Hazards Due to Overdischarge in Lithium-ion Cylindrical Cells in Multi-cell Configurations

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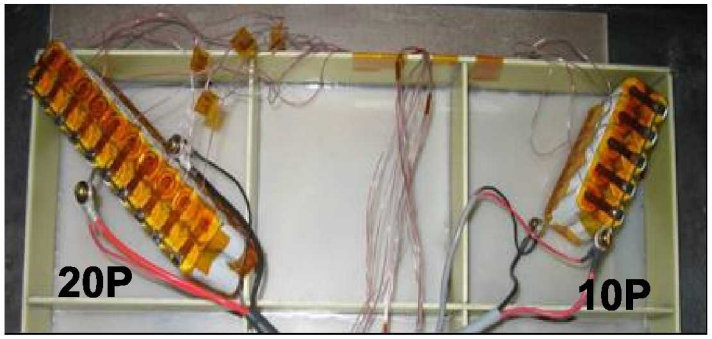
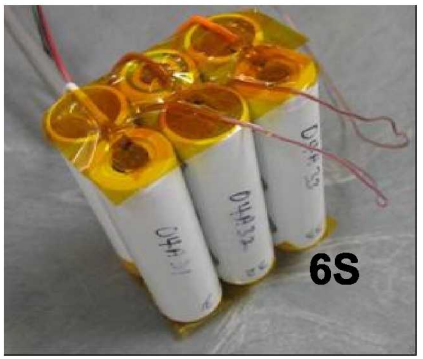
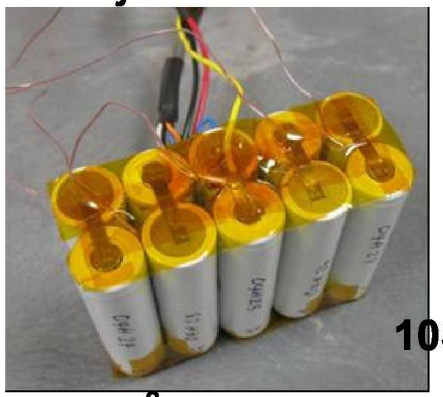
Introduction

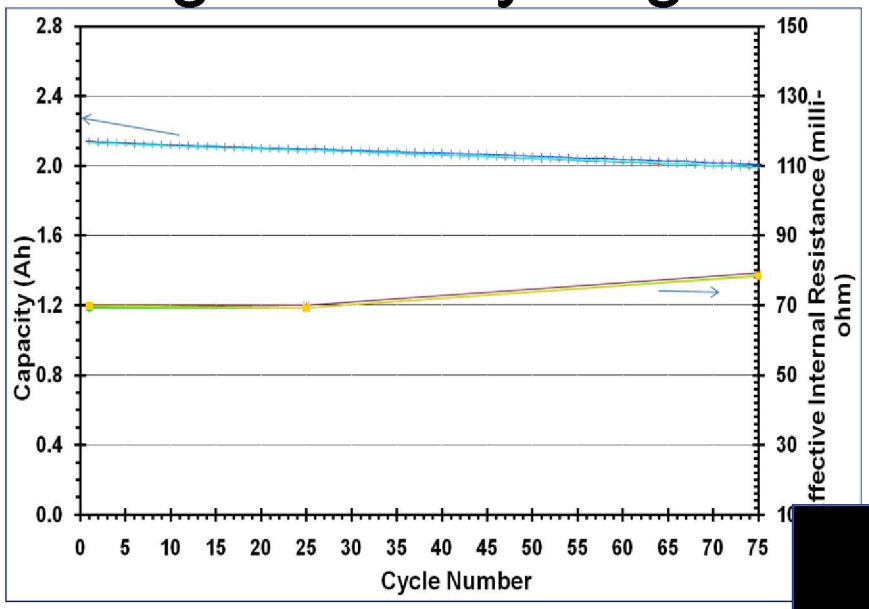
- Lithium-ion cells in the cylindrical Commercial-off-the-shelf 18650 design format were used to study the hazards associated with overdischarge.
- The cells in series or in parallel configurations were subjected to different conditions of overdischarge.
- The cells in parallel configurations were all overdischarged to 2.0 V for 75 cycles with one cell removed at 25 cycles to study the health of the cell.
- The cells in series were designed to be in an unbalanced configuration by discharging one cell in each series configuration before the start of test. The discharge consisted of removing a pre-determined capacity from the cell. This ranged from 50 to 150 mAh removal. The cells were discharged down to a predetermined end-of-discharge voltage cutoff which allowed the cell with lower capacity to go into an overdischarge mode.
- The cell modules that survived the 75 cycles were subjected to one overvoltage test to 4.4 V/cell.

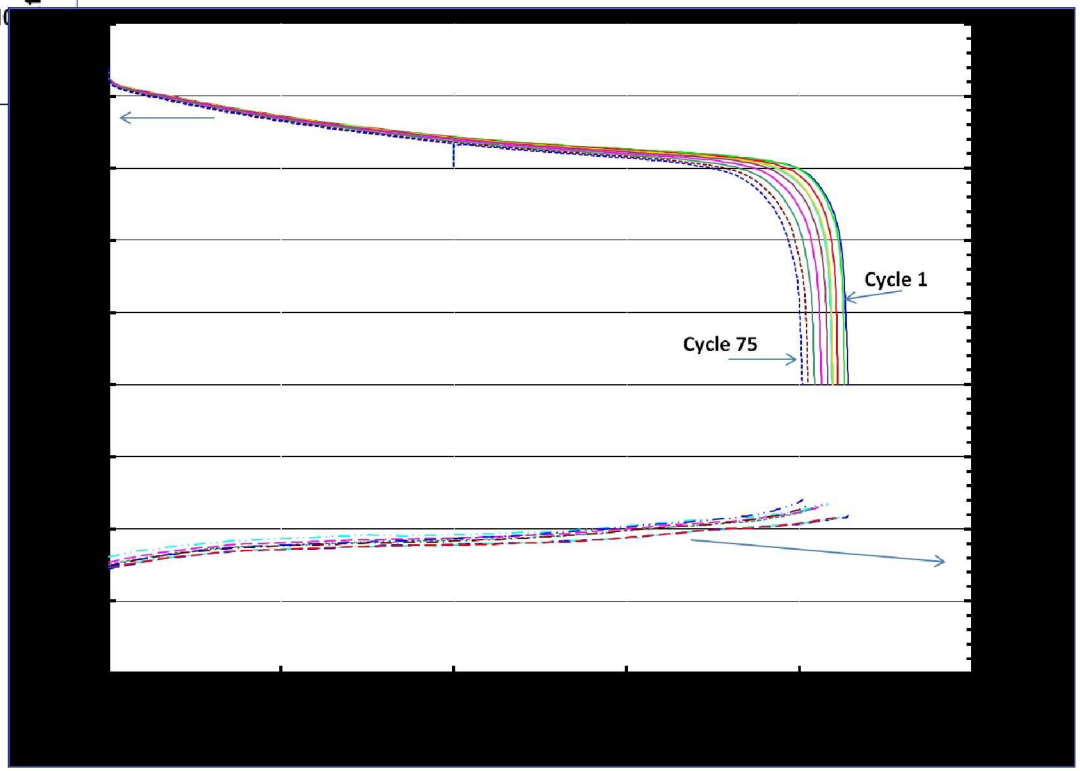






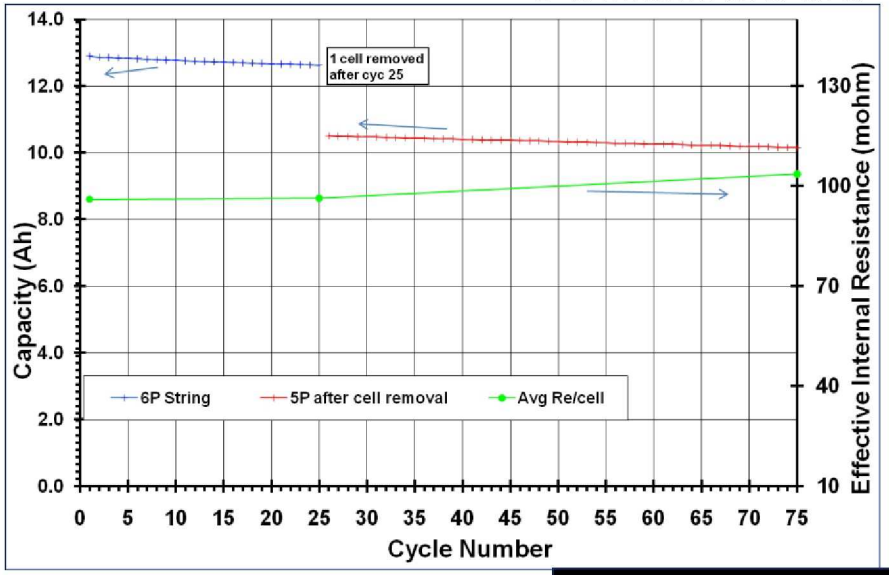
Single Cell Cycling with Continuous Deep Discharge

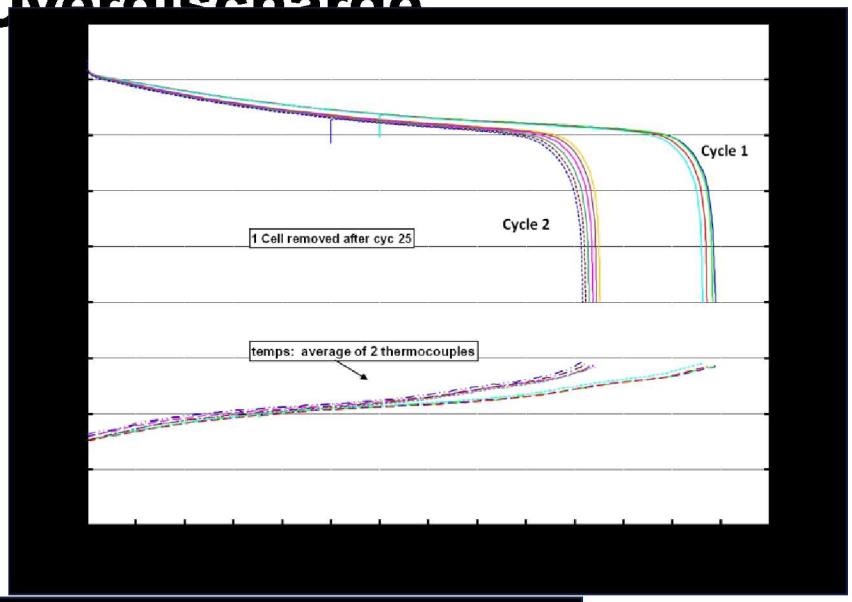


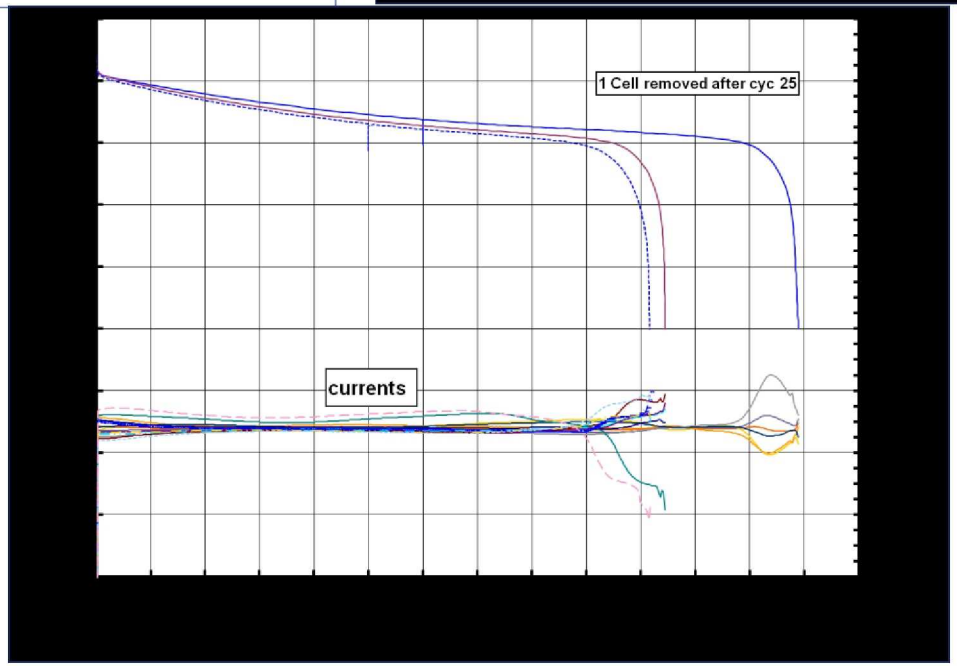


Charge: C/2 to 4.2 V
Discharge: C/2 to 2.0 V

Cycling Life Test for a 6P Lithium-ion Module with continuous Overdischarge

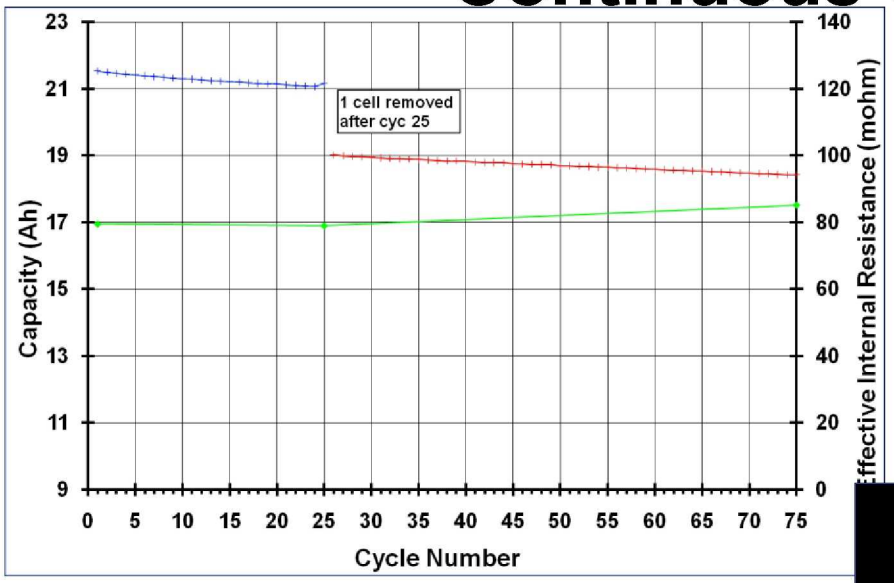




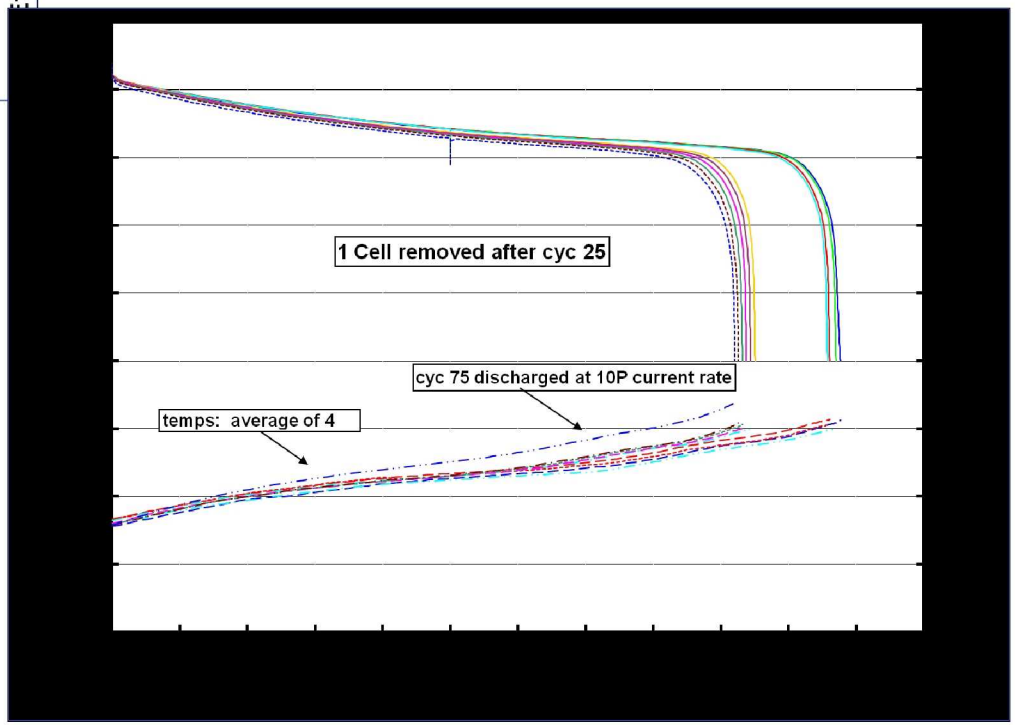


Charge: C/2 (1.08 A); EOCV: 4.2 V
Discharge: C/2 A; EODV: 2.0 V

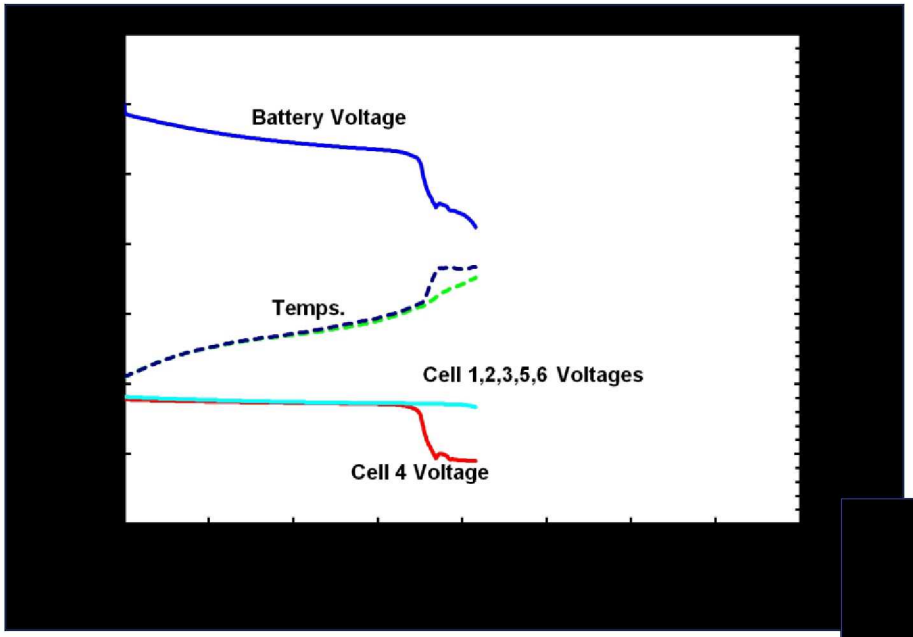
Cycling Life Test for a 10P Lithium-ion Module with Continuous Overdischarge



Similar test on a 20P module was carried out and the max temperature recorded was 45 deg C

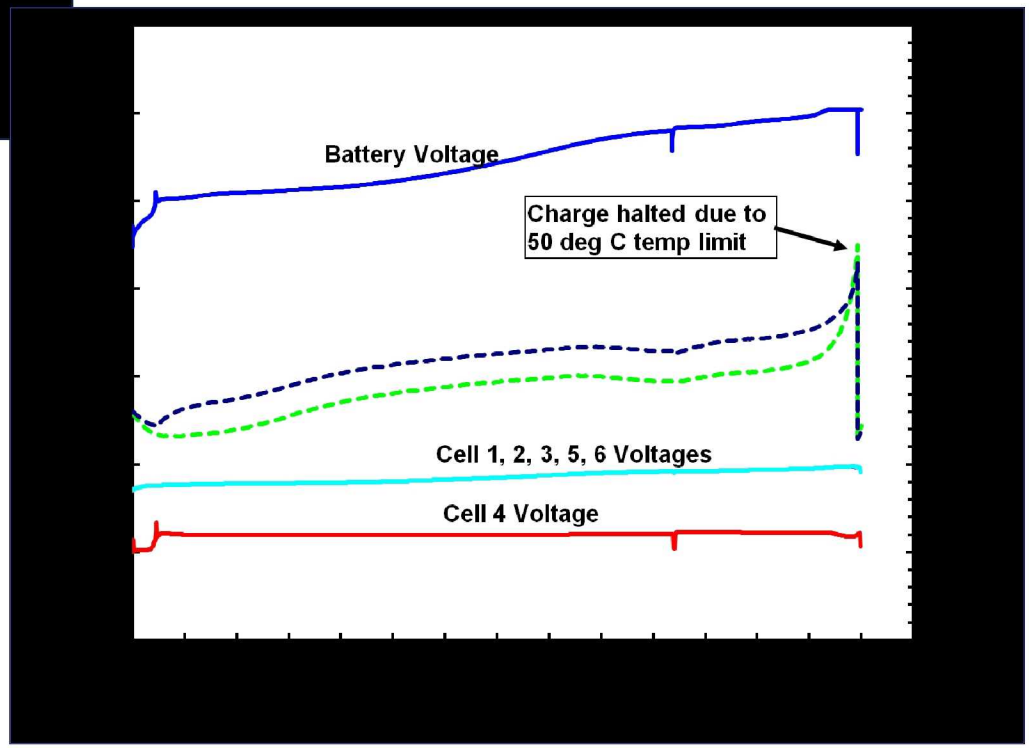


Overdischarge Test on 6S Unbalanced Cell Module

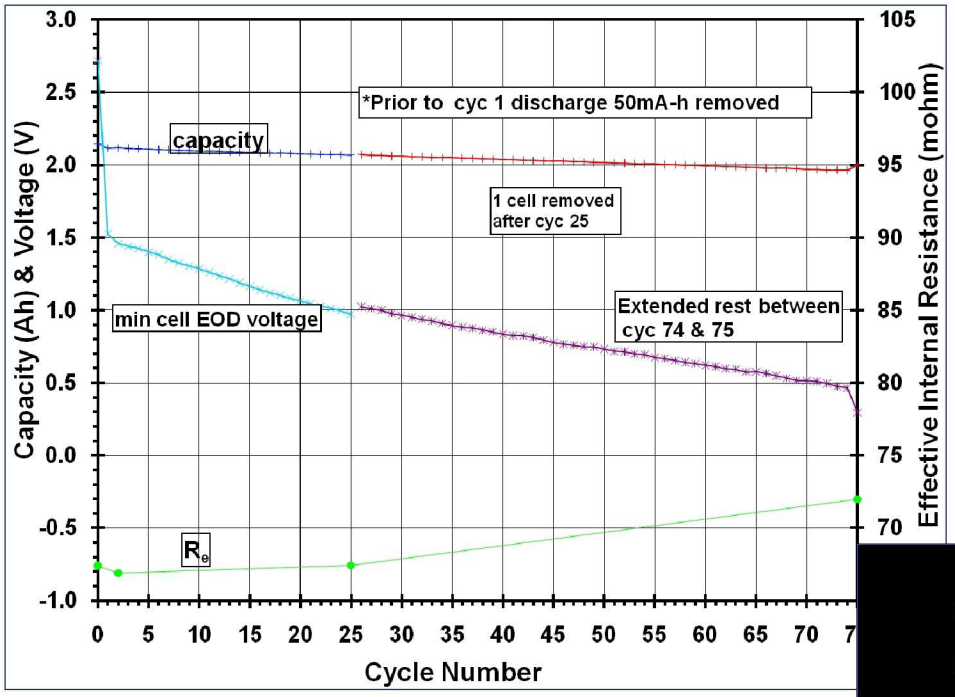


~150 mAh capacity

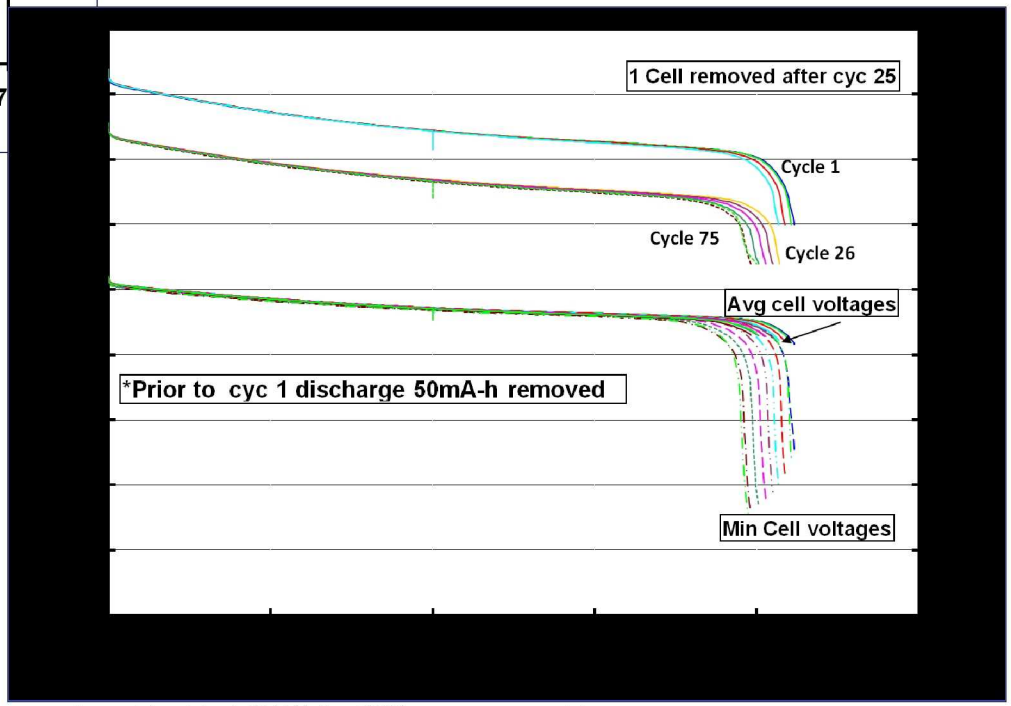
Charge: C/2 (1.08 A); EOCV: 4.2 V/cell
Discharge: C/2 A; EODV: 3.0 V/cell



Overdischarge Test on 10S Unbalanced Cell Module

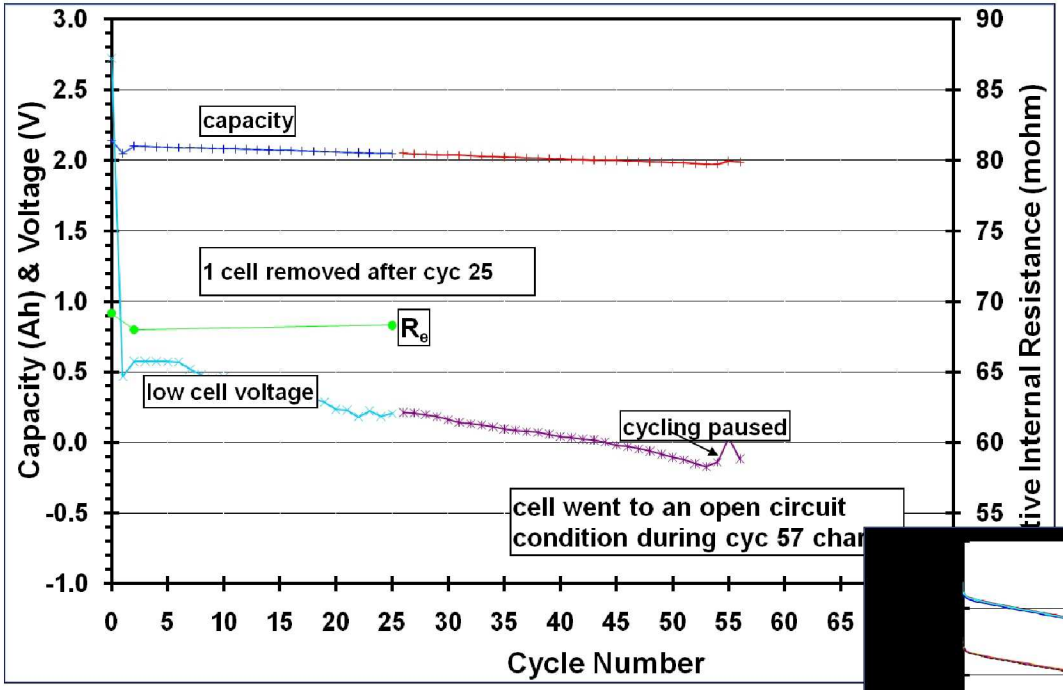


50 mAh capacity removed from one cell and placed back in the string before cycling was initiated

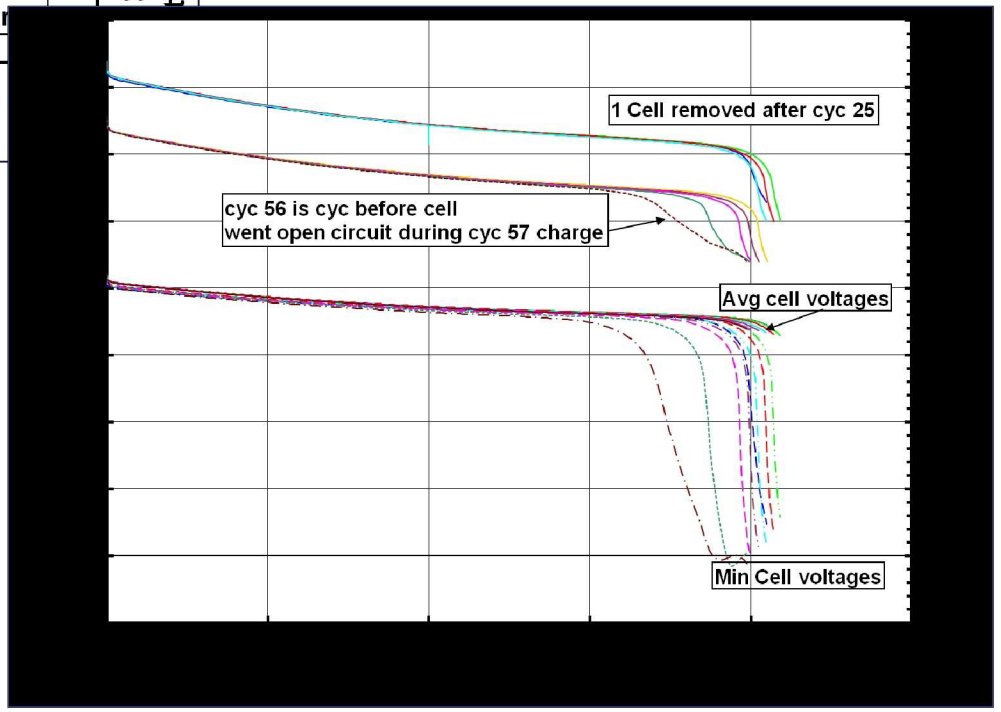


Charge: 1.08 A; EOCV: 4.2 V/cell
Discharge: 1.08A; EODV: 3.0 V/cell

Overdischarge Test on 10S Unbalanced Cell Module

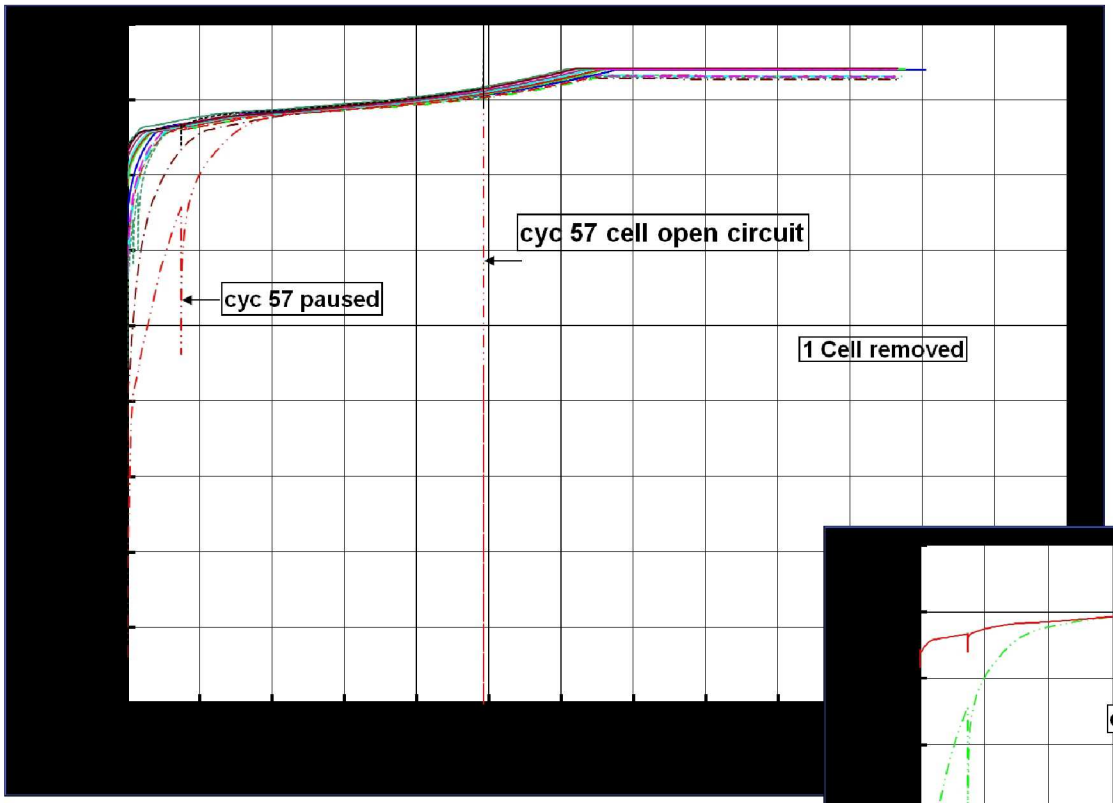


100 mAh removed

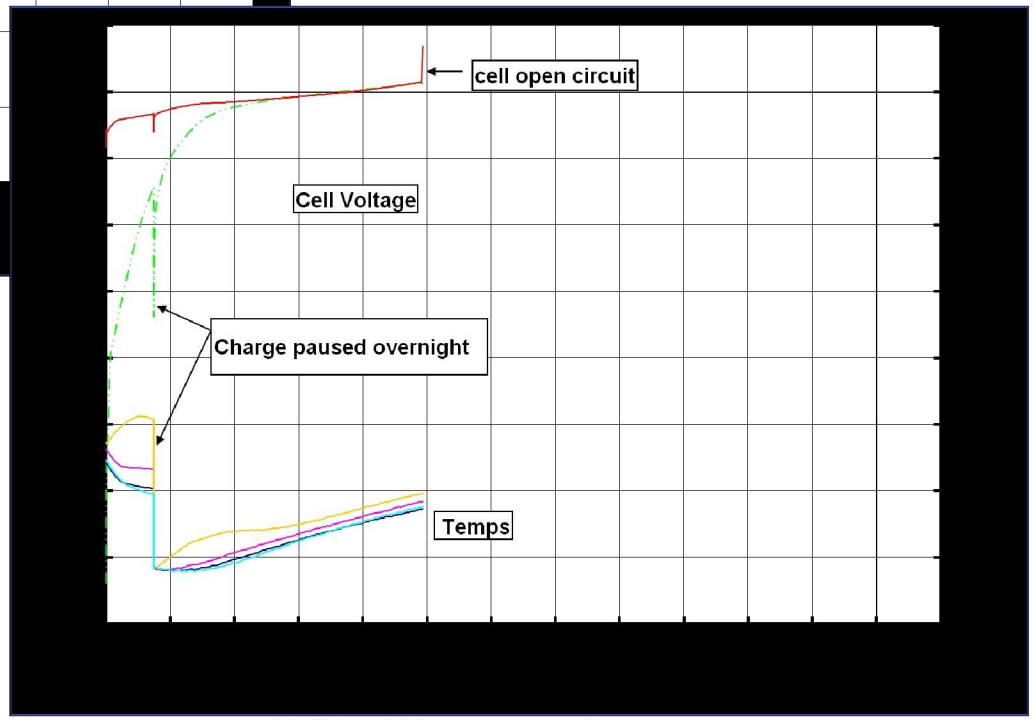


Prior to cyc 1 discharge 150mAh removed from cell 25.
***Cycle 1 discharge terminated to prevent extreme min cell voltage.**
***During cyc 2 charge, the charge was halted and 50mAh added to the cell for a net 100mAh removed from cell 25.**

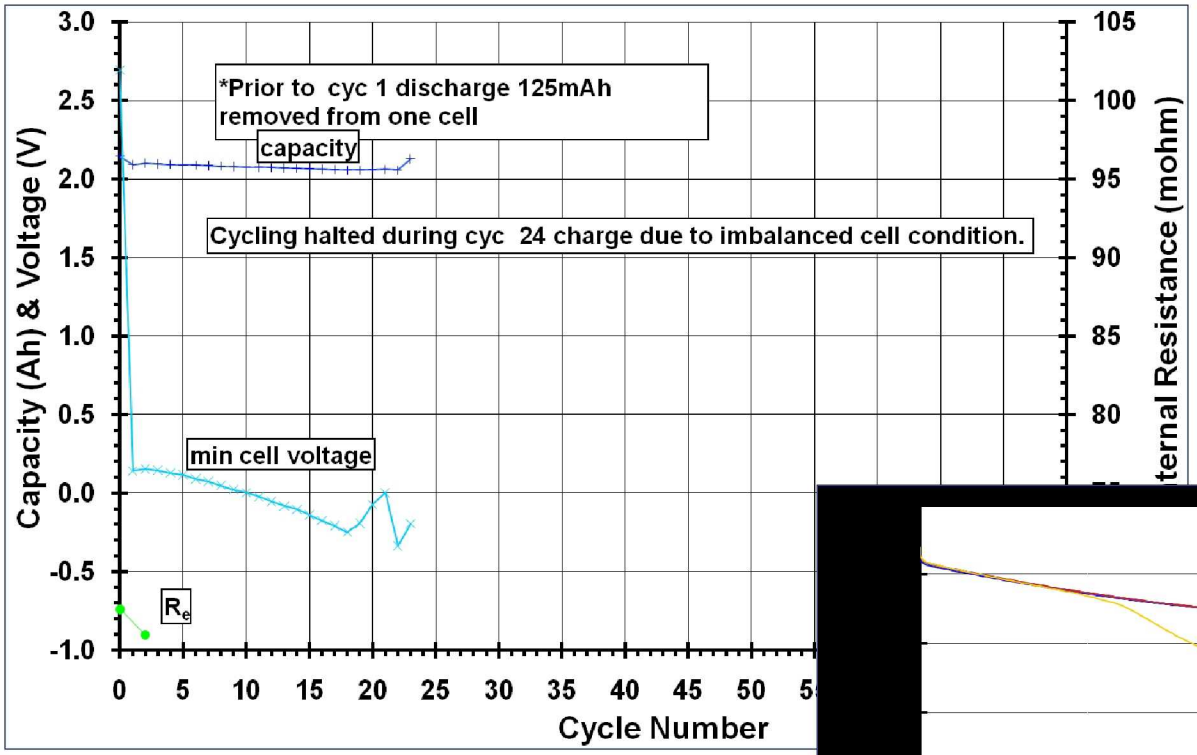
Overdischarge Test on 10S Unbalanced Cell Module



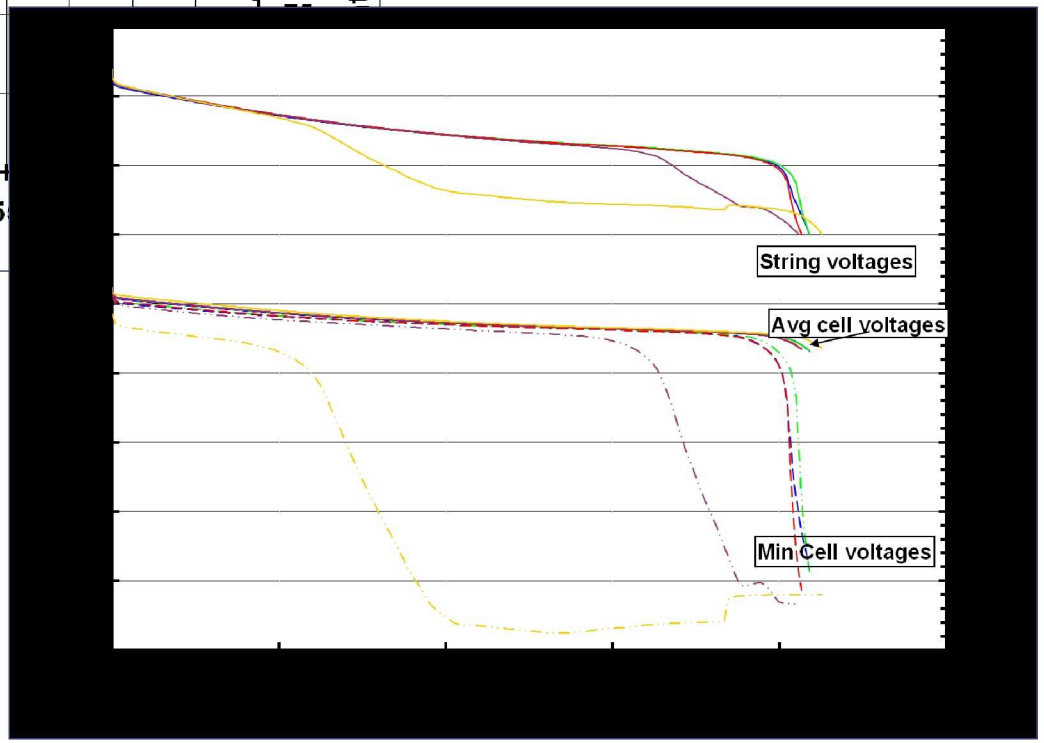
100 mAh removed



Overdischarge Test on 10S Unbalanced Cell Module



125 mAh removed



Summary and Conclusions

- The single cells as well as the cells in parallel design configurations did not display any anomalous behavior. There was a very slight increase in resistance with the deep discharges that they were subjected to. This may be due to the fact that the discharges were not deep enough to cause significant dissolution of copper that would in turn cause internal shorts to develop with cycling.
- The series configuration test modules with the unbalanced cells displayed different behavior. If the capacity removed from the unbalaced cell was 100 mAh or greater, the cells did show internal shorting at some point and this caused instability in the whole string.
- If the imbalance in the cells strings was in the range of 50 mAh, no significant changes in cycling behavior were observed even though the imbalanced cell went to very low voltages (less than 1.0 V) throughout the program.
- The test results indicate that several factors have to be taken into consideration while using cells in series and parallel configurations.
  - Cell matching should be stringent and based on capacity as well as internal resistance of the cells and not just the Open circuit voltage
  - Cell modules should have a undervoltage cutoff to prevent cells from going into very low voltages especially if they are in an imbalanced condition
  - Have cell balancing to prevent one or more cells from being significantly imbalanced from the others.
  - Without monitoring and balancing, it would be difficult to capture deep discharge or voltage reversal of one or more cells.

Acknowledgment

SRI for the flexibility in changing the test program based on the results obtained throughout the test.