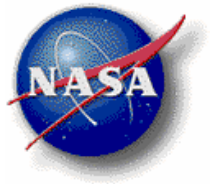

Hazards, Safety and Design Considerations for Commercial Lithium-ion Cells and Batteries

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- Hazards
- Controls and Design Considerations
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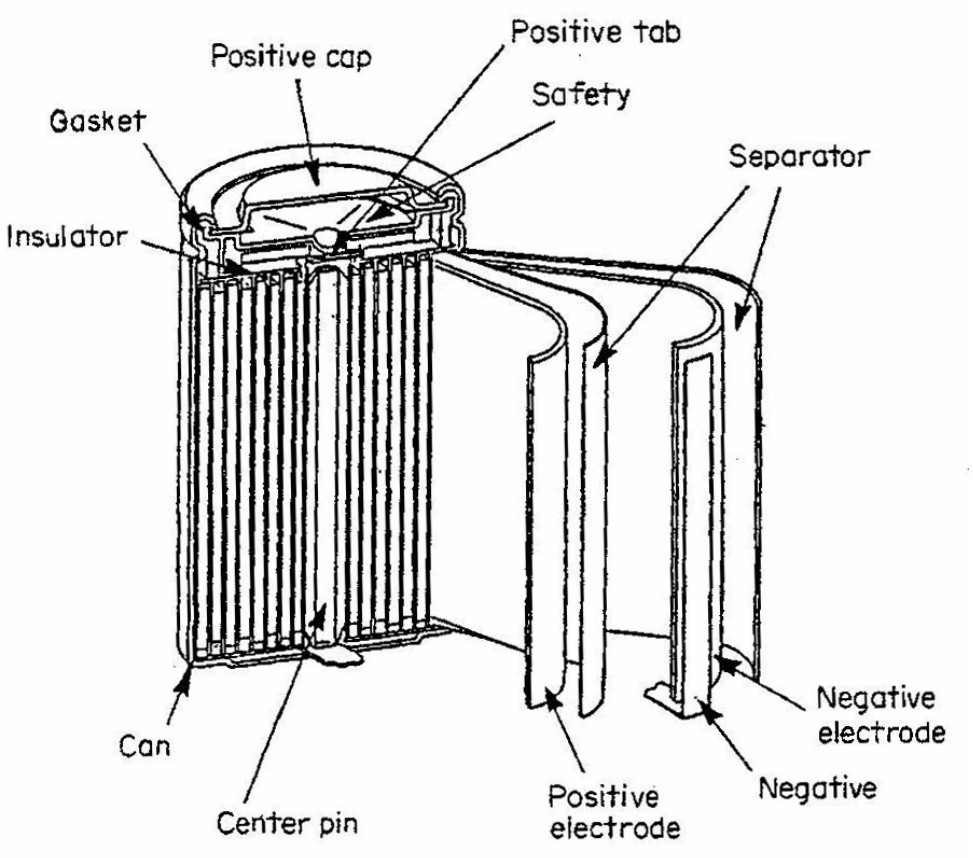
Introduction

- Highest Energy Density of Rechargeable Battery Chemistries
- No metallic lithium
- Leading edge technology
- Contains flammable electrolyte
- Charge cut-off voltage is critical (overcharge can result in fire)
- Open circuit voltage higher than metallic lithium anode types with similar organic electrolytes
- Intercalation is a process that places small ions in crystal lattice. Small ions (such as lithium, sodium, and the other alkali metals) can fit in the interstitial spaces in a graphite lattice. These metallic ions can go farther and force the graphitic planes apart to fit two, three, or more layers of metallic ions between the carbon sheets.
- The graphite is conductive.
- Very high energy density compared to NiMH or NiCd
- Corrosion of aluminum occurs very quickly in the presence of air and electrolyte due to the formation of HF from LiPF6 and HF is highly corrosive.
- For DoT, lithium equivalents should be calculated: 0.3 g per Ah.

Typical Li-ion Cylindrical Cell Construction



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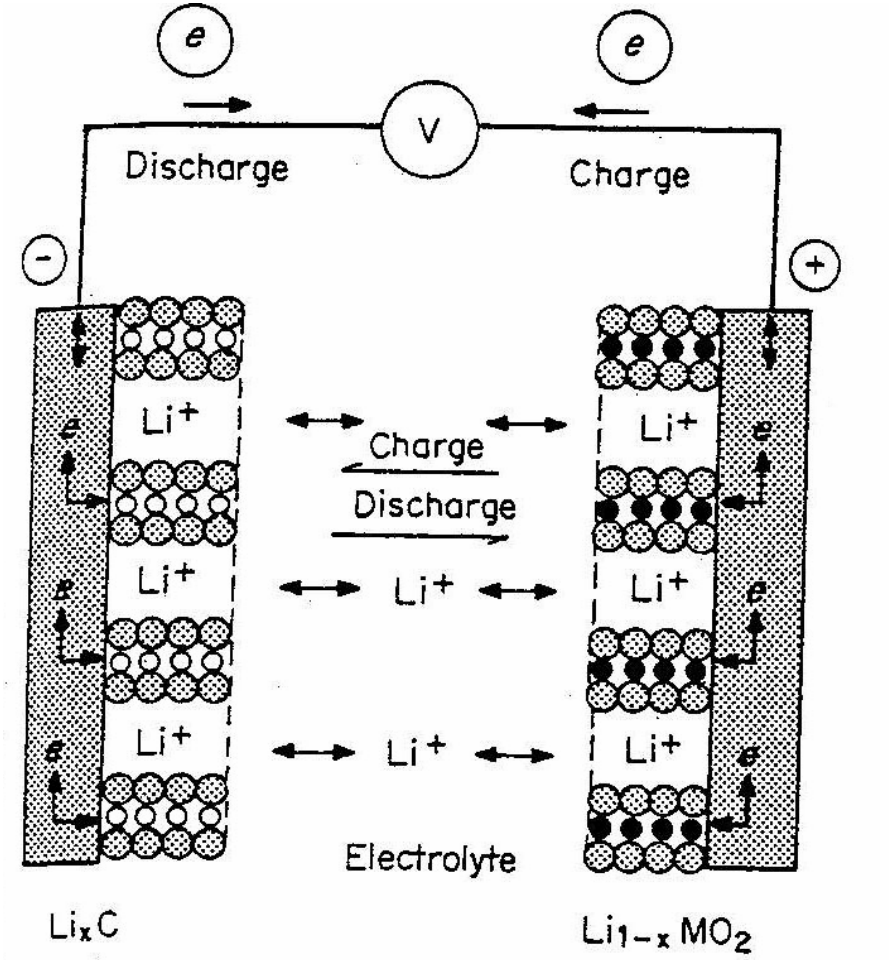
Schematic Depicting Li-ion Charge/Discharge Process



Intercalation
Deintercalation

Li-ion Cell Reactions

Anode: Carbon compound (graphite)

Cathode: Lithium metal oxide such as $LiCoO_2$, $LiNi_{0.3}Co_{0.7}O_2$, $LiNiO_2$, LiV_2O_5, $LiMn_2O_4$, $LiNiO_{0.2}Co_{0.8}O_2$

Electrolyte: LiPF6 (has a problem with aluminum corrosion), combination of carbonates (Co is very expensive)

The half reactions are:

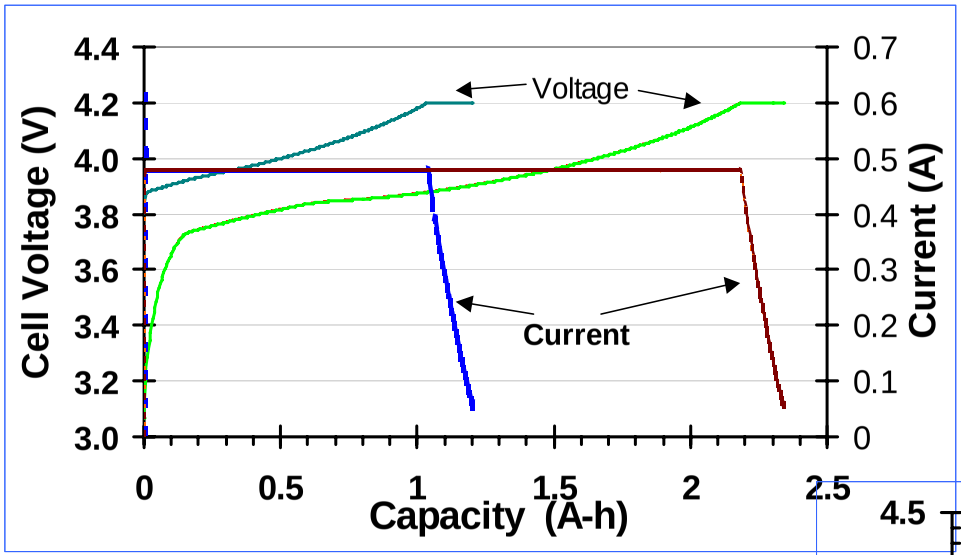
Cathode: $LiMO_2 \rightarrow Li_{1-x}MO_2 + xLi^+ + xe^-$

Anode: $C + xLi^+ + xe^- \rightarrow Li_xC$

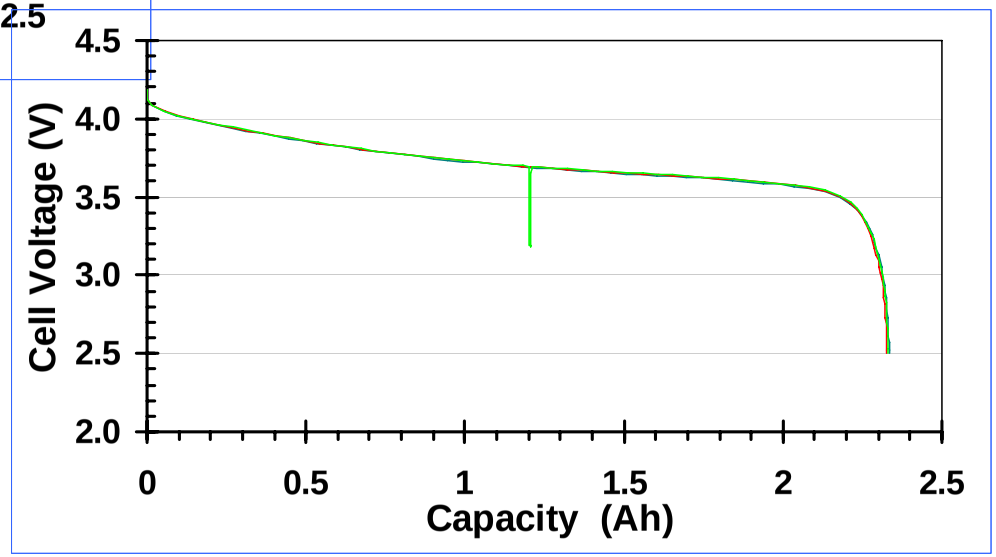
The overall reaction is: $LiMO_2 + C \Leftrightarrow Li_xC + Li_{1-x}MO_2$

Where $LiMO_2$ represents the lithiated metal oxide intercalation compound.

Typical Charge and Discharge for a Cylindrical 18650 Li-ion Cell



Charge: C/5
Discharge: 2.6 W



Hazards Associated with Commercial Li-ion Cells

- Overcharge
- Overdischarge into reversal
- External short Circuit
- Internal Short Circuit
- OverTemperature

Controls in Commercial Li-ion Cells and Batteries

Cell Level:

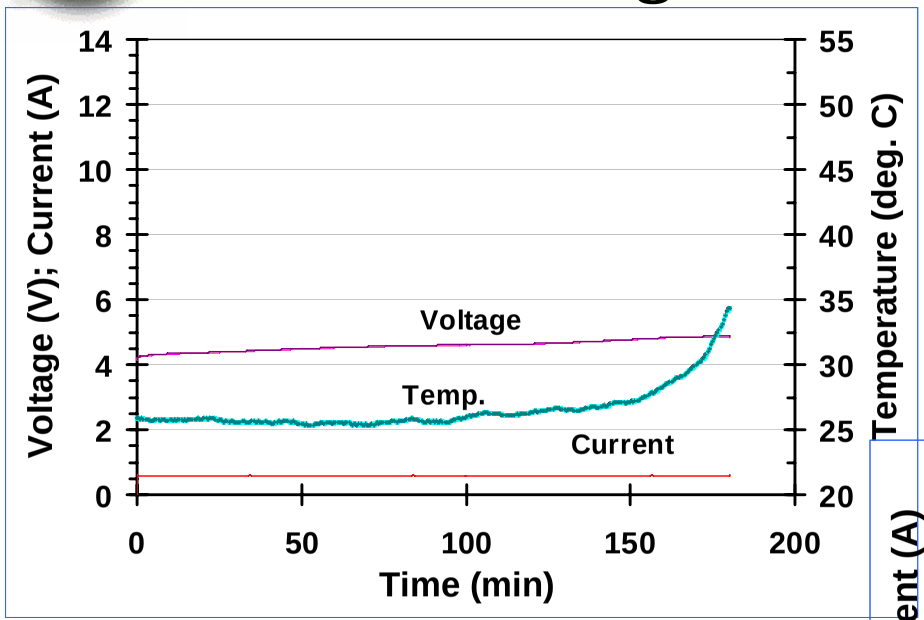
- **PTC (Positive Temp. Coefficient)– External Short Protection**
- **CID (Current Interrupt Device) – Overcharge/ overvoltage Protection**
- **Shut-down Separator**

Battery Level:

"Smart" Circuit Board:

1. **Cell Balancing**
2. **Individual cell/bank voltage monitoring**
3. **Current control**
4. **Hard-blow and thermal fuses**
5. **Overvoltage and Undervoltage cutoff using MOSFET switches**
6. **Thermal sensors**

Overcharge of Commercial Li-ion Cells

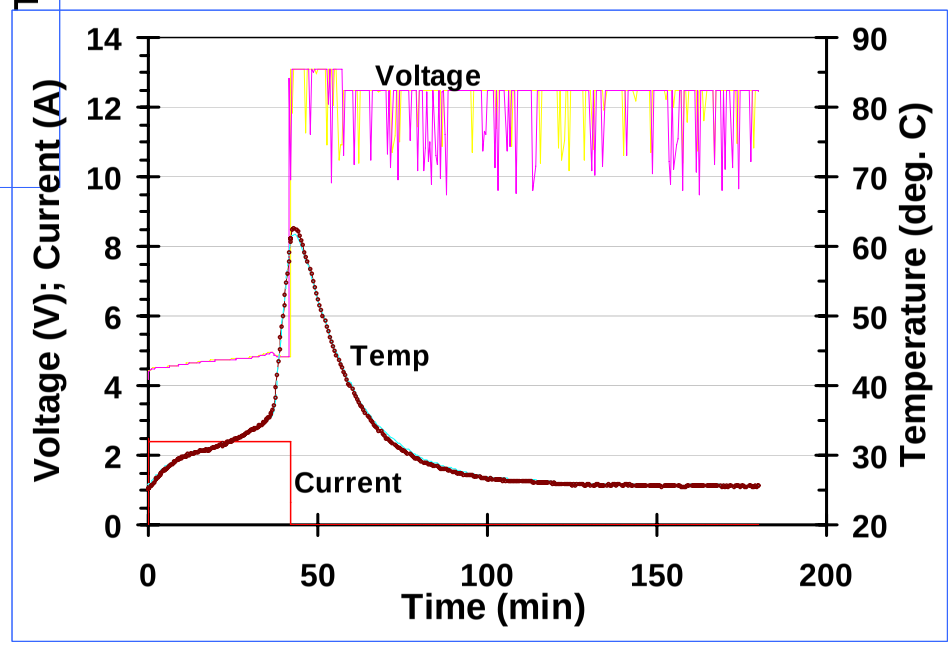


0.6 A Charge

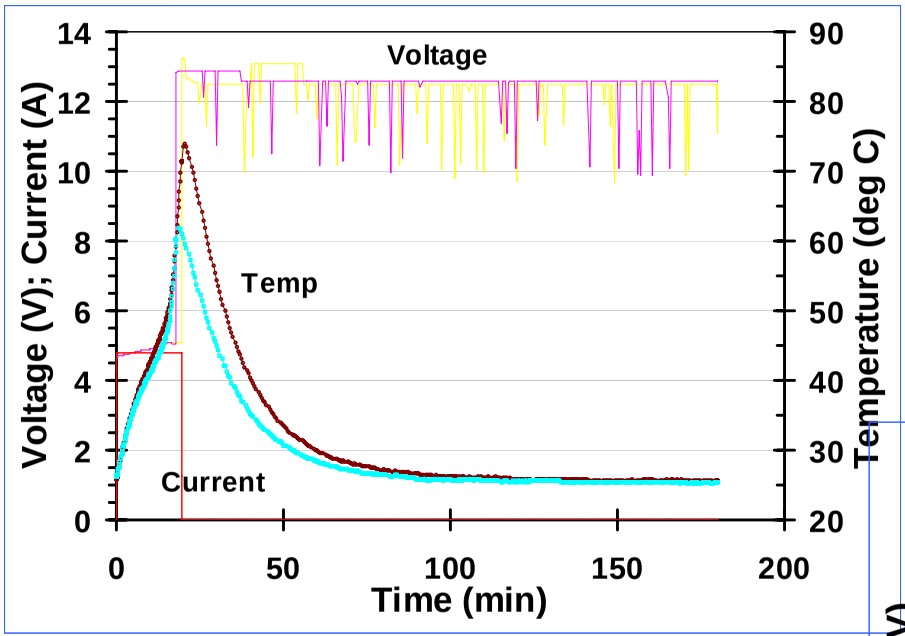
No CID trip

2.4 A Charge

CID trip in 42 min



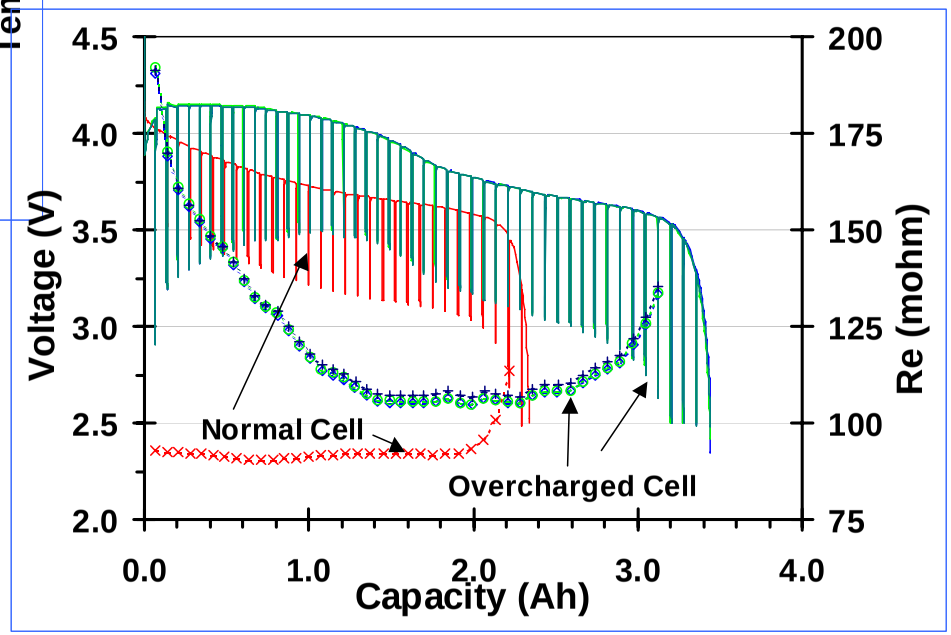
Overcharge Tests on Li-ion Cells



4.8 A Charge

CID Trip in 18 min.

Internal Resistance Comparison



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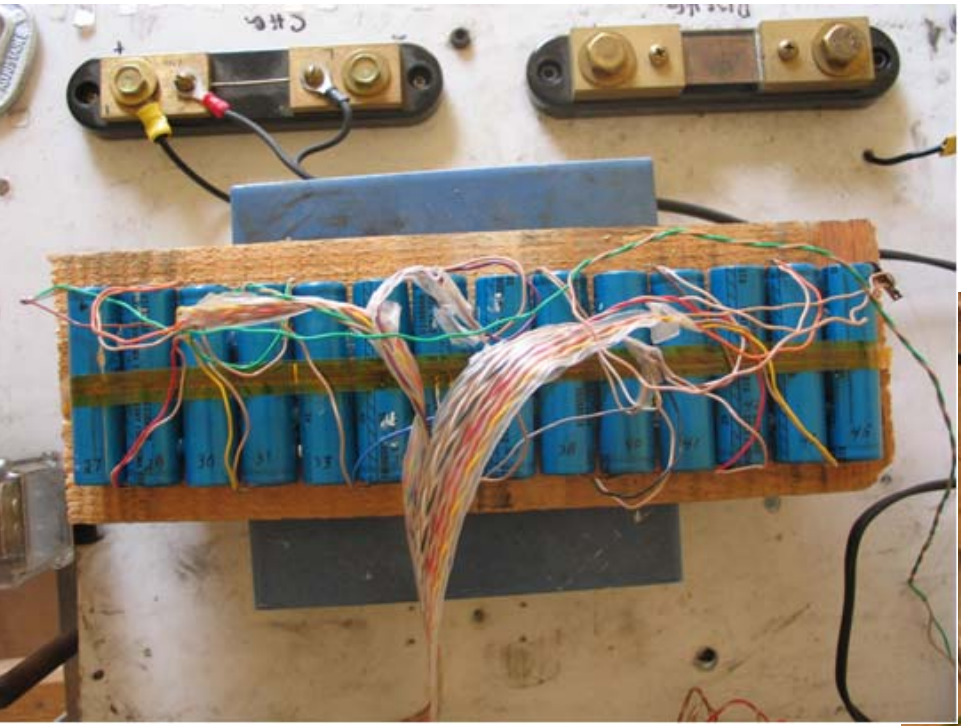
Limitations of Overcharge Protection ??

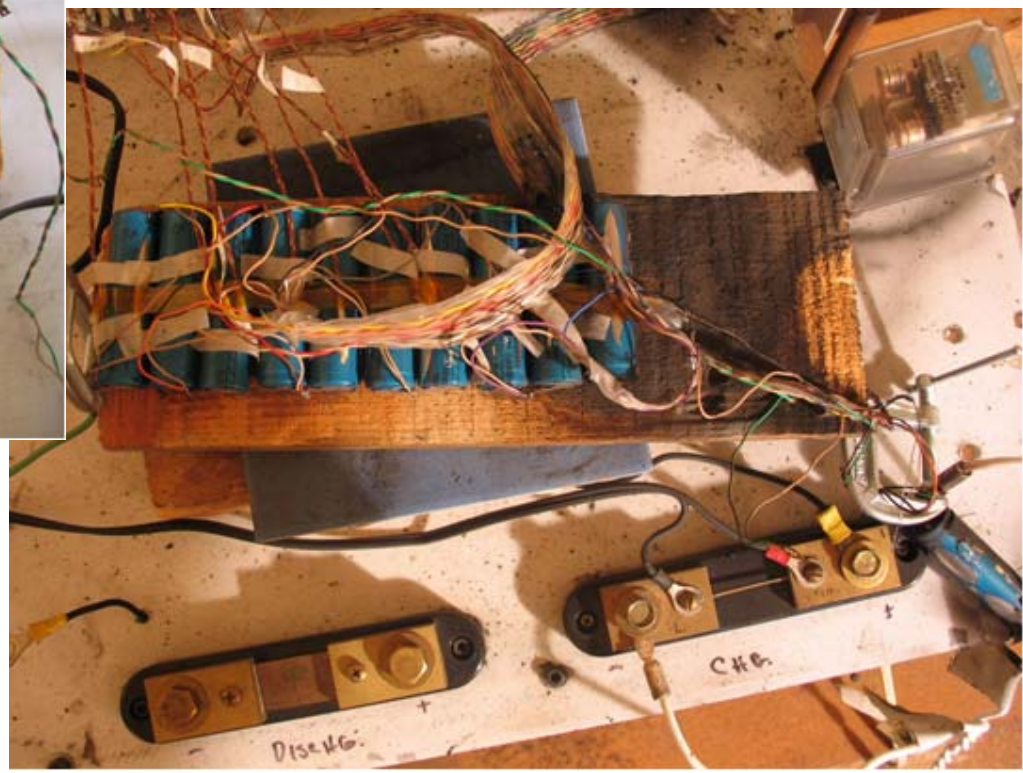
- **Overcharge Protection in some COTS Cylindical Cells is provided by the Current Interrupt Device**
- **Works for single cells and a group of four cells but does not hold for higher voltage cell strings**

Cell #31

Cell #30

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





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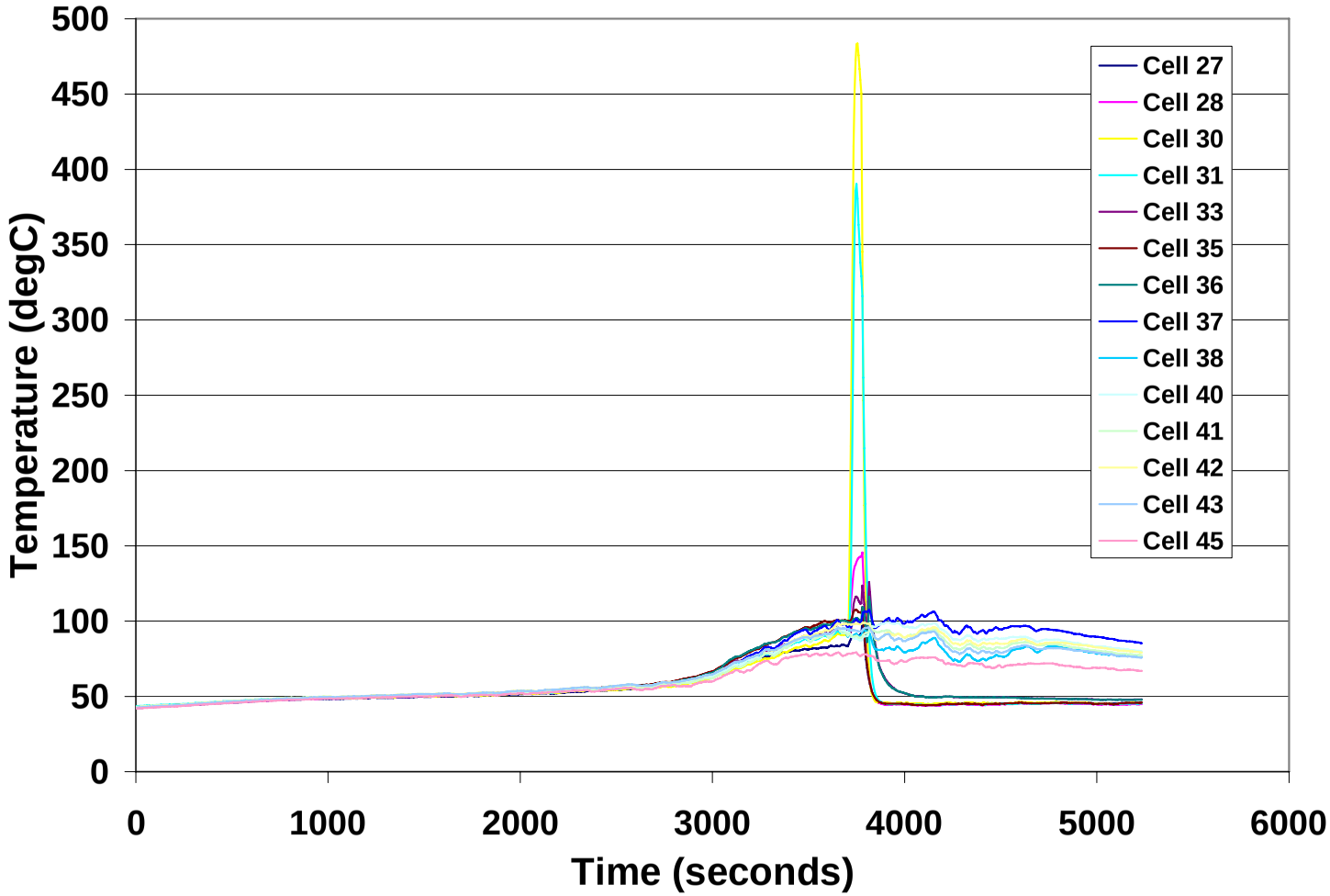
Overcharge Test on a 14-Cell String Showing Cell Temperatures for the Cylindrical Li-ion Cells



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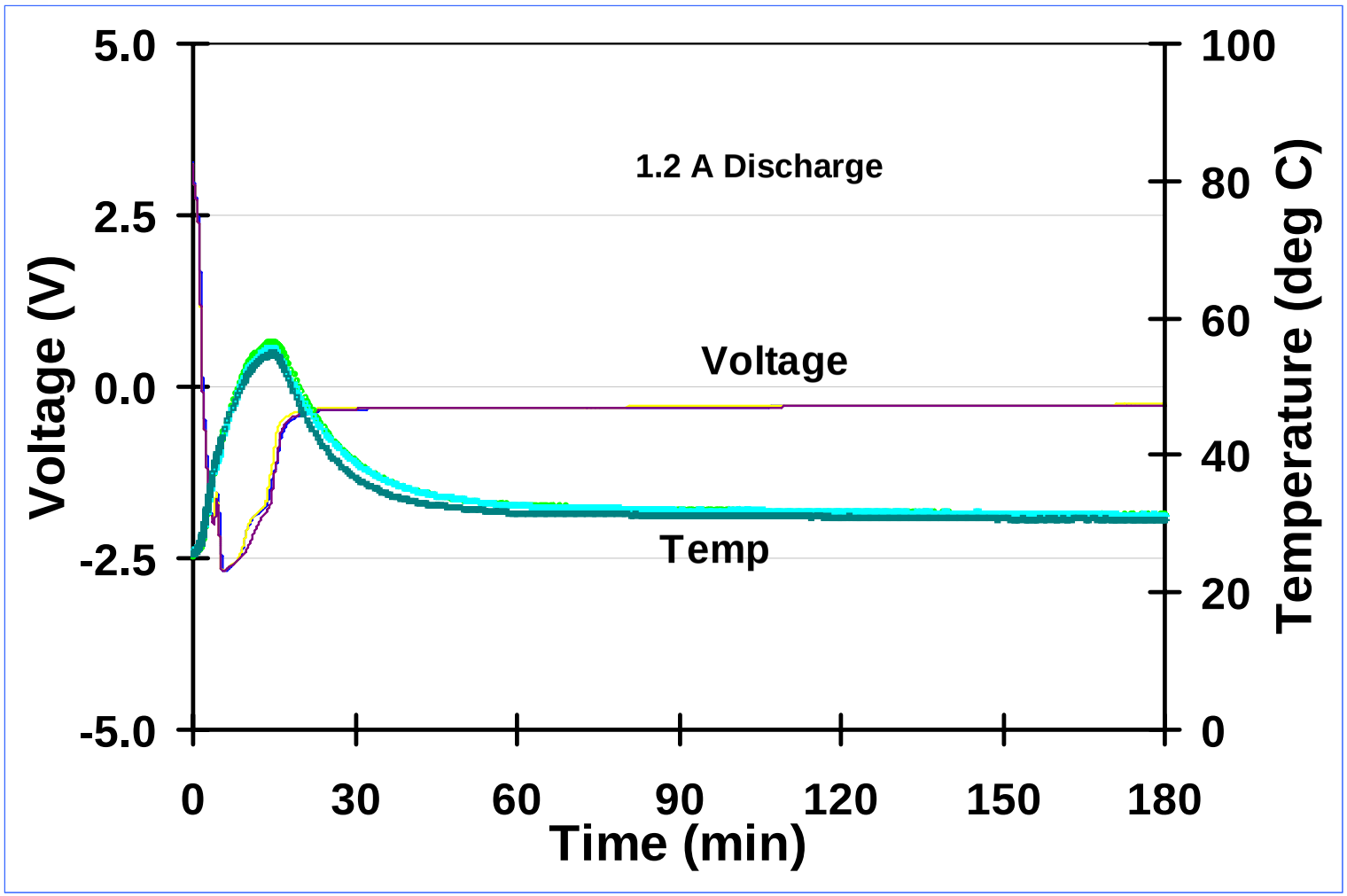
Overdischarge into Reversal for a Li-ion Cell



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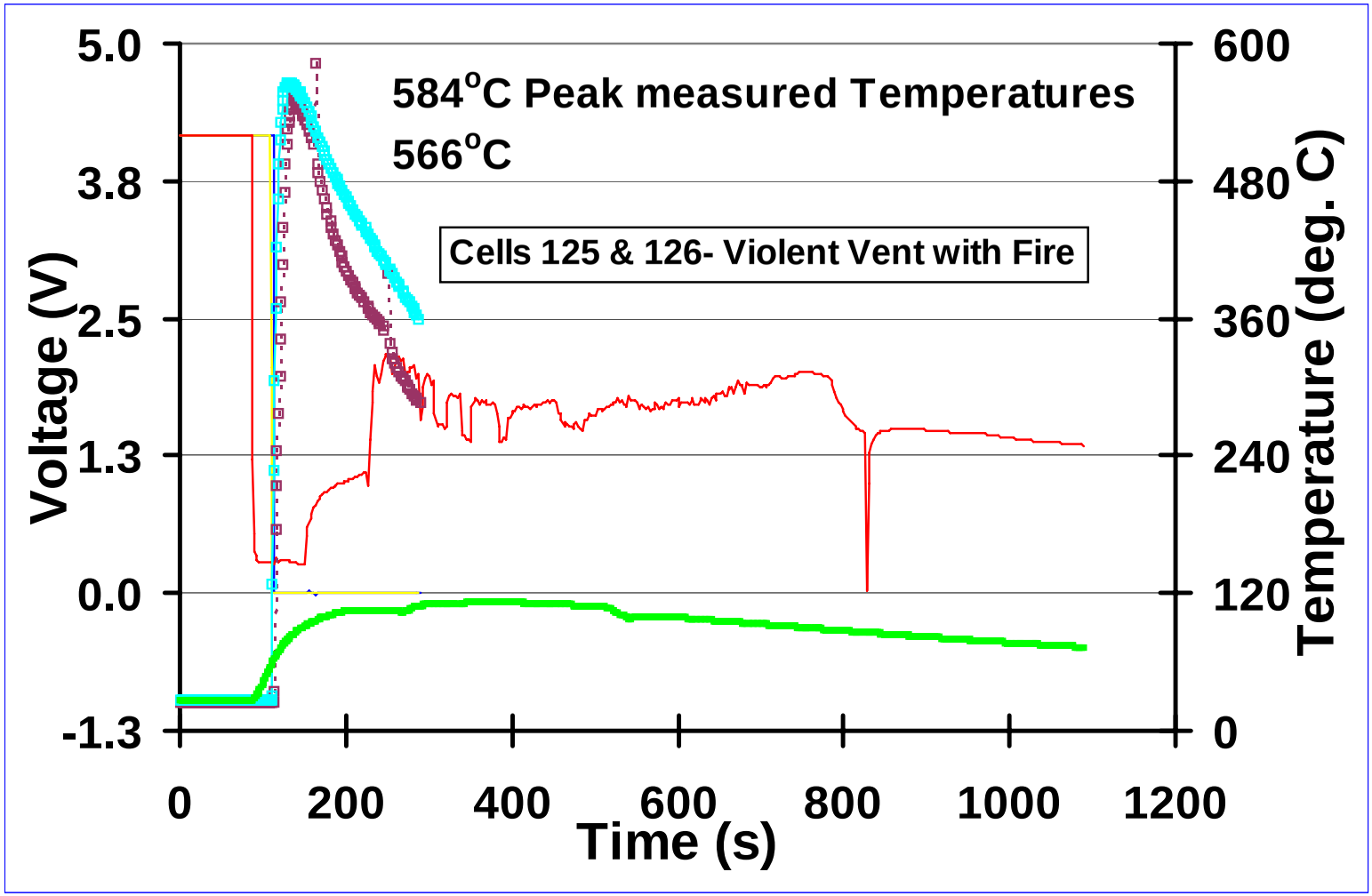
Simulated Internal Short or Crush Test on Moli Li-ion Cells



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Simulated Internal Short or Crush on Sanyo Li-ion Cells

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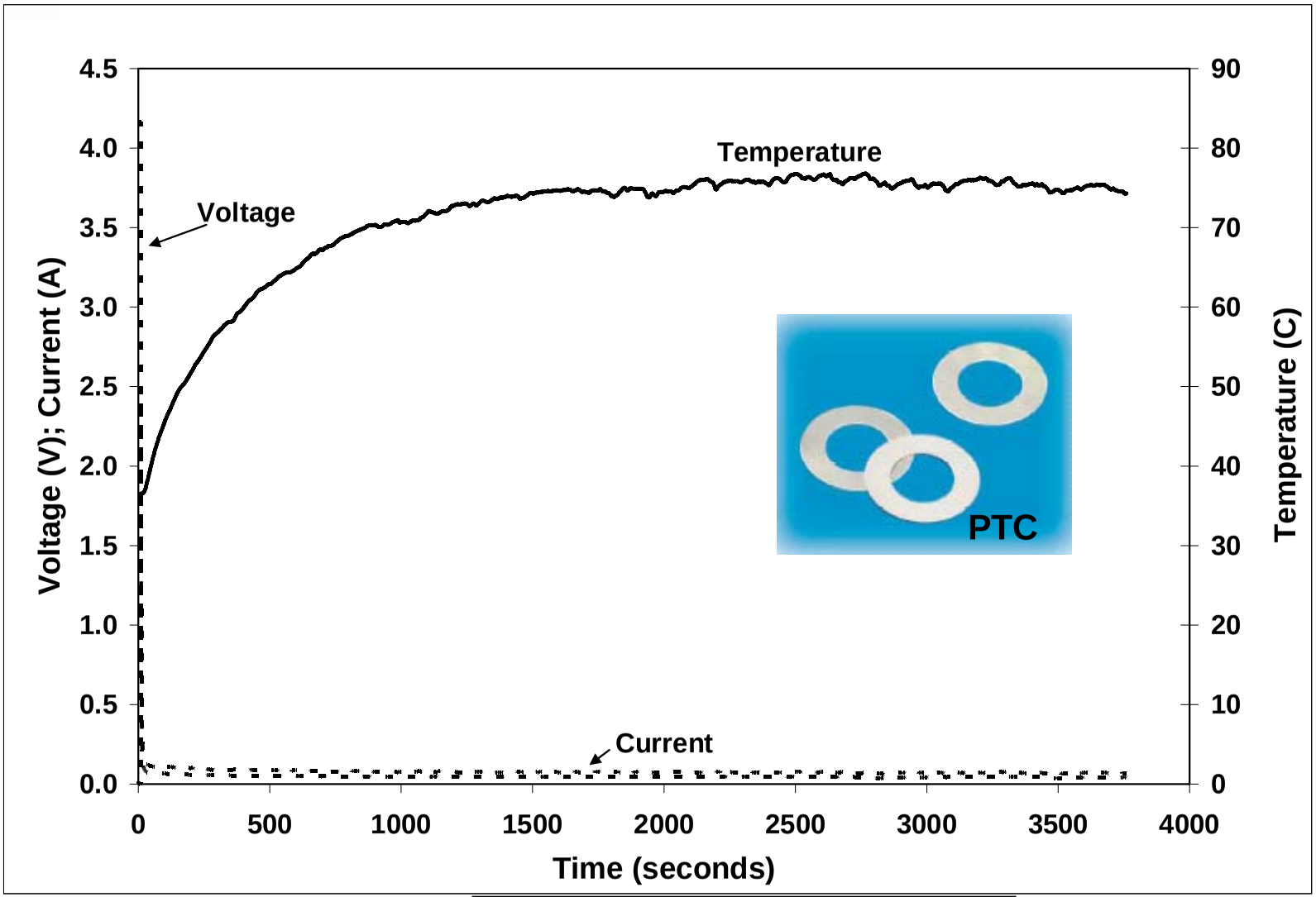
External Short Circuit on a Li-ion Cell



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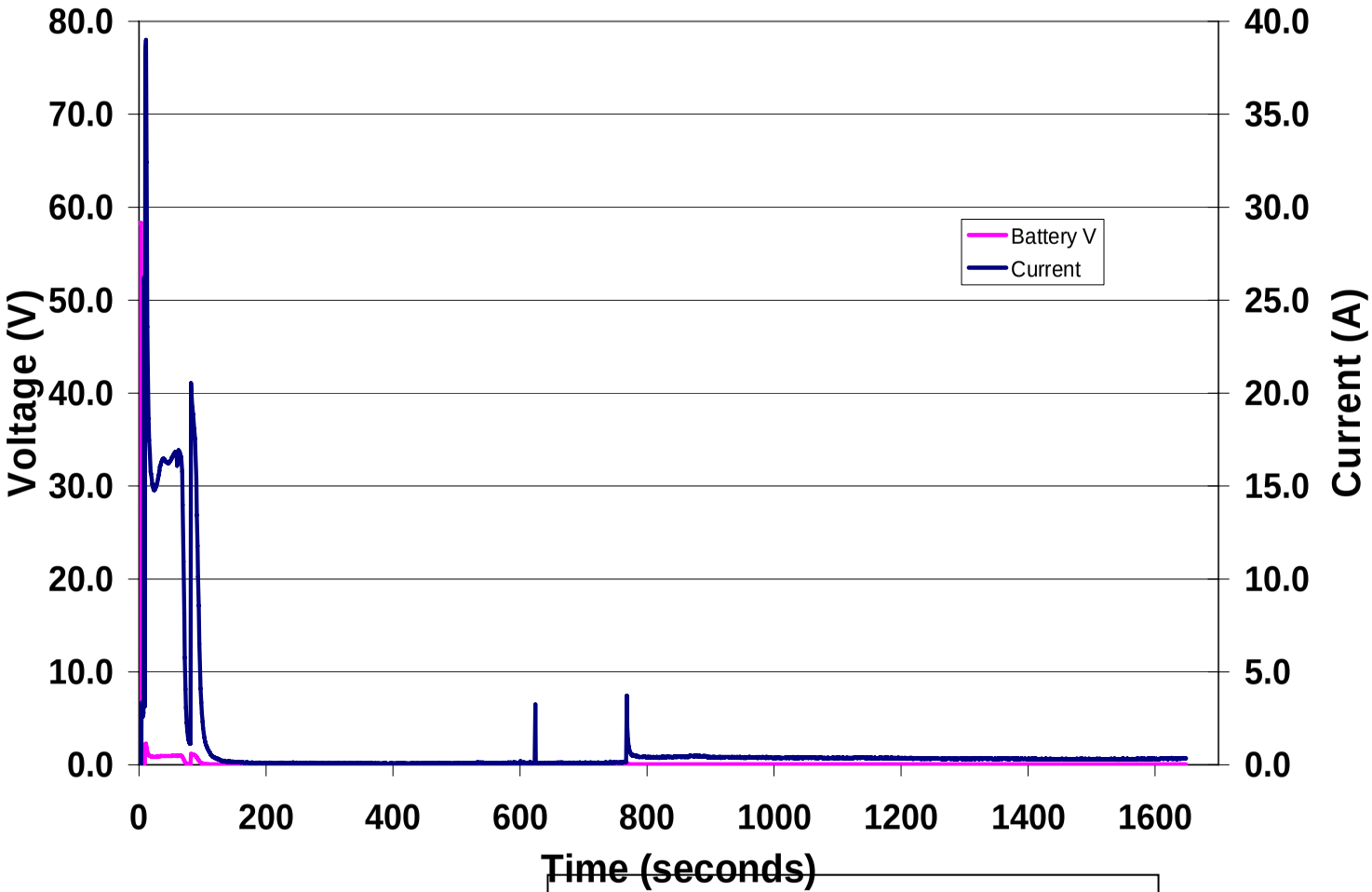
Battery Characteristics Under an External Short Test on a 14-Cell String of Sony Li-ion Cells



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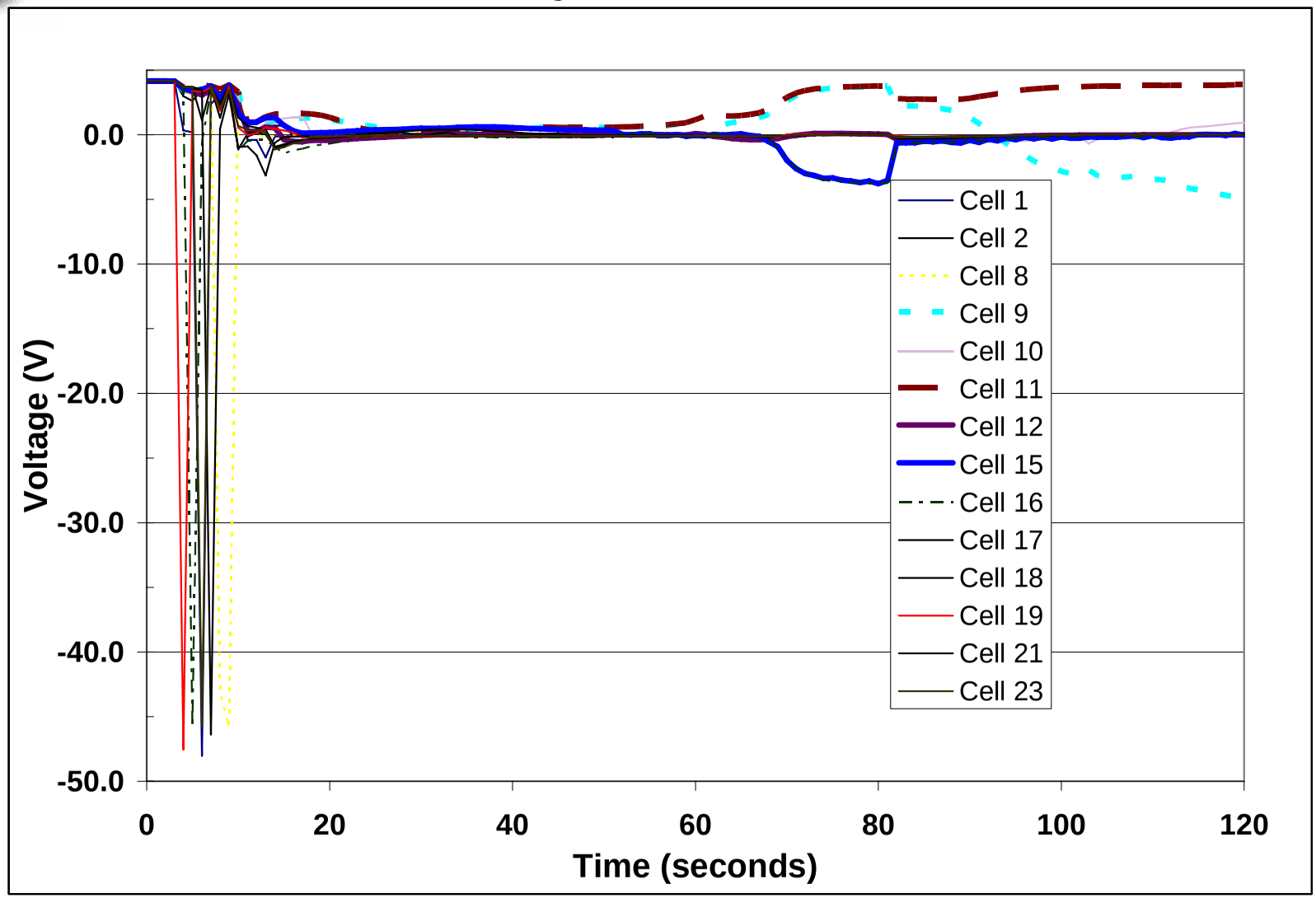
Cell Voltages During 14-Cell String Short Circuit Test on Cylindrical Li-ion Cells



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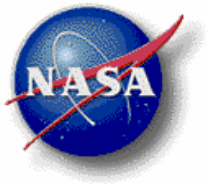
COTS Cell Uncertainties

- Quality Control may not be stringent enough.
- Always had issues with cells made under less stringent quality control methods
- Contamination may cause internal shorts that can be hazardous after launch vibration.
- Can cause cell voltage divergence and hence overcharge or overdischarge if cell balancing is not available.
- At battery level, lack of quality control can again cause issues of shorting, high temperatures and resulting flame and fire.



Summary and Conclusions

- Due to lack of control over manufacturing line, need to have adequate heritage and data on cells and batteries used for flight.
- Need to perform engineering, qualification and flight acceptance testing.
- Need to perform Lot sample testing for each new lot.
- Need to understand cell and protective device limitations

Acknowledgment

NASA-JSC Test Team Members