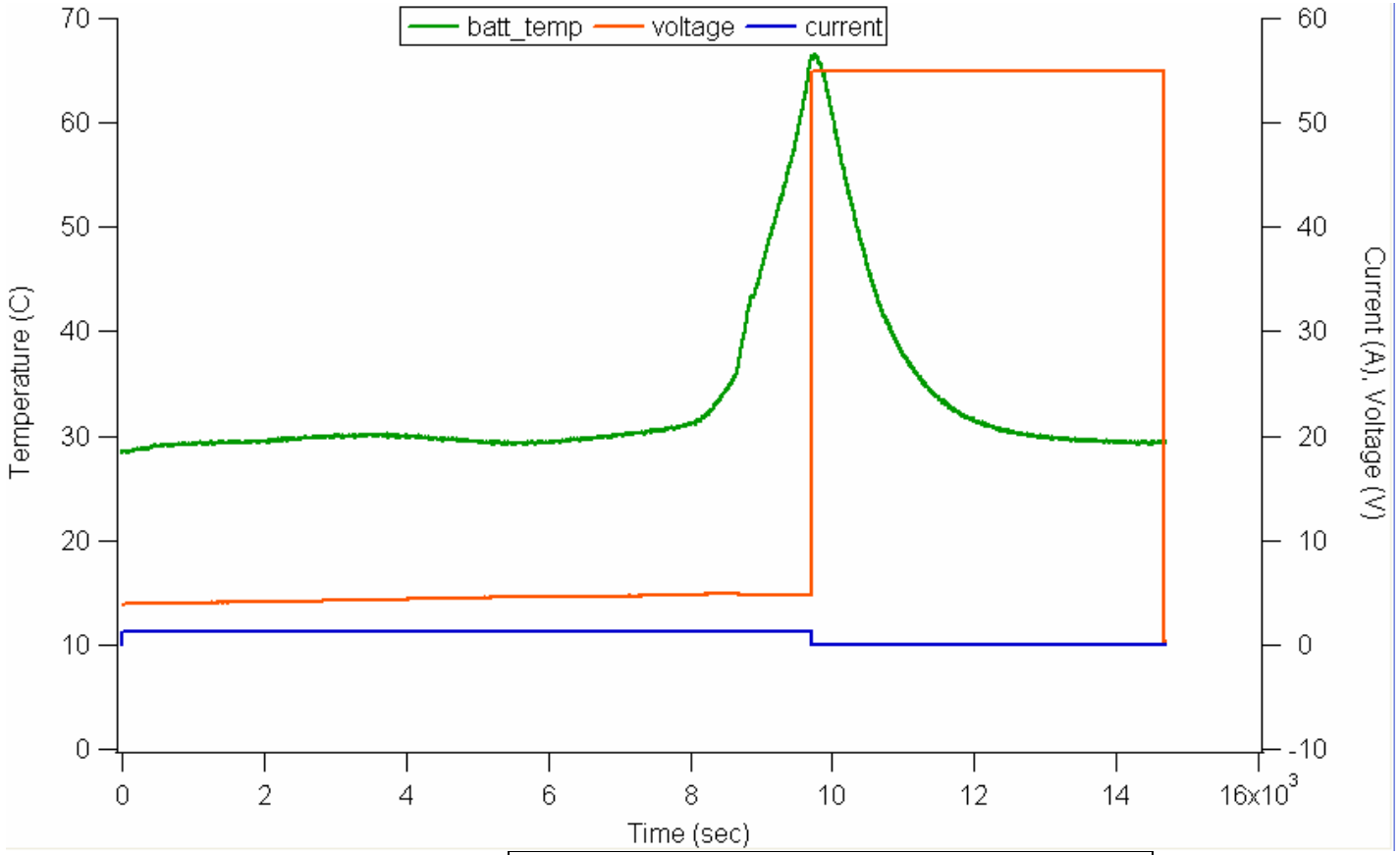
- **Single Cell Test with power supply – cells to be tested at different voltages to determine if there is arcing**
- **Header with safety features pressurized slowly in CO_2 gas environment**



Current Work

- Live Cell testing currently underway
  - Moli 18650 2.2Ah Lithium-Ion cell
  - Evidence of possible arcing seen at 5





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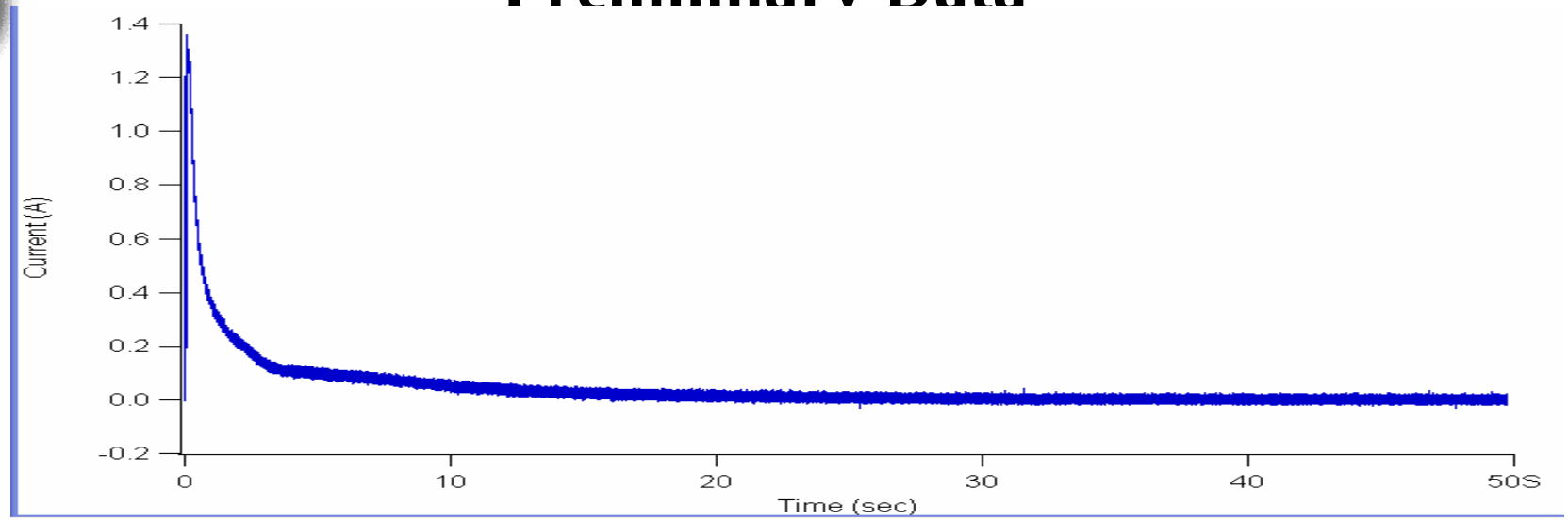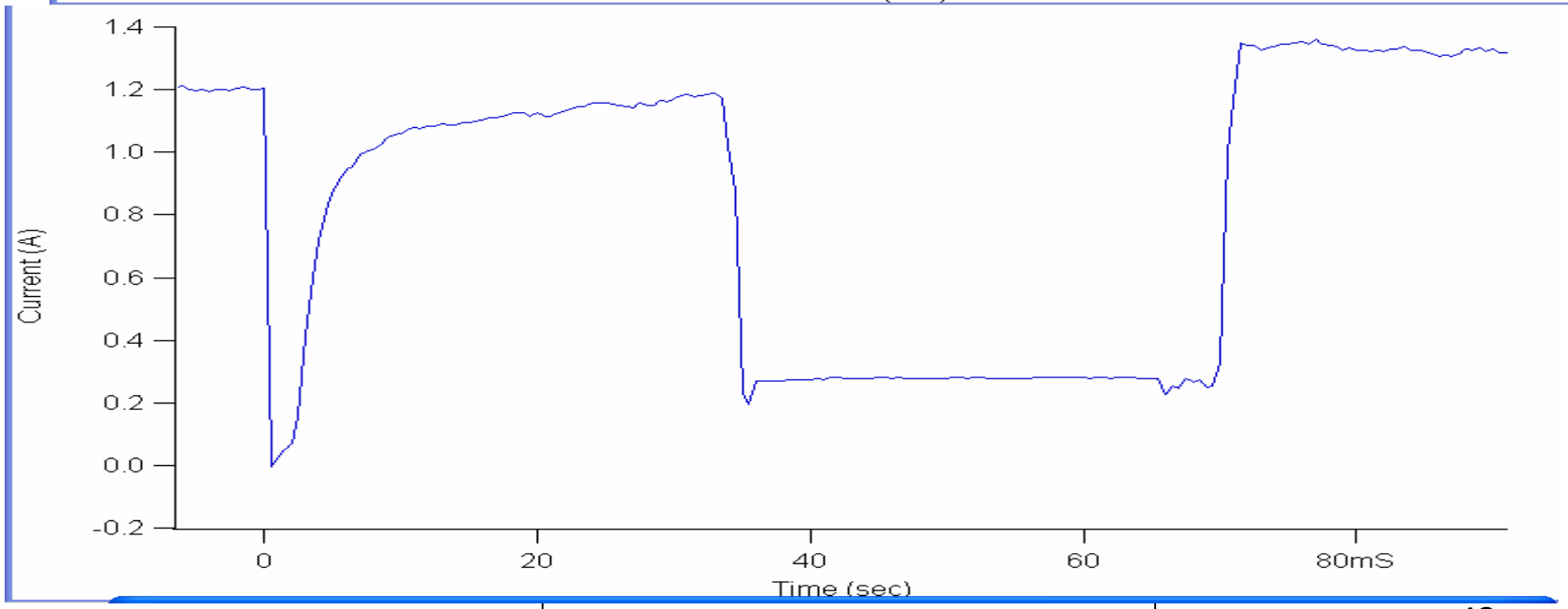
Preliminary Data