Use of Lithium IronDisulfide Cell for the Orbiter Wing Leading Edge Impact Sensor

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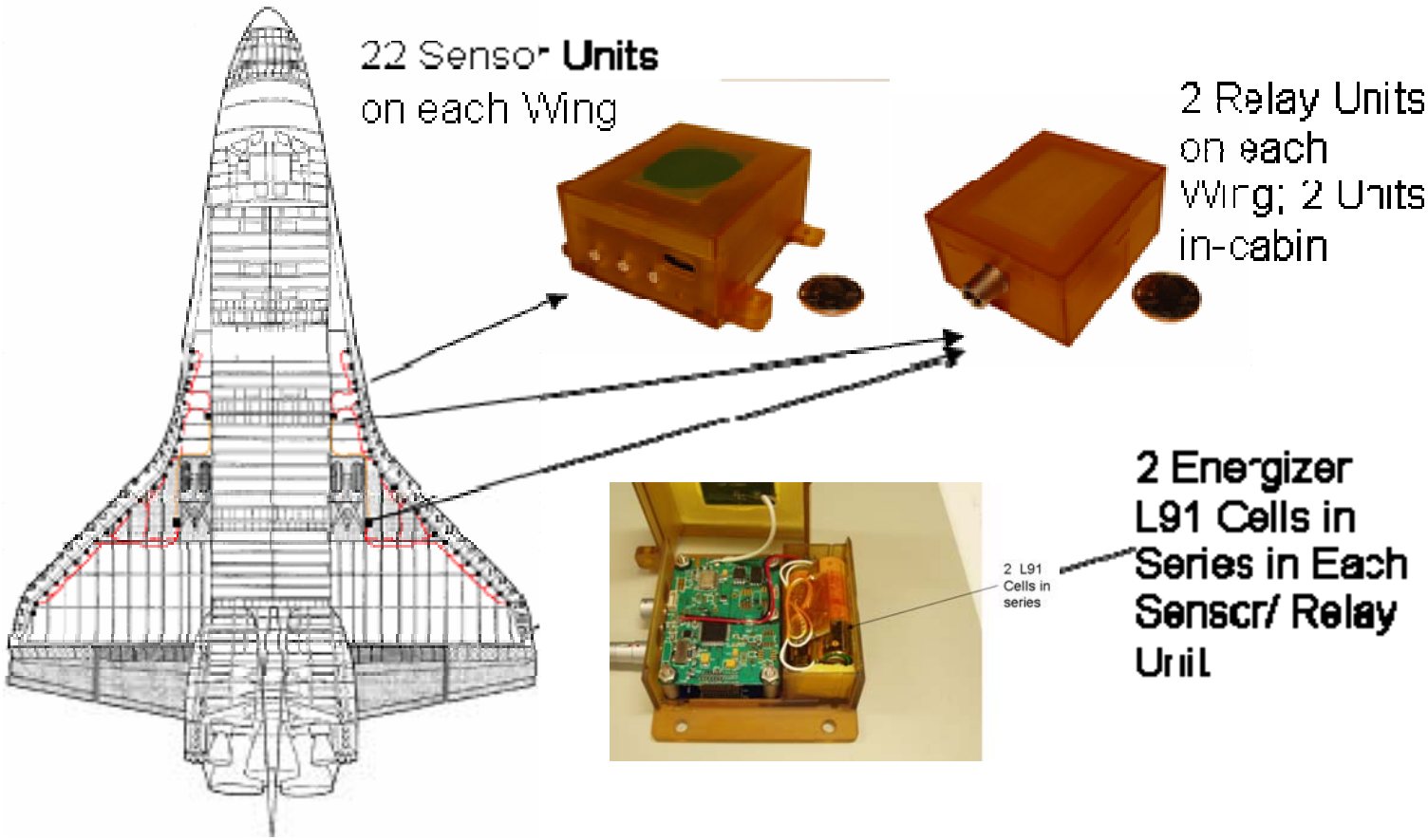
Introduction

- The Wing Leading Edge Impact Sensors used two $LiFeS_2$ (Energizer) cells in a series combination.
- The first design for the battery had a single LiBCX cell.
- Due to the high temperatures predicted during the descent phase of the Mission, the battery was changed from a LiBCX to a $LiFeS_2$ cell.

Orbiter Schematic with Locations of the Impact Sensors



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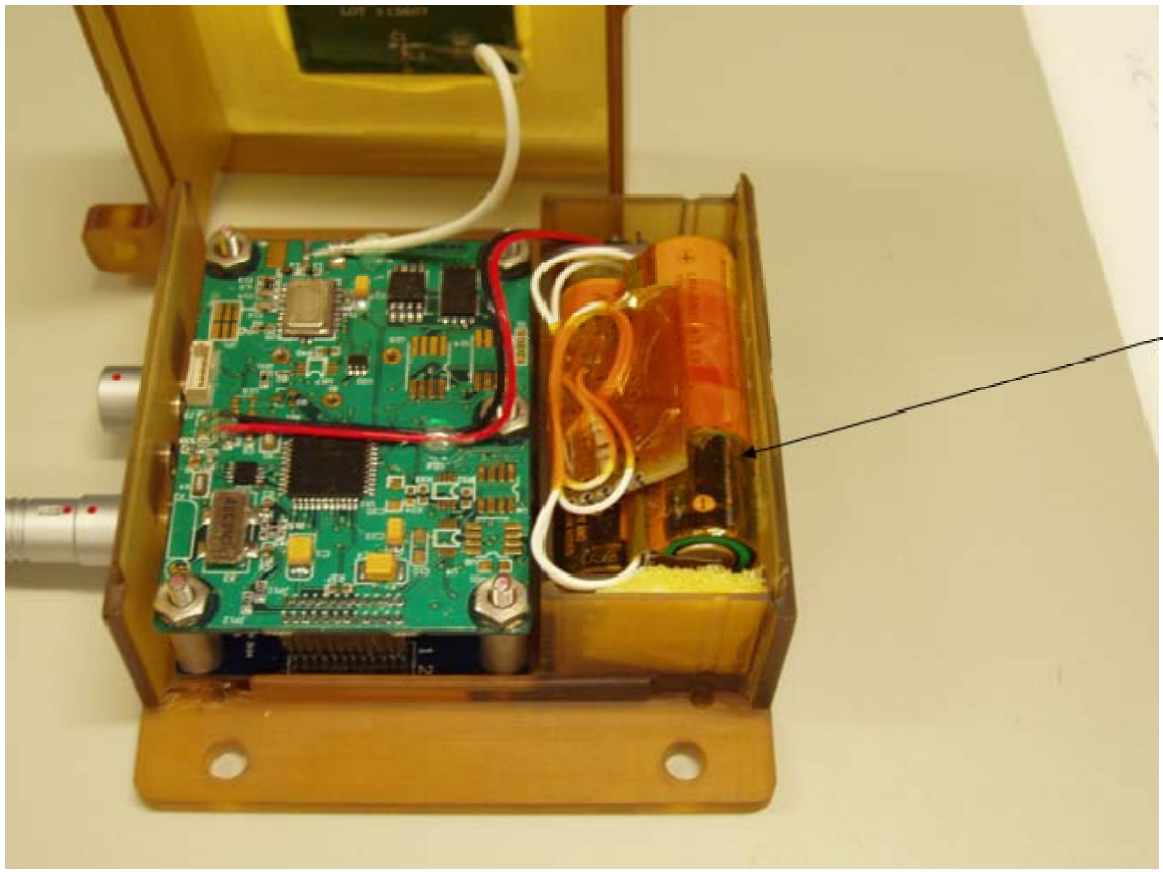
Sensor Unit with Battery



Chemistry of Two Li Batteries

$LiFeS_2$: Cathode is FeS_2 which is a solid that is mixed with carbon. FeS_2 has a high melting point. Electrolyte is organic in nature. Flammable but does not have explosive hazard potential like $SOCl_2$, SO_2 or SO_2Cl_2.

Lithium metal electrode.

LiBCX : contains $SOCl_2$ as major component with small amount of BrCl additive. In total electrolyte, $SOCl_2$ forms 83 %, Cl_2 forms 3.6 % and Br_2 forms 8.3 % with $GaCl_3$ and LiCl forming the rest of the electrolyte.

$SOCl_2$ is very energetic and explosive. Liquid forms 45 to 50 % of cell weight.

Lithium metal electrode.

Energizer L91 $LiFeS_2$ Cells

Flight Configuration

Background on Application and Requirements

- Initial choice by project team - LiBCX for the Wing and in-cabin application.

- Due to new Tox 4 awareness, rejected LiBCX battery usage for in-cabin application and recommended the use of $LiFeS_2$ cells instead.

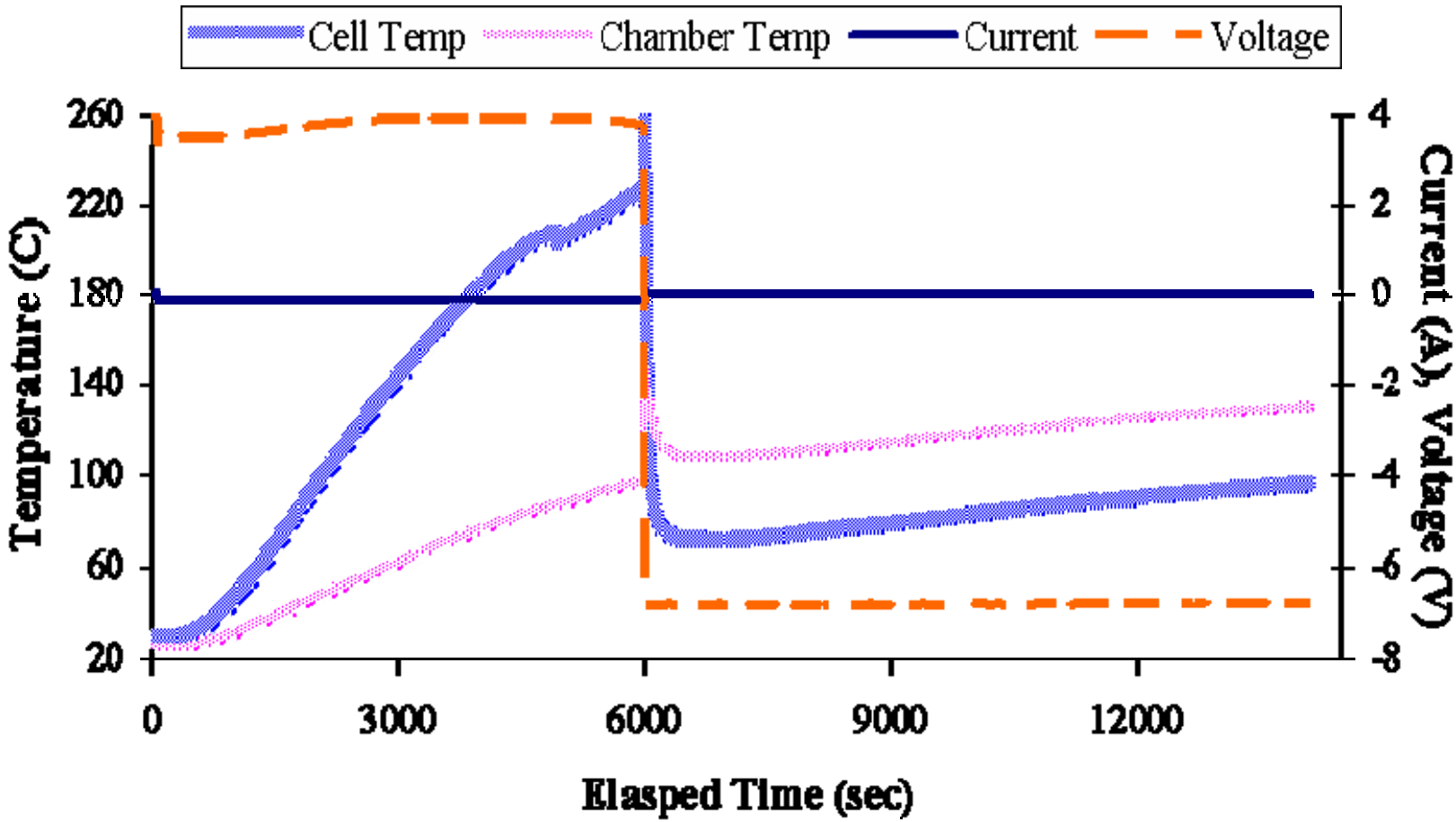
- $LiFeS_2$ cells: 2 cells will be required to provide the required voltage.
  - **The performance will be less than half that of the LiBCX (2.9 Ah for $LiFeS_2$ vs 6.5 Ah for LiBCX). But toxicity is level 2.**

- Thermal environments on the wing are higher than those specified for nominal operation of LiBCX cell design.
  - **Concerns raised by the safety panel on off-nominal thermal environments as LiBCX cells have TNT equivalency when they explode.**

- Thermal environments as provided in WLE ICD: -135 to 160 ° F during on-orbit;
  - **temperature expected during reentry is 215 ° F.**
  - **Qualification test was to 240 ° F at hot end and -135 ° F at cold end.**

Test Data on Li-Sulfur type and $LiFeS_2$

Heat-to-Vent Test on LiBCX Cells



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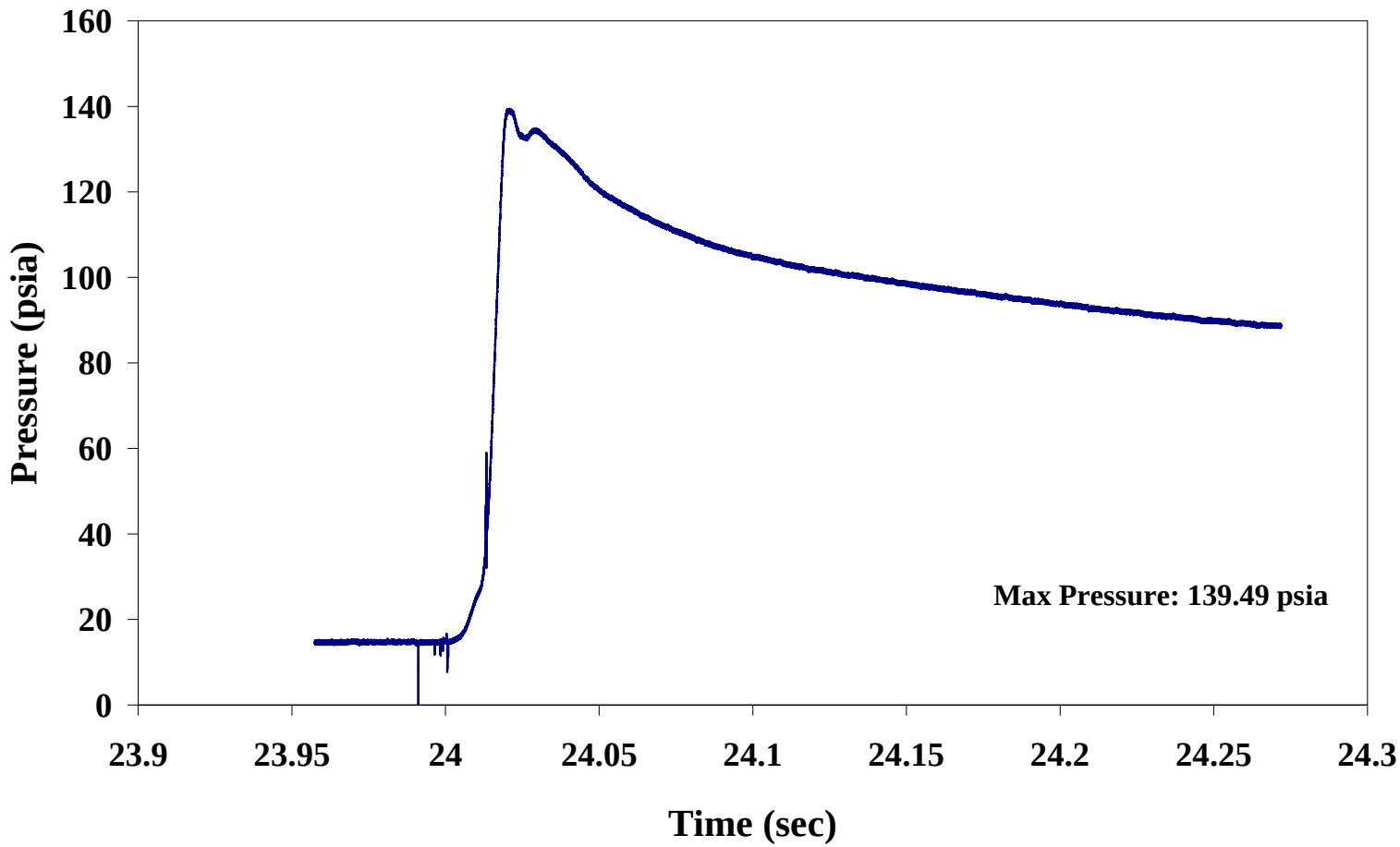
Pressure Data During the Heat-to-Vent Test on a LiBCX Cell



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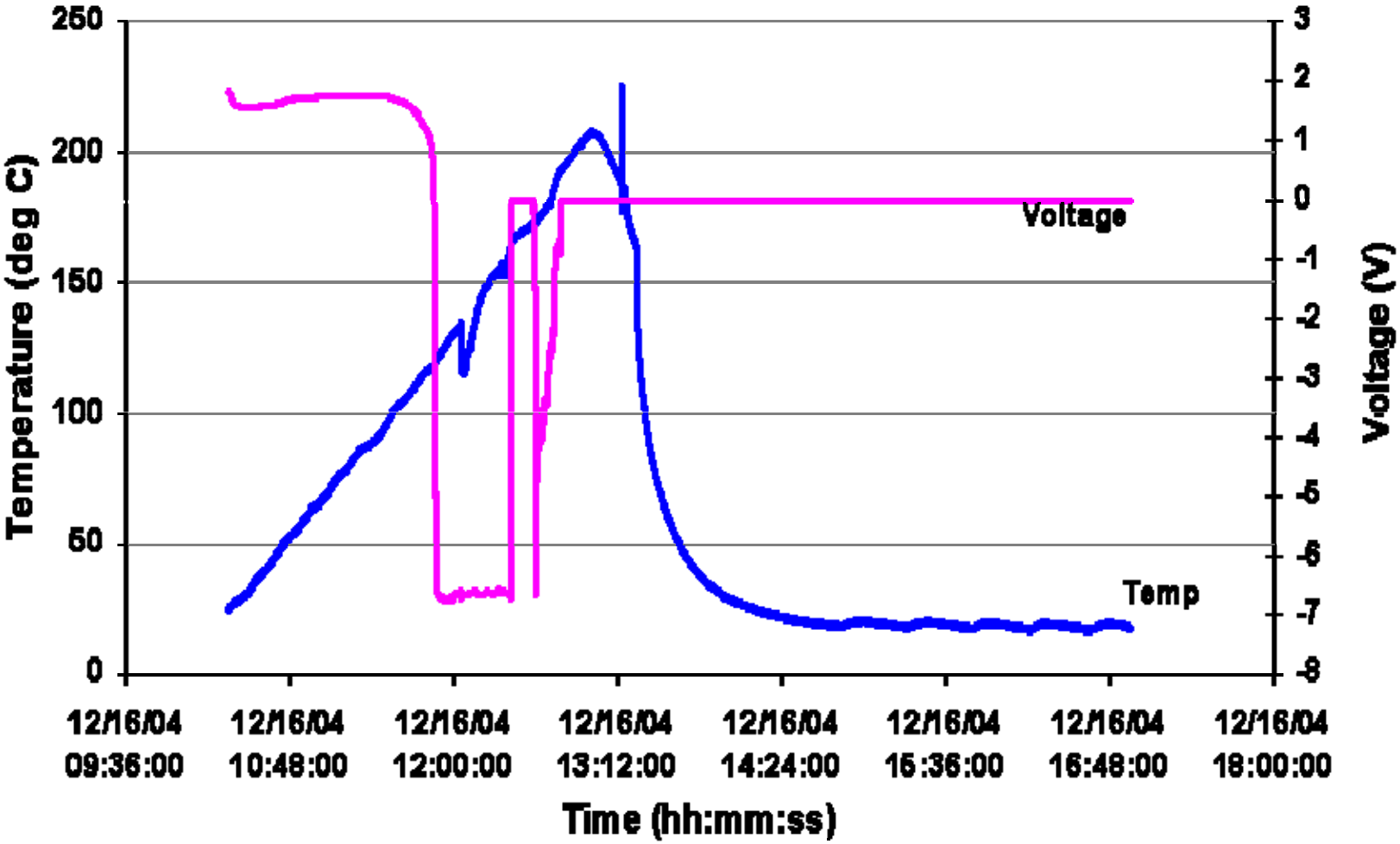
Heat-to-Vent Test on LiBCX Cell

Heat-to-Vent Test on $LiFeS_2$ Cells



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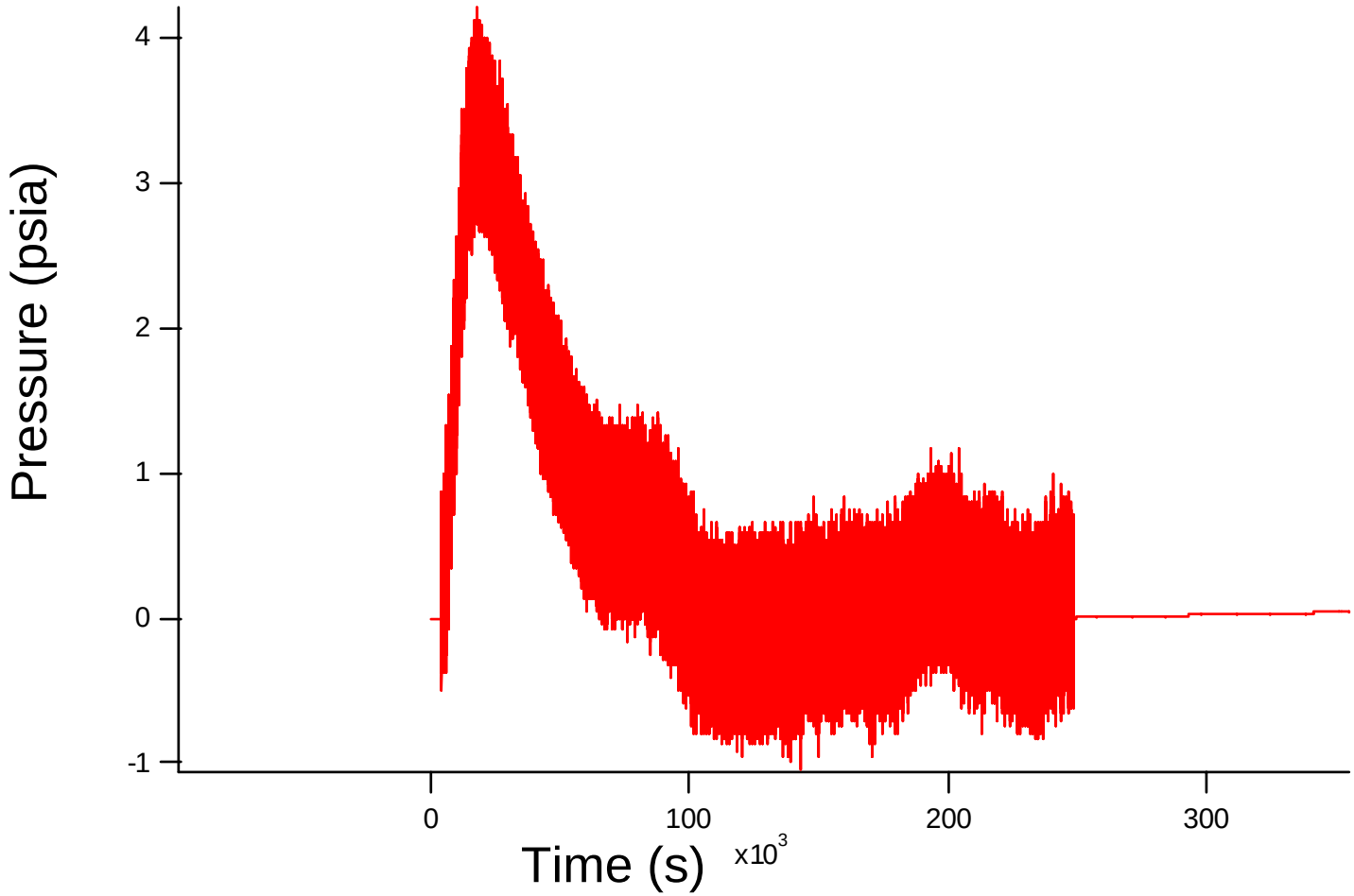
Pressure Data During the Heat-to-Vent Test on Energizer L91 Cells



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Heat-to-Vent Test on $LiFeS_2$ Cell

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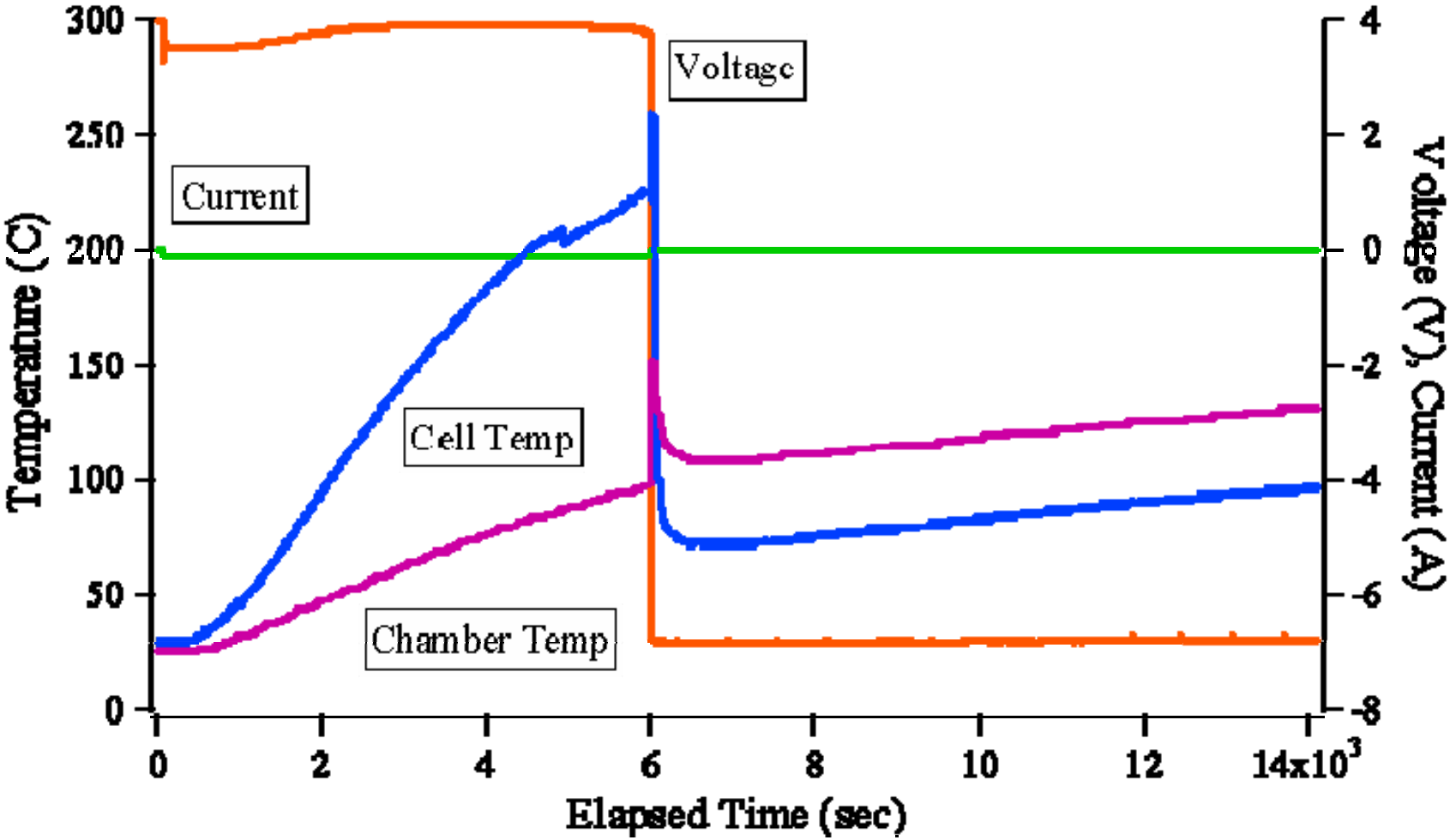
Heat-to-Vent Test on $LiSO_2Cl_2$ Cell



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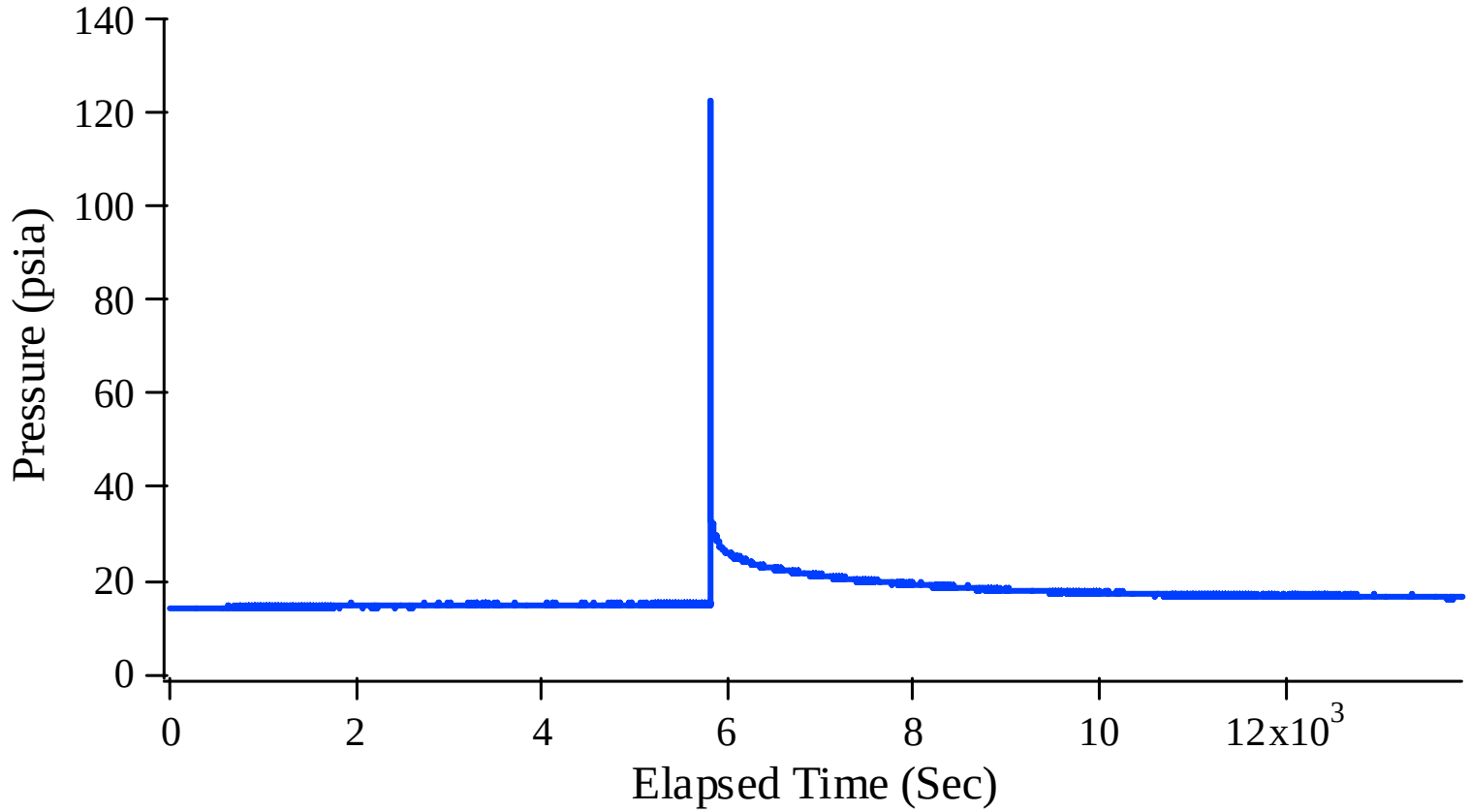
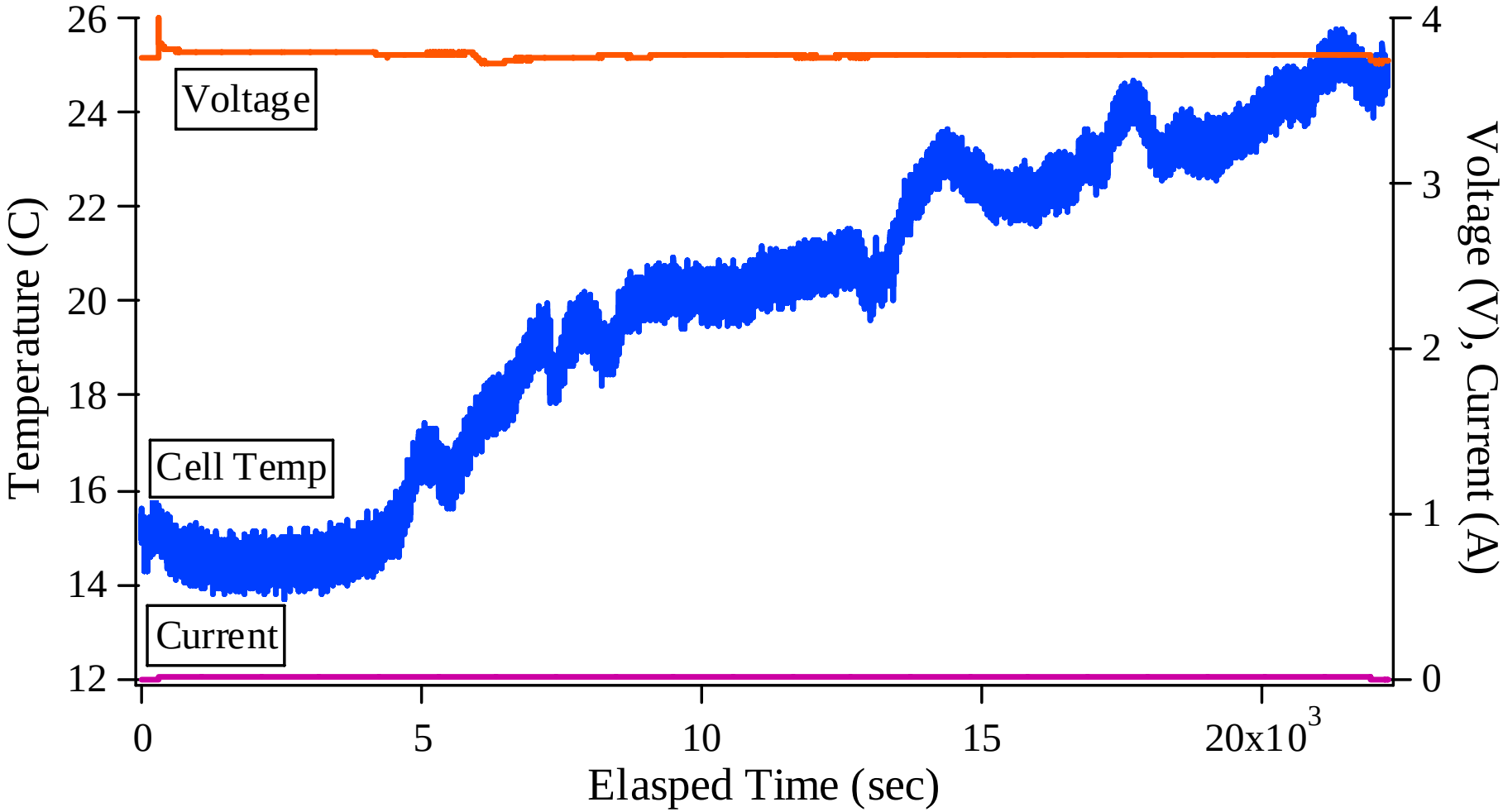
Pressure Data during Heat-to Vent on $LiSO_2Cl_2$ Cell



Charge Test

- During test process, it was determined that during data download, the USB was putting out leakage current when the battery voltage dropped below 2.6 V.
- This would cause an inadvertent charging of primary batteries. Charge current up to 20 mA was measured.
- Since USB can put out up to 500 mA, tests were performed at 20 mA and 500 mA.

Charge Test on LiBCX Cell with 20 mA



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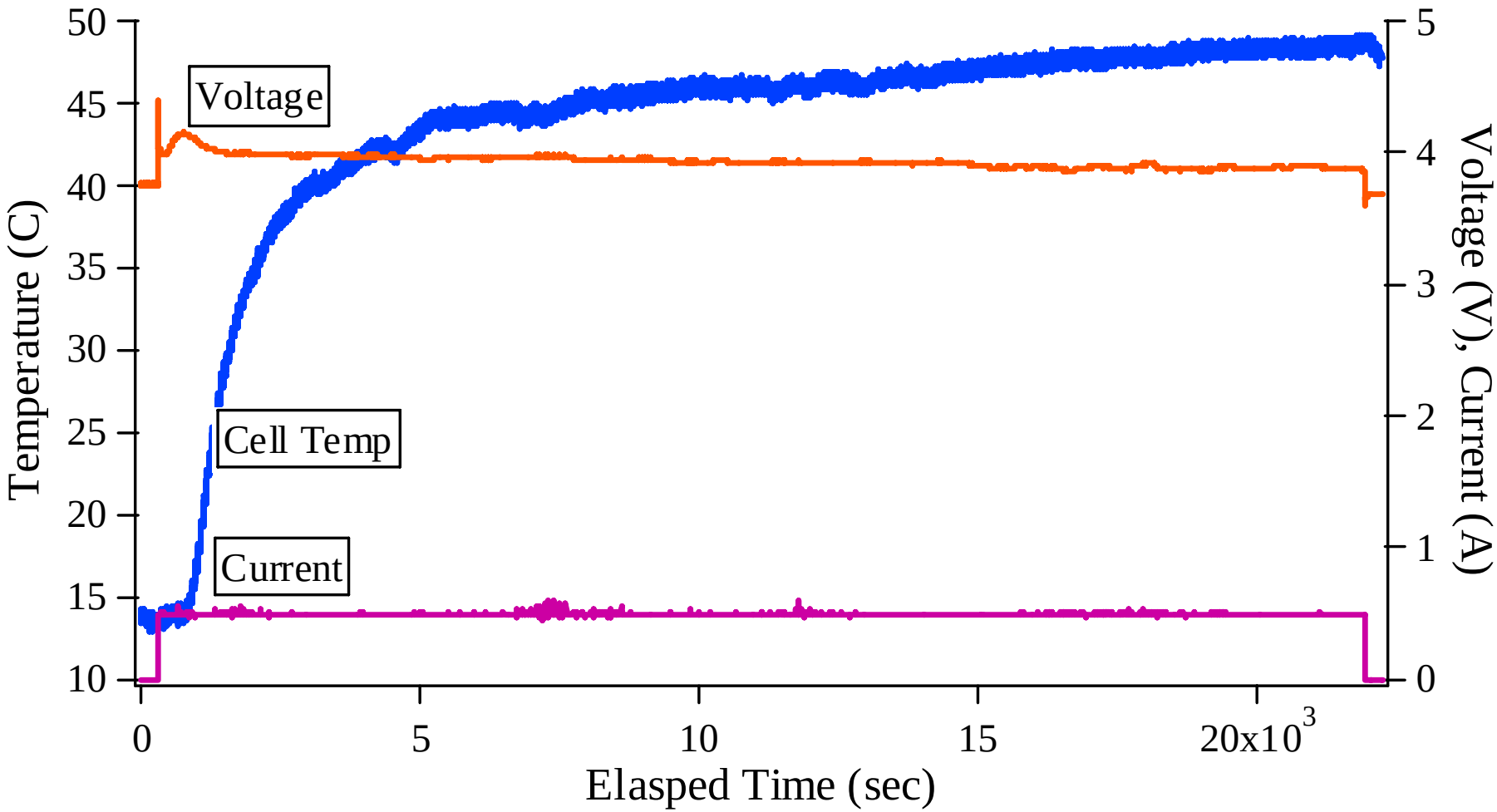
Charge Test on LiBCX Cell with 500 mA



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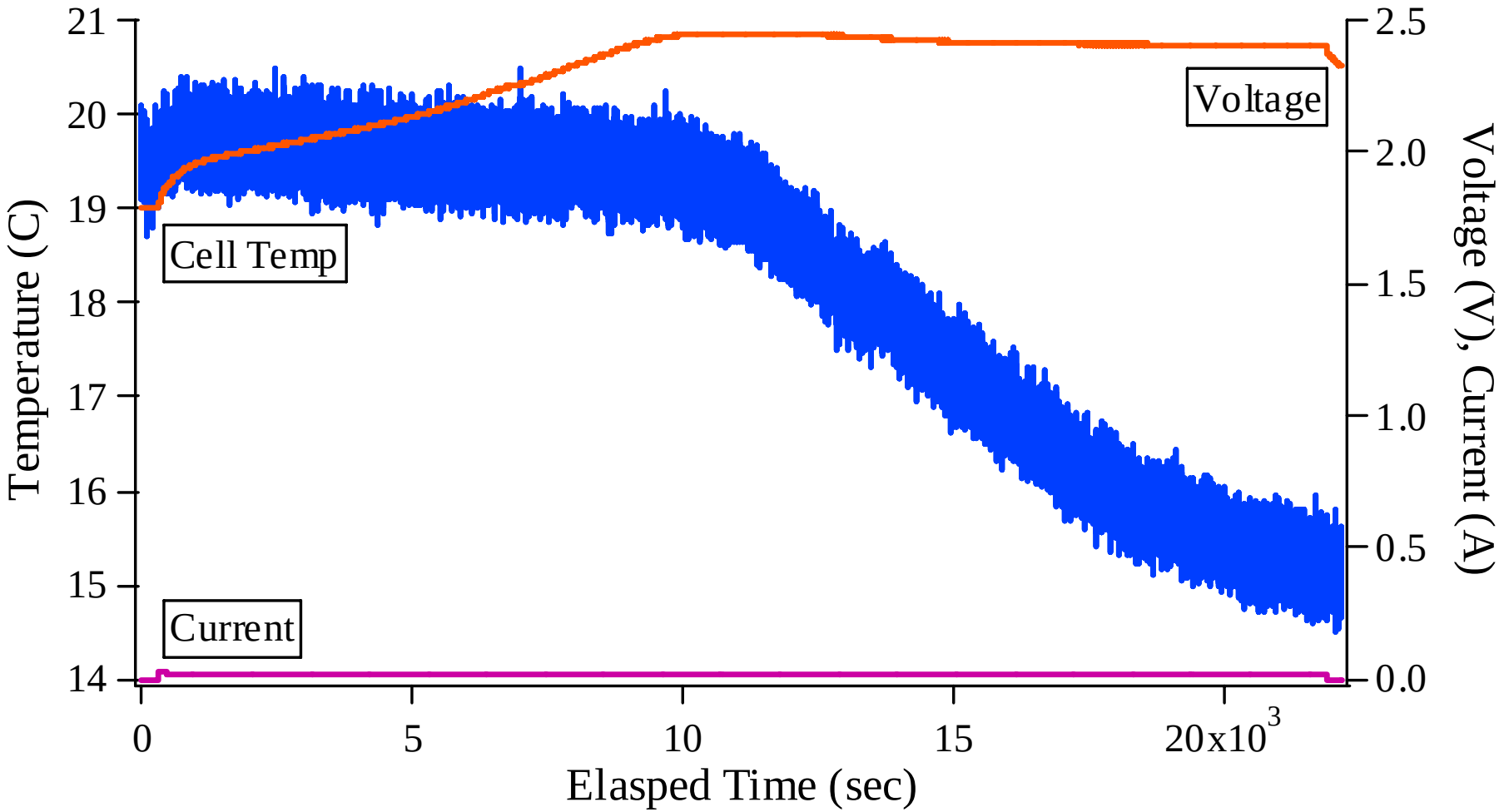
Charge Test on L91 $LiFeS_2$ Cell at 20 mA



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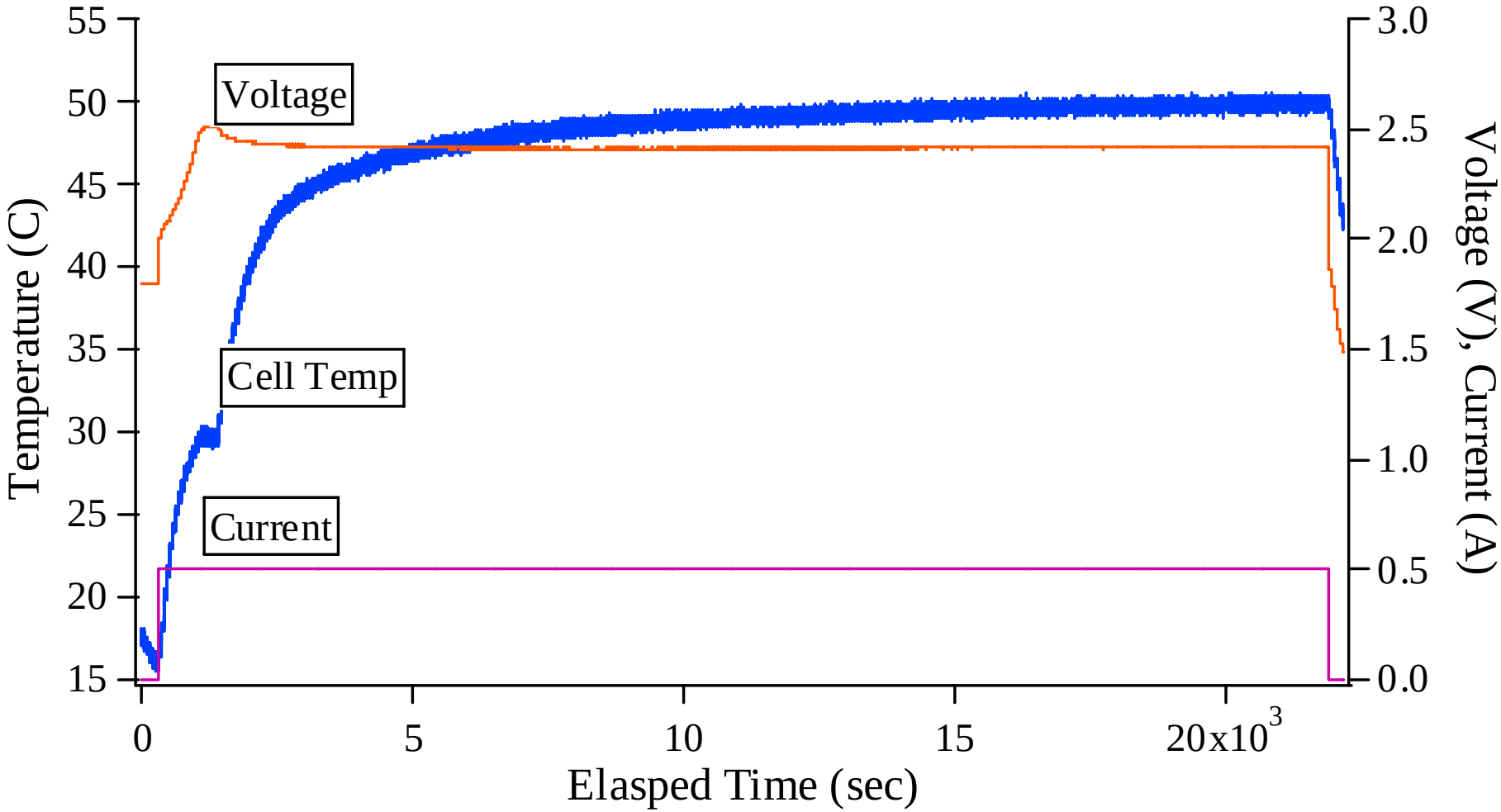
Charge Test of L91 $LiFeS_2$ Cell with 500 mA



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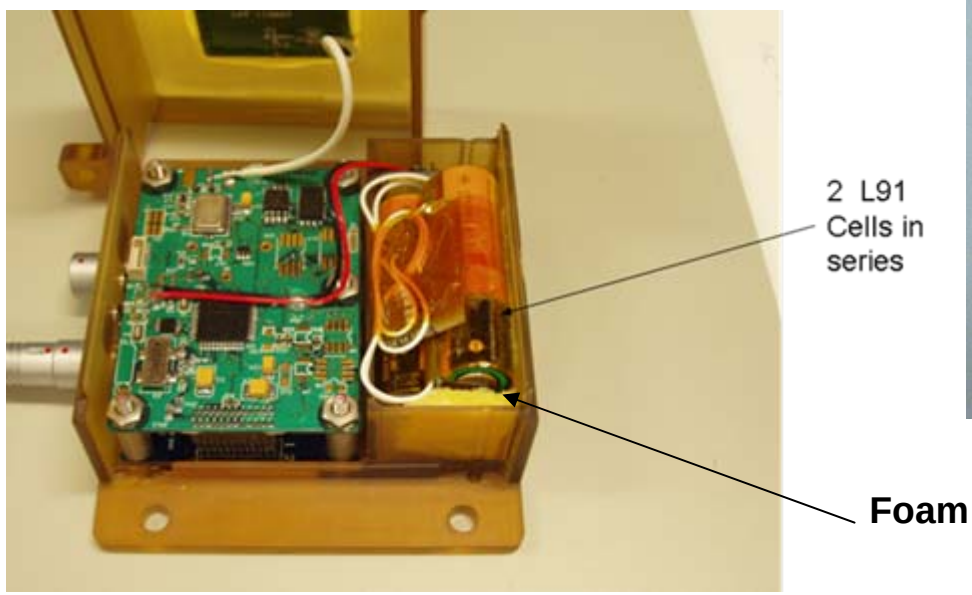
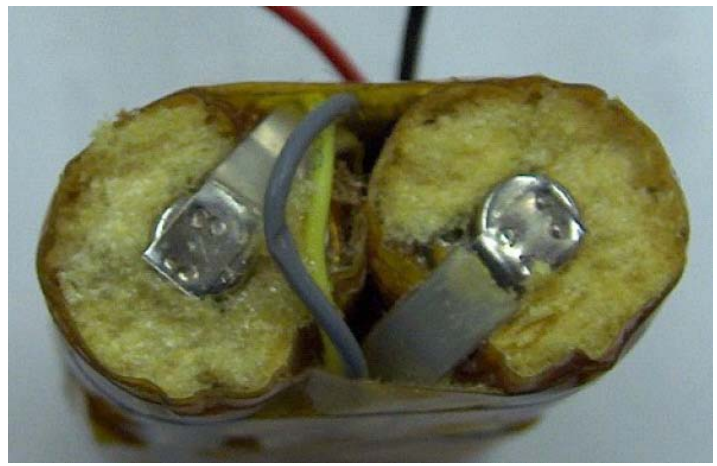
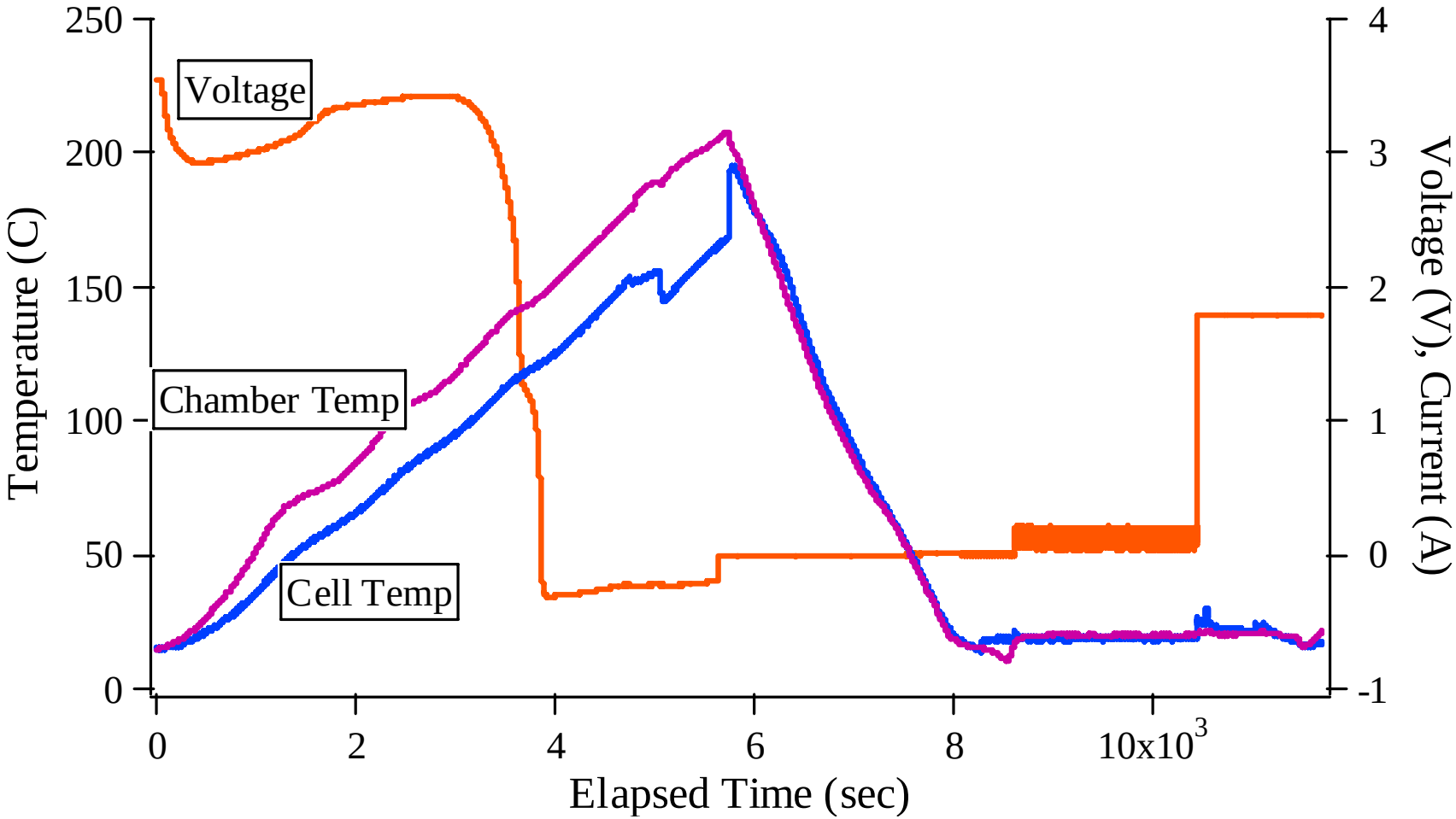
Foam Blockage of Vent Holes during Vibration

- During vibration test of the sensor with the batteries, the foam used in the battery compartment disintegrated completely and covered the vent holes of the cells.





Heat-to-Vent test with foam covering the vent holes of two $LiFeS_2$ cells in series



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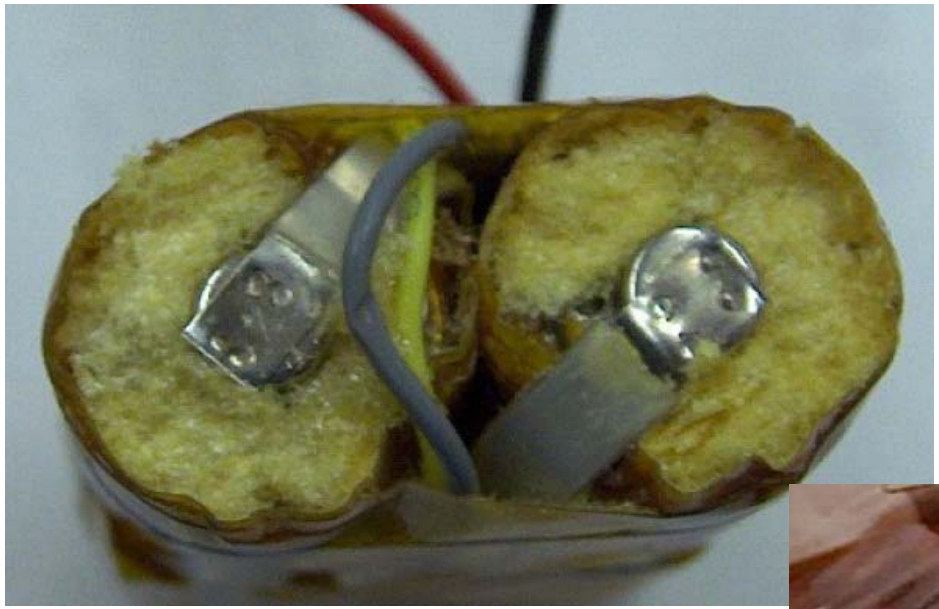
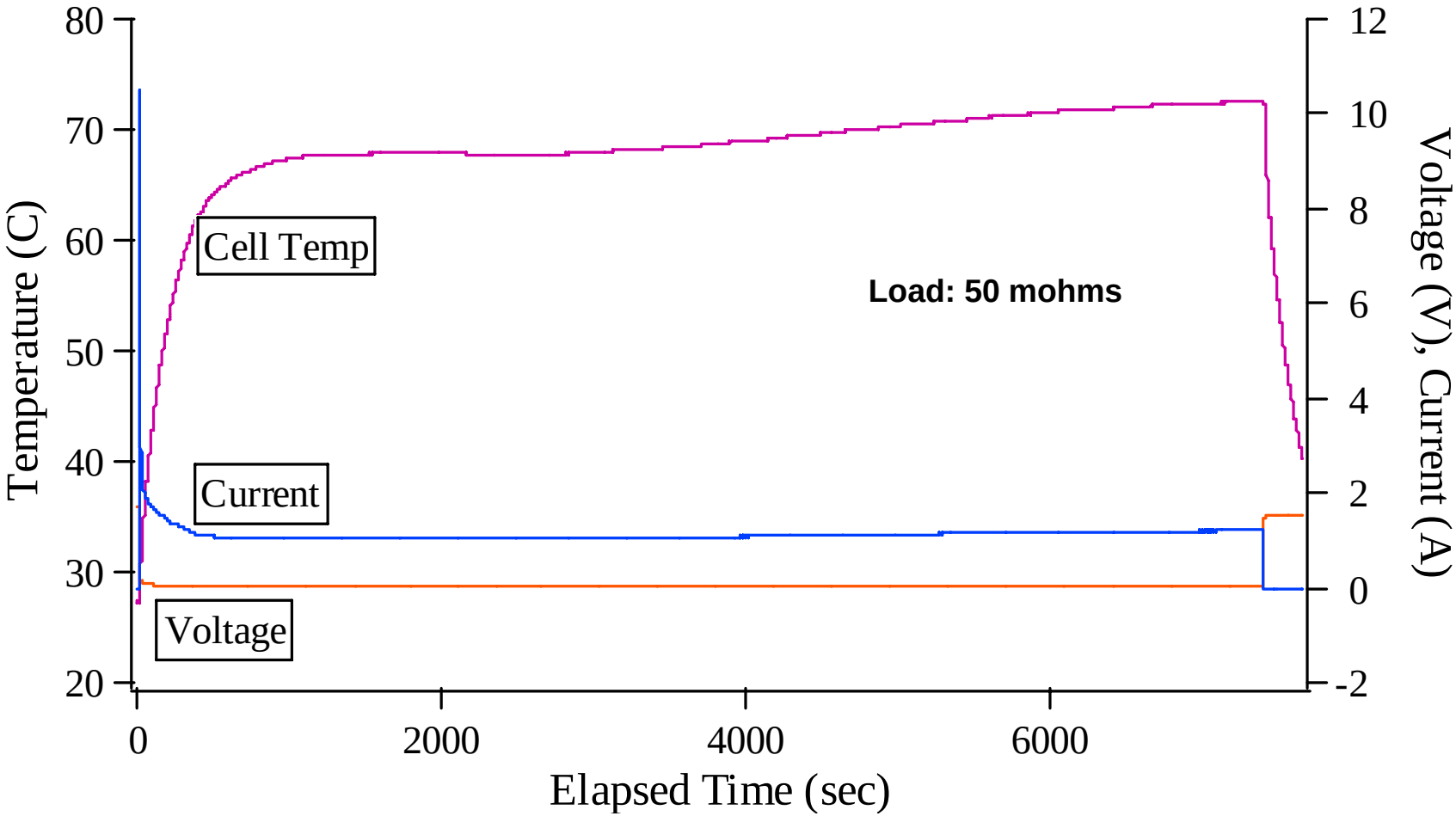
Heat-to-Vent test with foam covering the vent holes of two $LiFeS_2$ cells in series



External Short Circuit Test on L91 $LiFeS_2$ Cells



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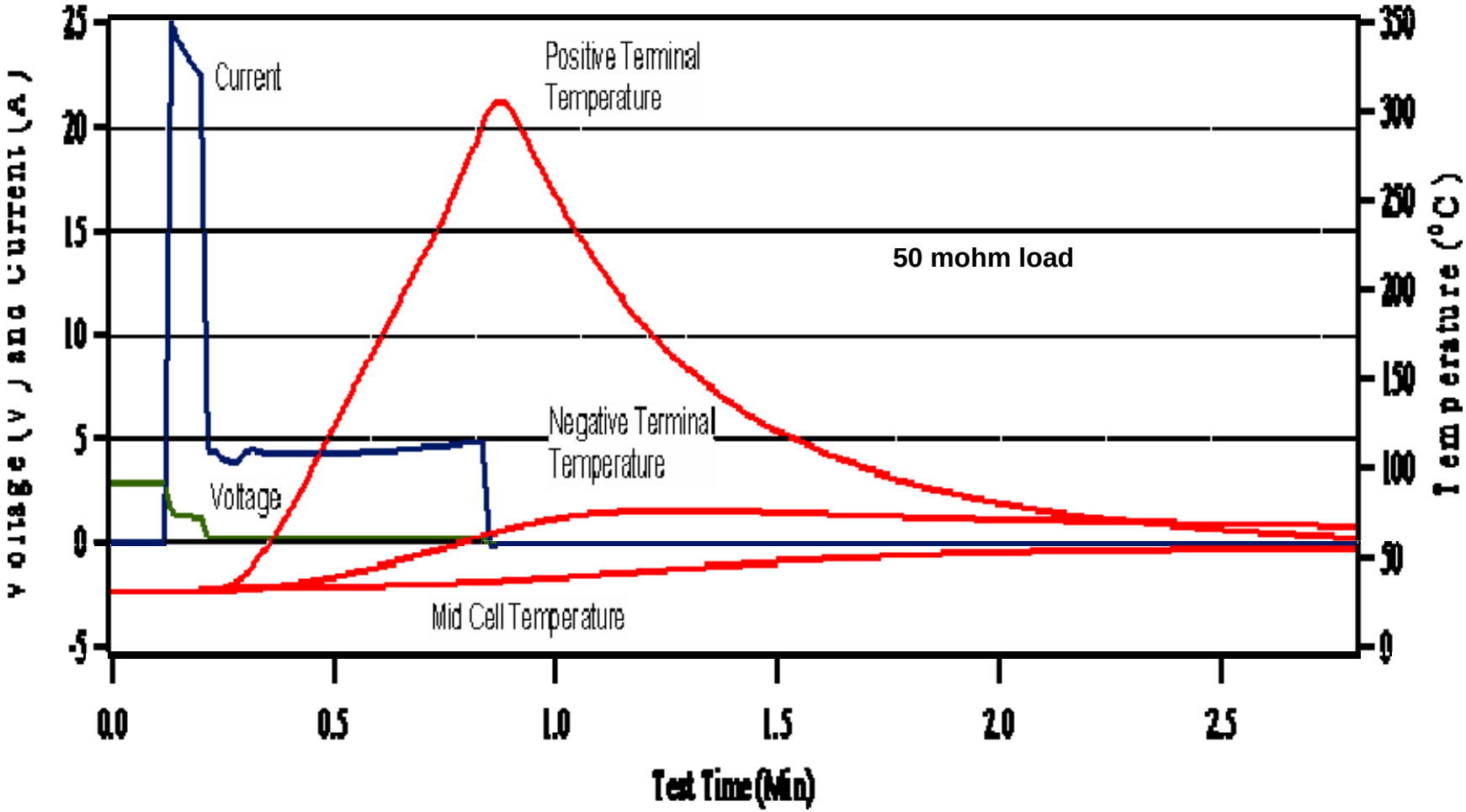
External Short on Li-SO_2 Cells



Cell explodes

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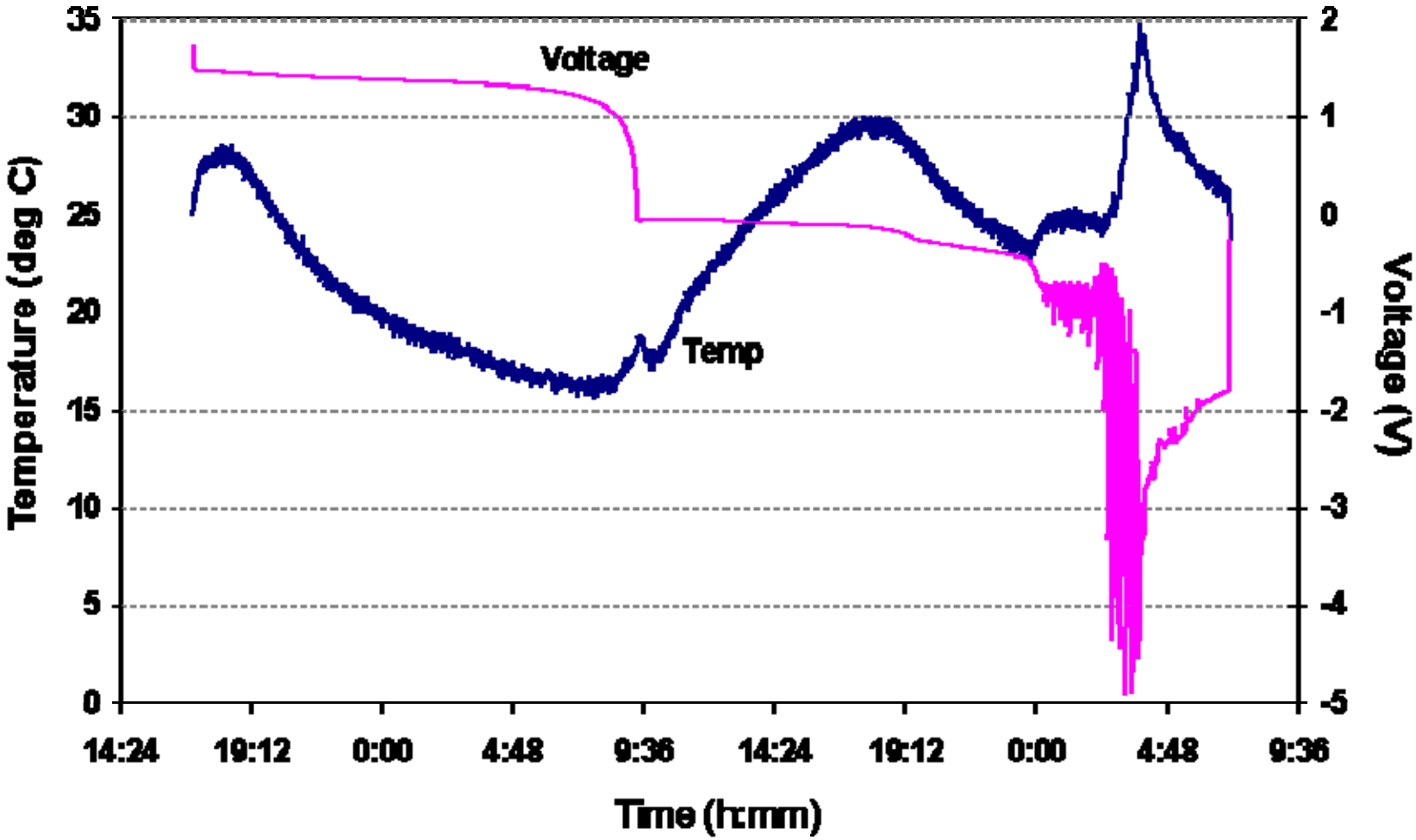
Overdischarge of $LiFeS_2$ Cells



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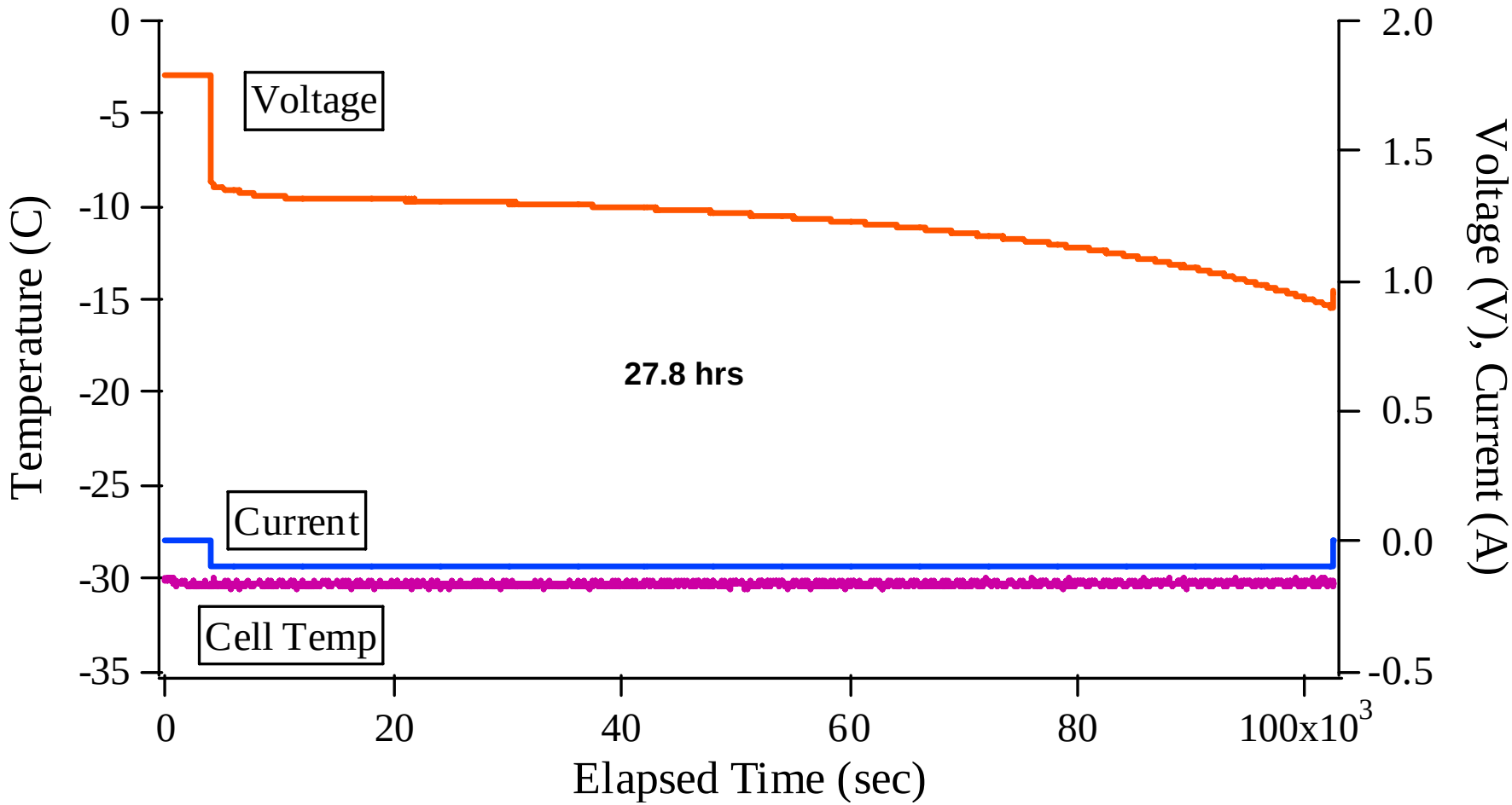
Overdischarge of LiBCX Cells

- Tests performed on LiBCX C and D size cells showed the following results:
  - 60 % bulged, a few leaked, few reached temperatures of 205 deg C and leaked after the glass-to-metal seal cracked.
  - When the batteries were left on the shelf at 0 V for a week to 10 days, and then discharged again, the cells exploded.

Performance of $LiFeS_2$ cell at -28 Deg C



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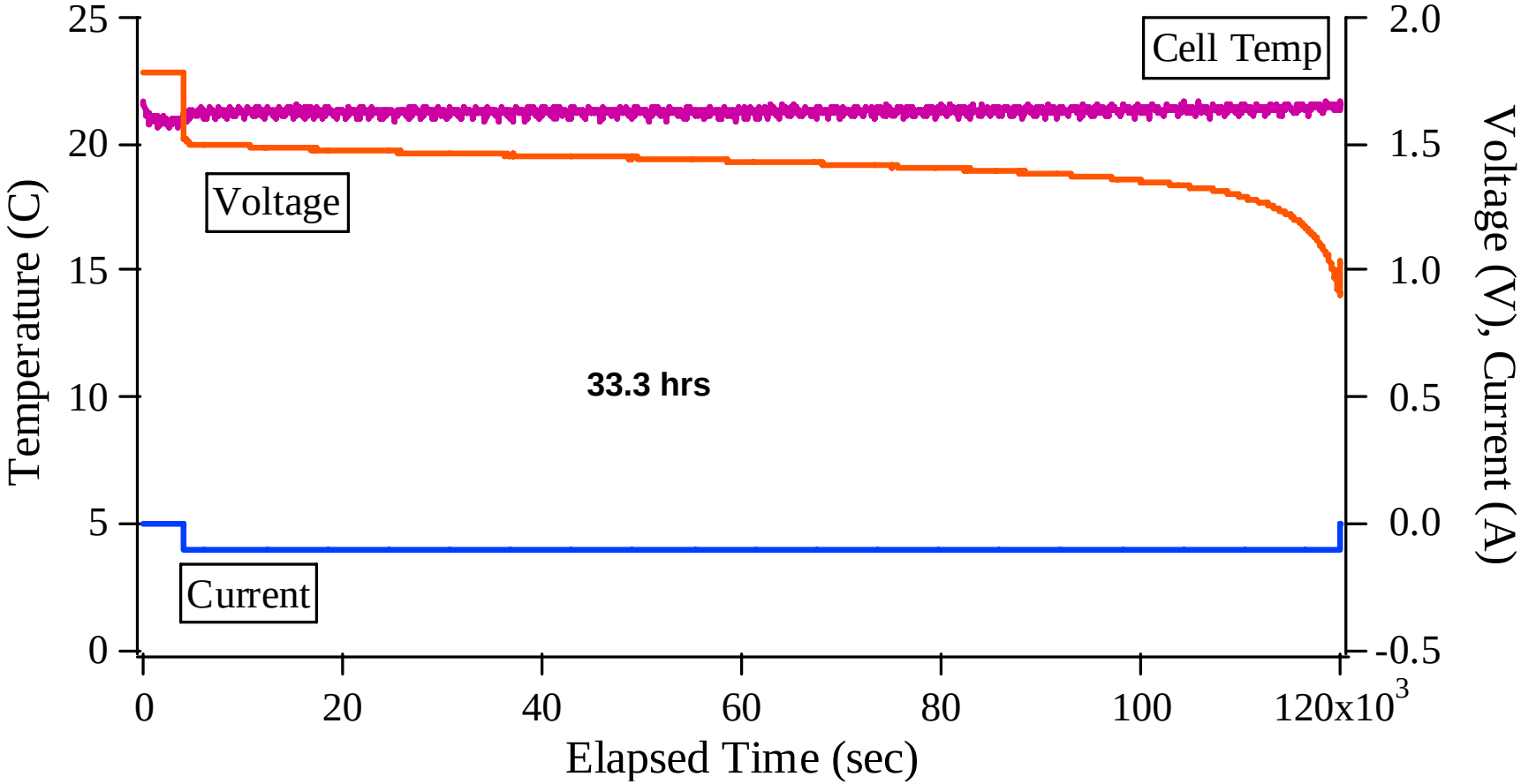
Performance of $LiFeS_2$ Cells at 21 deg C



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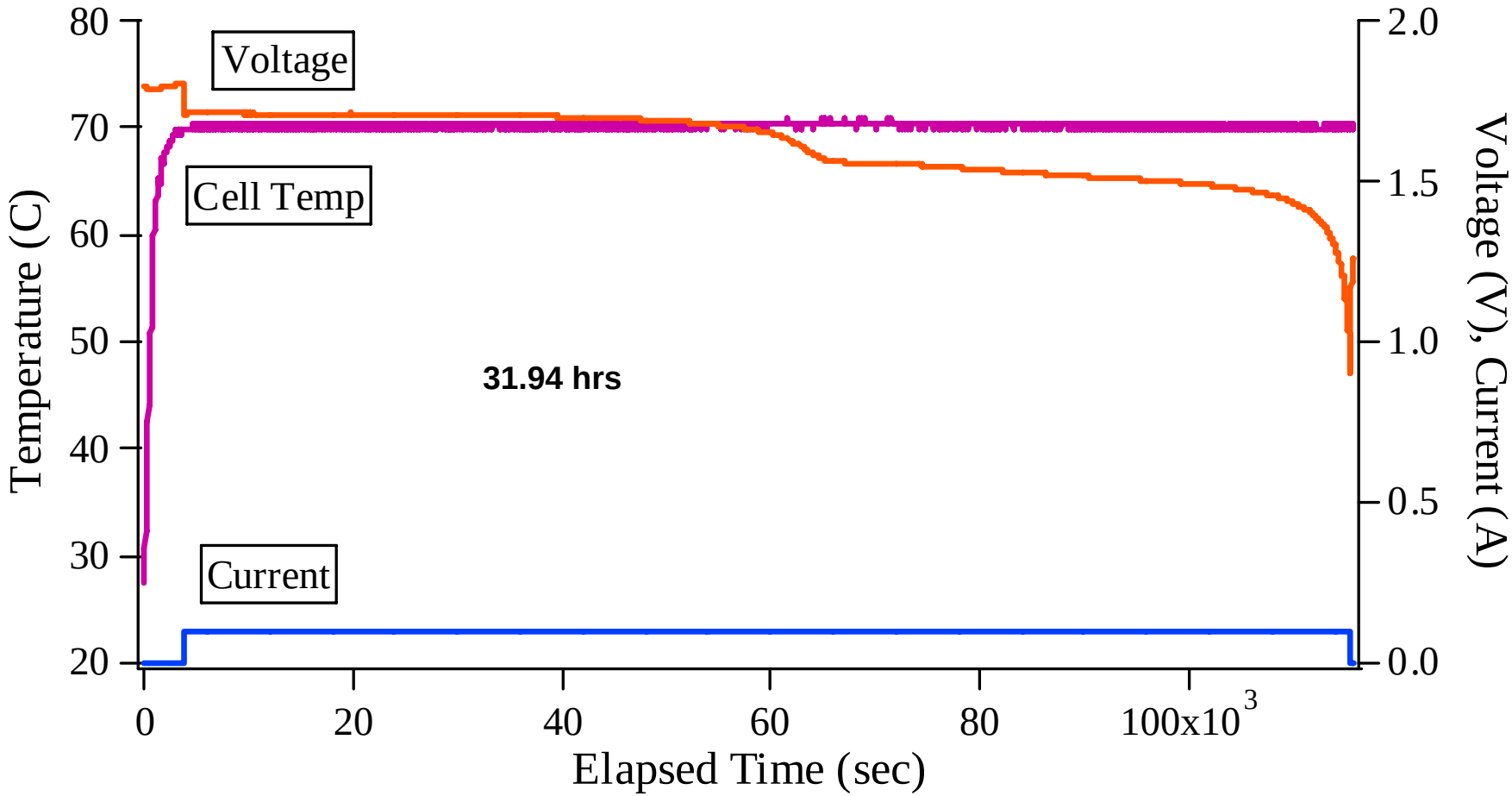
Performance of $LiFeS_2$ at 71 Deg C



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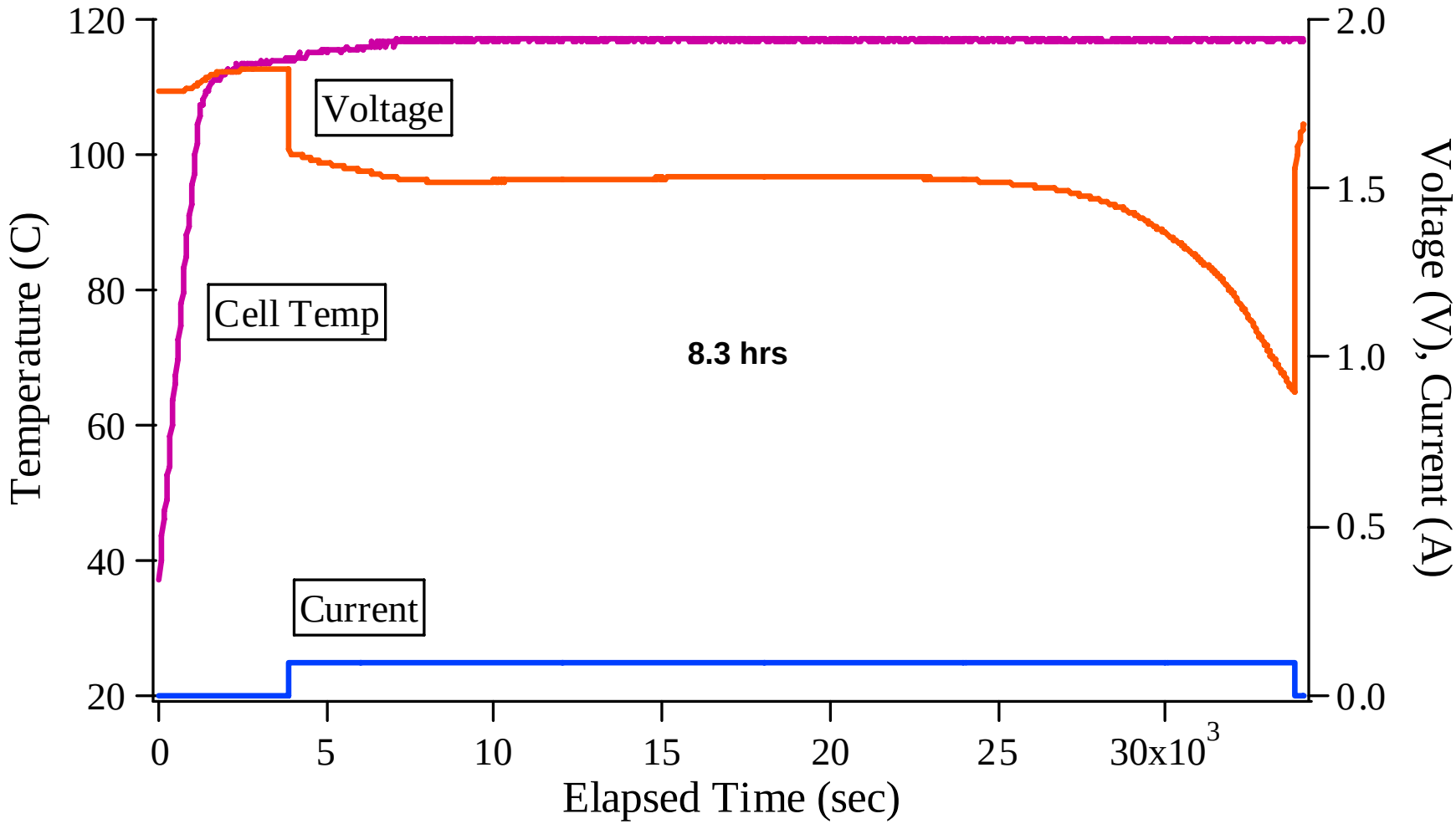
Performance of $LiFeS_2$ Cells at 115 deg C



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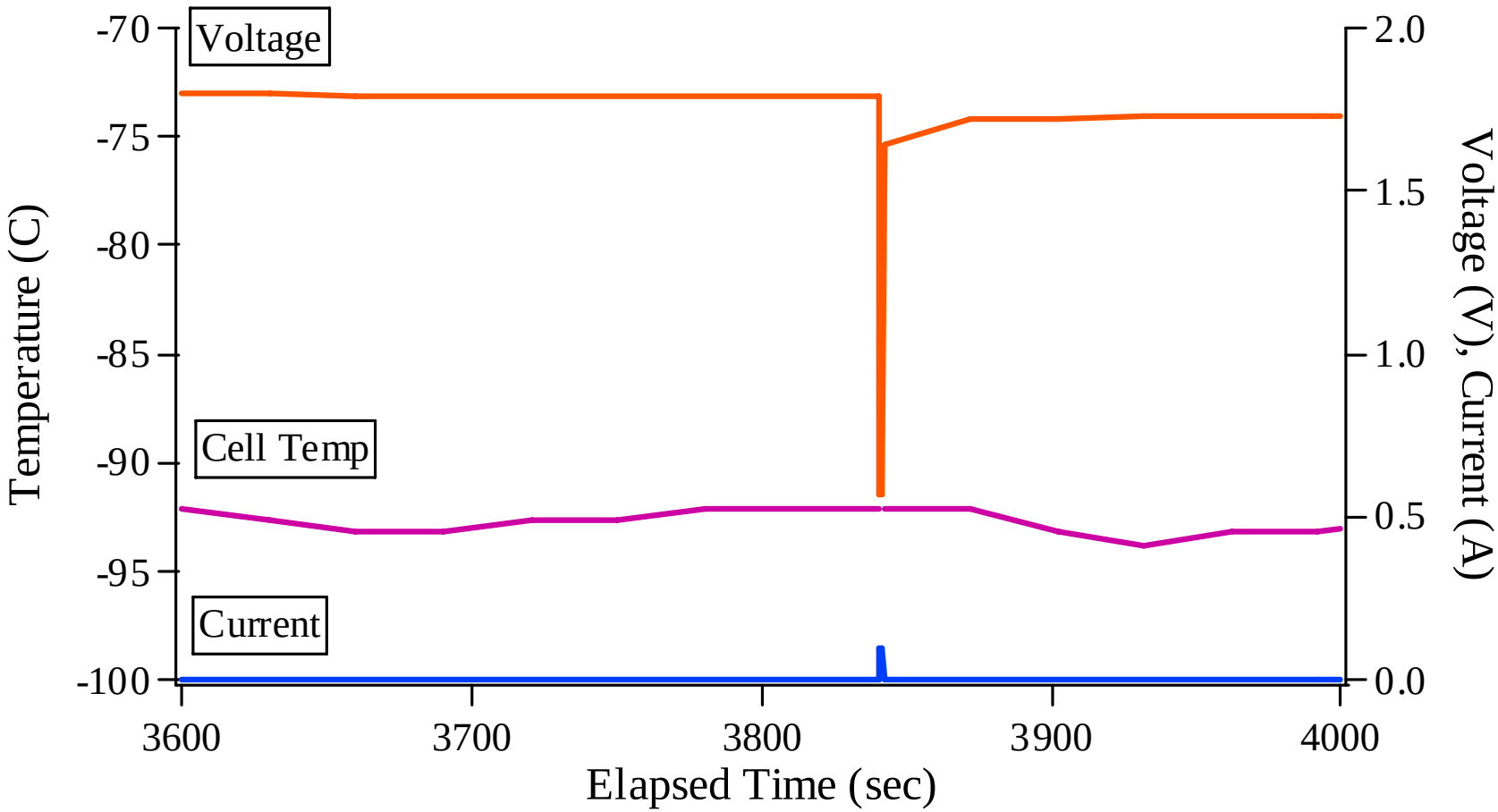
Performance of $LiFeS_2$ at -93 Deg C



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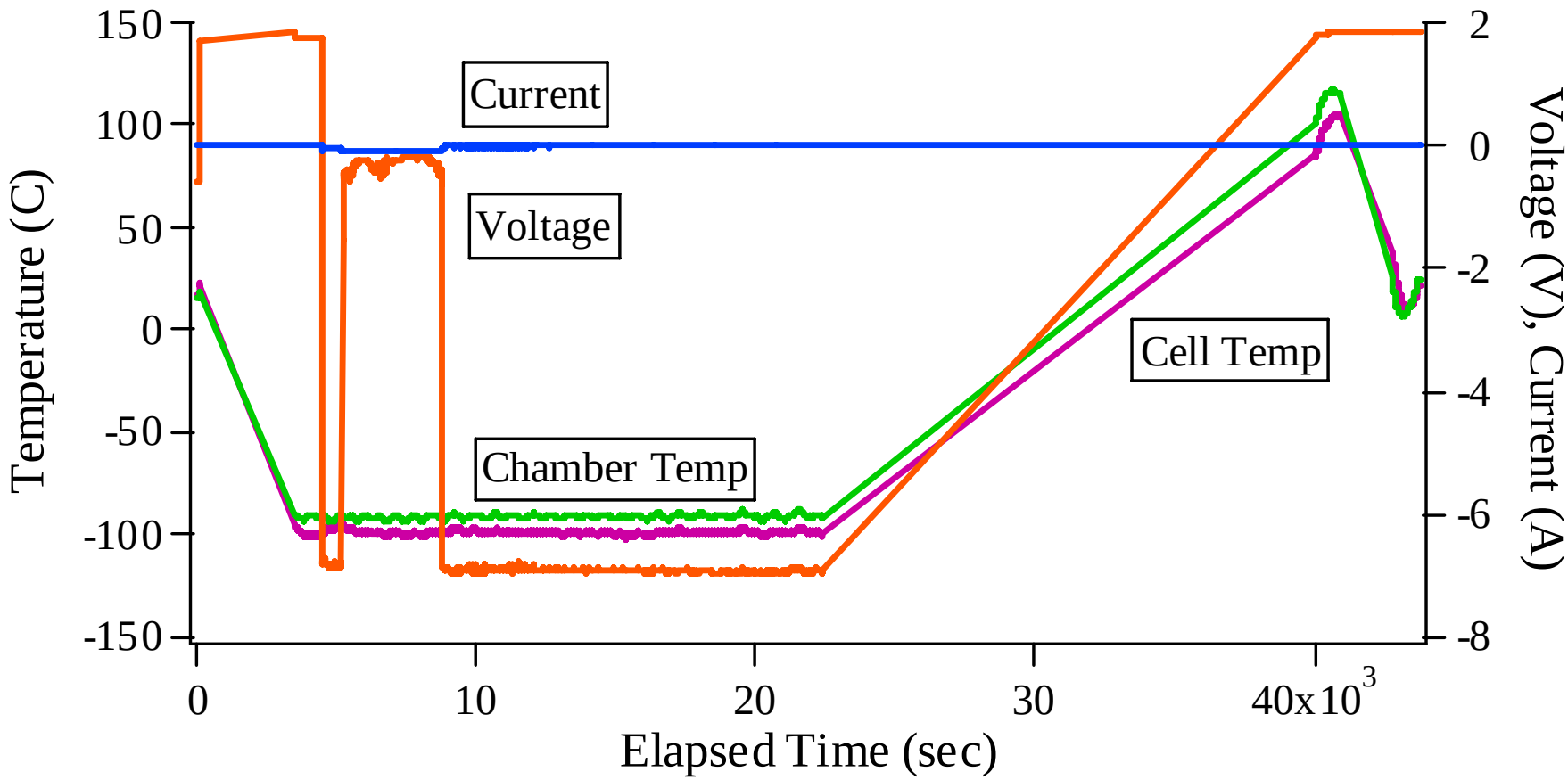
Safety of $LiFeS_2$ Cells at Thermal Extremes during Descent Phase (-93 to + 115 Deg C)



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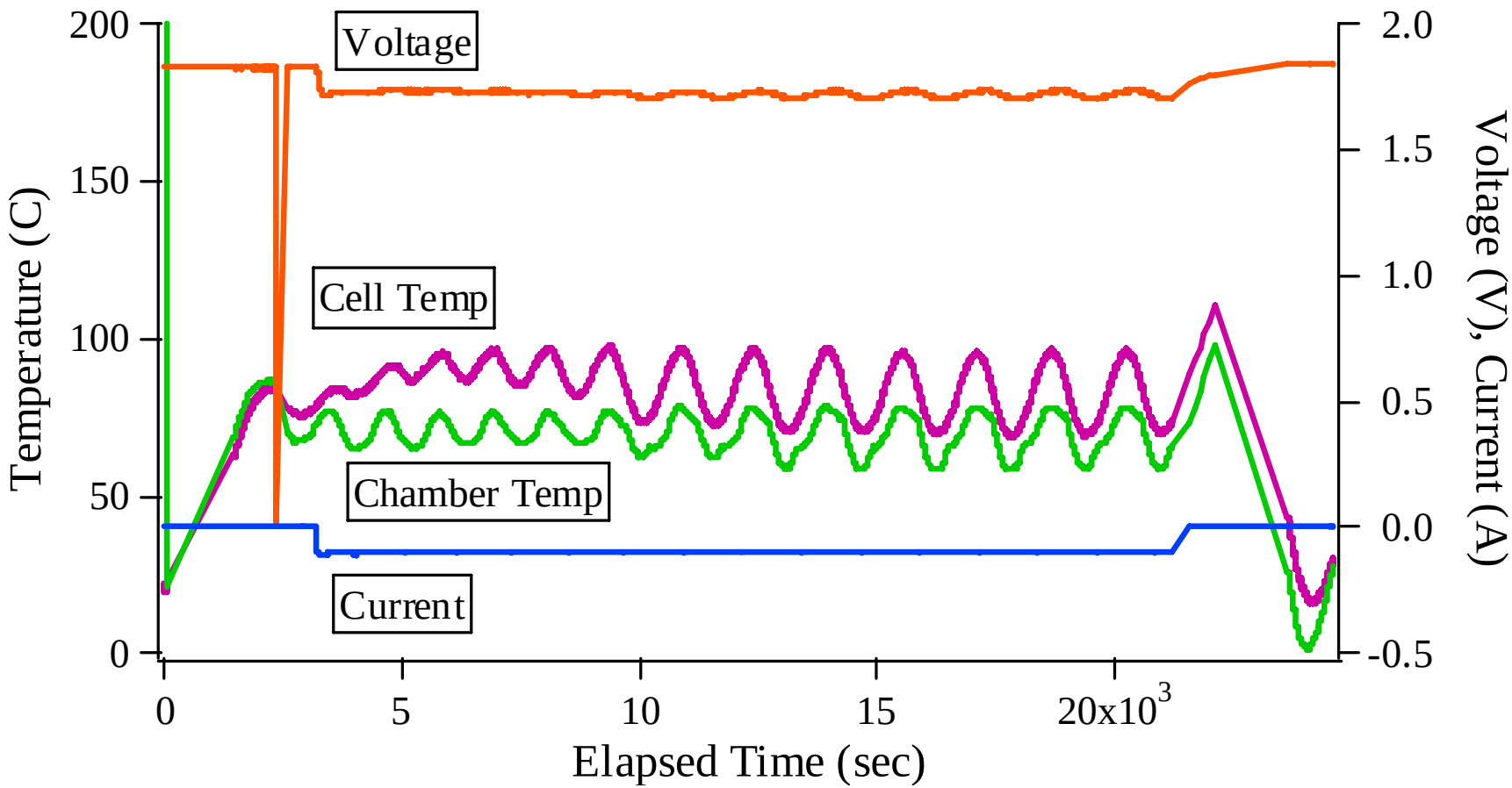
Safety of $LiFeS_2$ Cells at Thermal Extremes during Descent Phase (80 to + 115 Deg C)



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Conclusions

- The thermal tests performed on the LiBCX and $LiFeS_2$ cells for the Wing-Leading-Edge application showed the following results:
  - The LiBCX cells are not safe for use in the thermal environment of the Wing-Leading-Edge
  - The LiBCX cells display very high pressures and they undergo explosion producing a lot of shrapnel under high temperature conditions
  - The $LiFeS_2$ cells undergo benign venting and do not explode
  - The pressures recorded for the $LiFeS_2$ cells were very low indicating that they are not of an explosive nature
  - The $LiFeS_2$ cells will not compromise the safety of the Shuttle

Conclusions

- The charge test performed on the LiBCX and $LiFeS_2$ cells showed that the cells are tolerant to a 6-hour charge at both 20 mA and 500 mA. The temperatures recorded during the 500 mA charge was almost the same for both types of cells
  - The charge hazard has a chance of occurring during data-download on ground only. This condition arises when the battery voltage falls below 2.5 V. Hence procedures were drafted to verify that fresh batteries were installed for the ground data download process.

Conclusions

- The tests carried out on the $LiFeS_2$ cells, show that
  - **the batteries provide power to the sensor at temperatures between -30 to +115 deg C.**
  - **The battery does not provide any power at -115 deg C. Not a major concern since the electronics in the sensor does not work at that temperature.**
  - **The batteries provide power when the thermal environment warms up.**
- The tests simulating a wide swing in thermal environment that could occur during reentry show that the $LiFeS_2$ cells are tolerant to quick changes in temperature and do not exhibit any hazardous behavior.

The batteries performed very well during flight and excellent data was down-linked during the STS 114 flight.

Acknowledgment

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