

# Cell Lot Cert Testing

## Long Life Battery (LLB) for the Spacesuit



**Performed by SRI's  
Brad Strangways and Tim Nelson  
and NASA-JSC/ESTA**

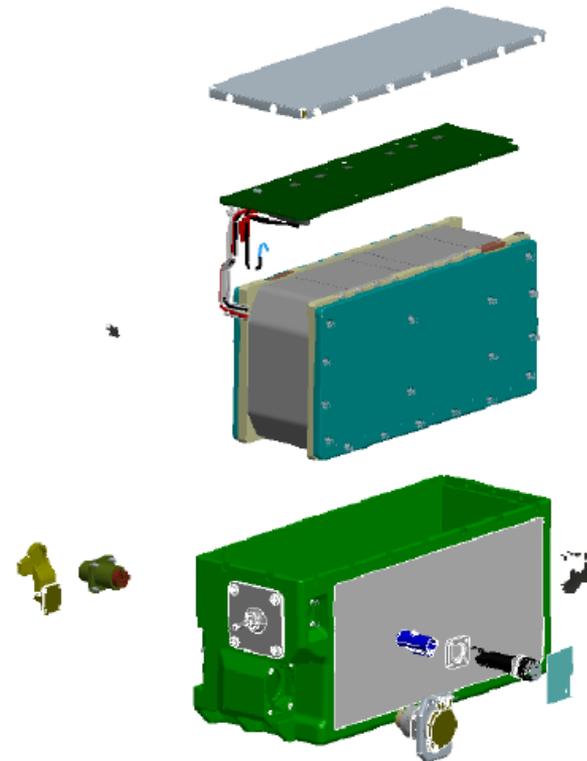
**Summarized By  
Eric Darcy/NASA-JSC**

**For the  
2009 NASA Aerospace Battery Workshop**



# Cell Designs for Long Life Battery

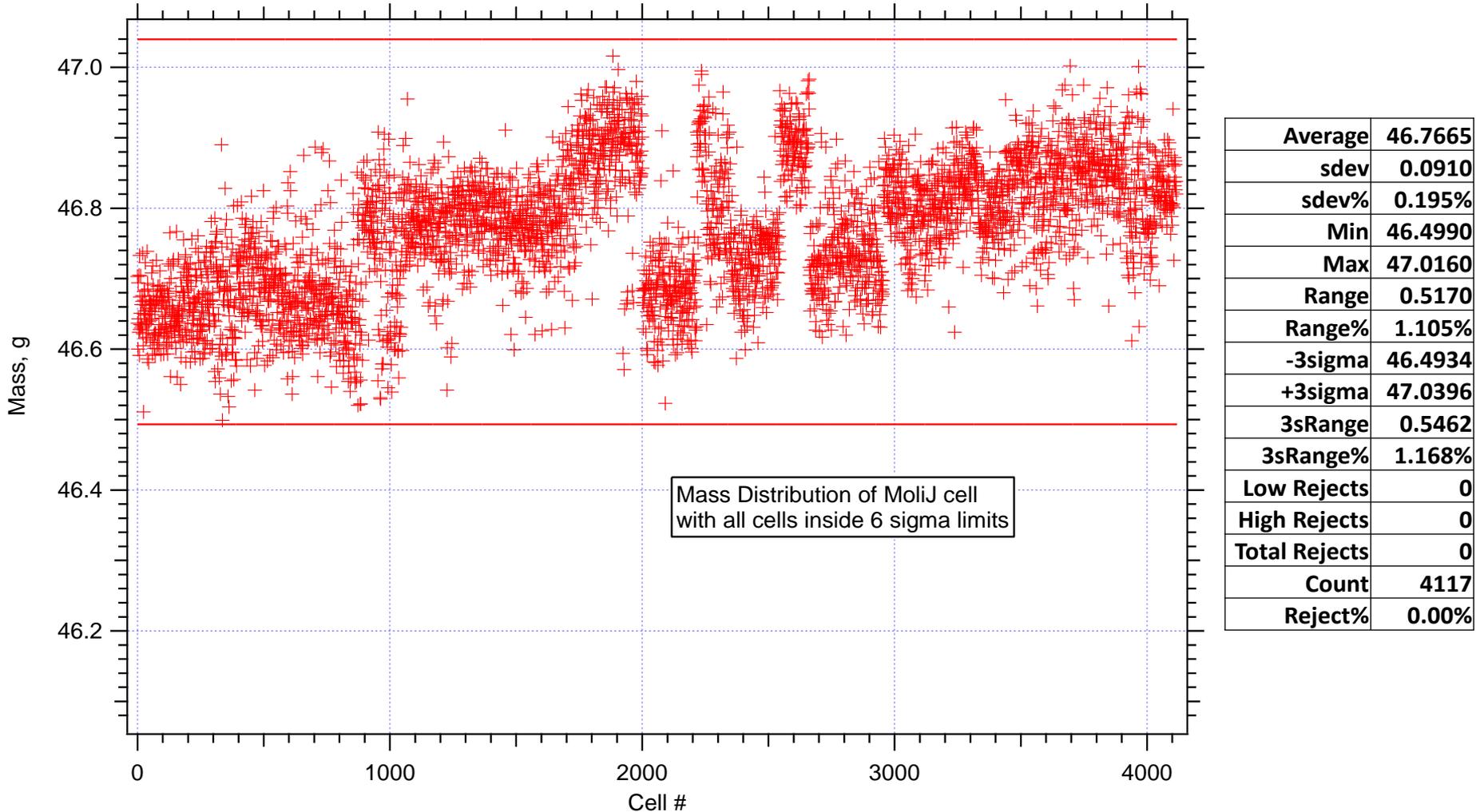
- 20V, 30-35Ah depending on COTS 18650 cell design selected
  - LV rated at 2.15Ah
  - MoliJ rated at 2.4Ah
- Designs selected due to
  - Maturity: > 5yrs in production (no recalls)
  - Extensively characterized for Shuttle EAPU in 2004



# Outline of Cell Lot Certification

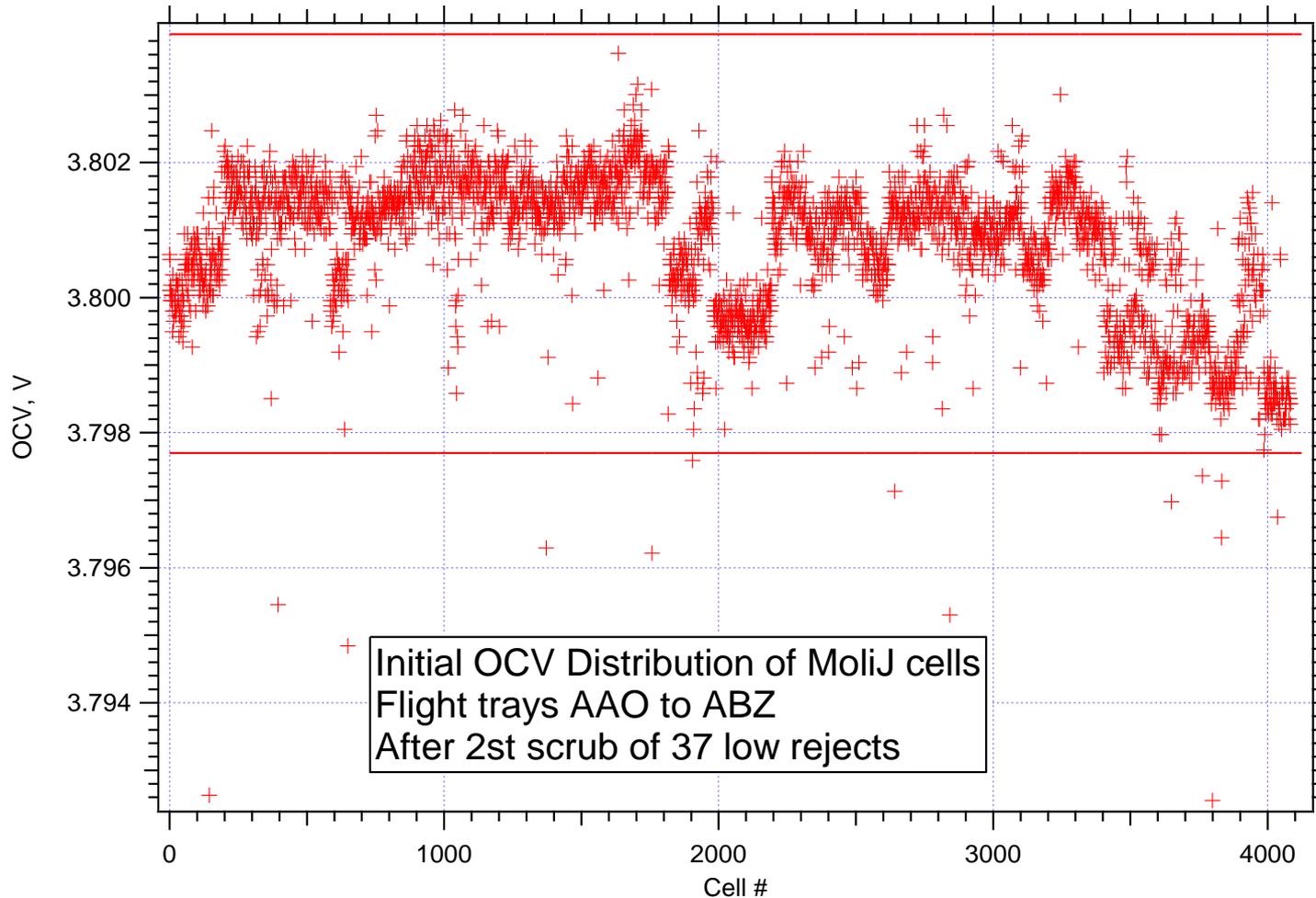
- ABSL randomly selected 220 cells from each lot that had passed their acceptance testing and shipped them to SRI, Arab, AL
- Cell Lot Certification (all at SRI unless otherwise noted) consisted of
  - Cell Acceptance
  - Certification Testing
    - Capacity vs Temperature characterization
    - Environmental Exposure (vibration at ESTA)
    - Post test check-out (repeats Ah vs temp characterization)
    - -50C exposure
    - Repeat Capacity vs room temperature characterization
    - Self-discharge vs SOC, Temp
    - OCV vs SOC
    - Cycle life at room temperature
    - Vent-burst pressure determination (ESTA)
    - Destructive Physical Analysis (SRI and Exponent)
    - Abuse Tolerance (SRI and ESTA)
    - Calorimetry (ESTA)

# ABSL MoliJ Flight Cell Acceptance – Mass w/o sleeve & donut



6 $\sigma$  range is still 0.55 g (1.2% of mean) with all conforming cells

# ABSL MoliJ Flight Cell Acceptance – As received OCVs



|                      |               |
|----------------------|---------------|
| <b>Average</b>       | <b>3.8008</b> |
| <b>sdev</b>          | <b>0.0010</b> |
| <b>sdev%</b>         | <b>0.027%</b> |
| <b>Min</b>           | <b>3.7926</b> |
| <b>Max</b>           | <b>3.8036</b> |
| <b>Range</b>         | <b>0.0111</b> |
| <b>Range%</b>        | <b>0.291%</b> |
| <b>-3sigma</b>       | <b>3.7977</b> |
| <b>+3sigma</b>       | <b>3.8039</b> |
| <b>3sRange</b>       | <b>0.0062</b> |
| <b>3sRange%</b>      | <b>0.162%</b> |
| <b>Low Rejects</b>   | <b>16</b>     |
| <b>High Rejects</b>  | <b>0</b>      |
| <b>Total Rejects</b> | <b>16</b>     |
| <b>Count</b>         | <b>3601</b>   |
| <b>Reject%</b>       | <b>0.44%</b>  |

**56 outliers found outside 6 sigma range of 6.2 mV (0.16% of avg)**

**OCVs measured > 27 months after cell date code (Apr 07)**

## Cell Acceptance at SRI

| <b><u>Moli J</u></b> | <b>Mass<br/>(bare) (g)</b> | <b>Mass<br/>(sleeved)</b> | <b>Delta wt.</b> | <b>OCV</b> | <b>CCV</b> |
|----------------------|----------------------------|---------------------------|------------------|------------|------------|
| average              | 46.7508                    | 47.3775                   | 0.6267           | 3.5178     | 3.2135     |
| std                  | 0.1170                     | 0.1170                    | 0.0111           | 0.0348     | 0.0449     |
| max                  | 47.0227                    | 47.6517                   | 0.6889           | 3.5963     | 3.3154     |
| min                  | 46.5288                    | 47.1553                   | 0.5882           | 3.4327     | 3.1010     |
| range                | 0.4939                     | 0.4964                    | 0.1007           | 0.1636     | 0.2144     |

| <b><u>LV</u></b> | <b>Mass<br/>(bare) (g)</b> | <b>Mass<br/>(sleeved)</b> | <b>Delta wt.</b> | <b>OCV</b> | <b>CCV</b> |
|------------------|----------------------------|---------------------------|------------------|------------|------------|
| average          | 42.9959                    | 43.6141                   | 0.6182           | 3.4585     | 3.2351     |
| std              | 0.0885                     | 0.0892                    | 0.0099           | 0.0077     | 0.0089     |
| max              | 43.3356                    | 43.9464                   | 0.6495           | 3.4729     | 3.2571     |
| min              | 42.7212                    | 43.3390                   | 0.5936           | 3.4410     | 3.2110     |
| range            | 0.6144                     | 0.6074                    | 0.0559           | 0.0319     | 0.0461     |

ABSL shipped all cells to SRI at 0% SoC

SRI removed original sleeving, measured cell masses, re-sleeved, and re-weighed each cell

CCV test done with 1C, 15 sec pulse

# Environmental Exposure Test Regime

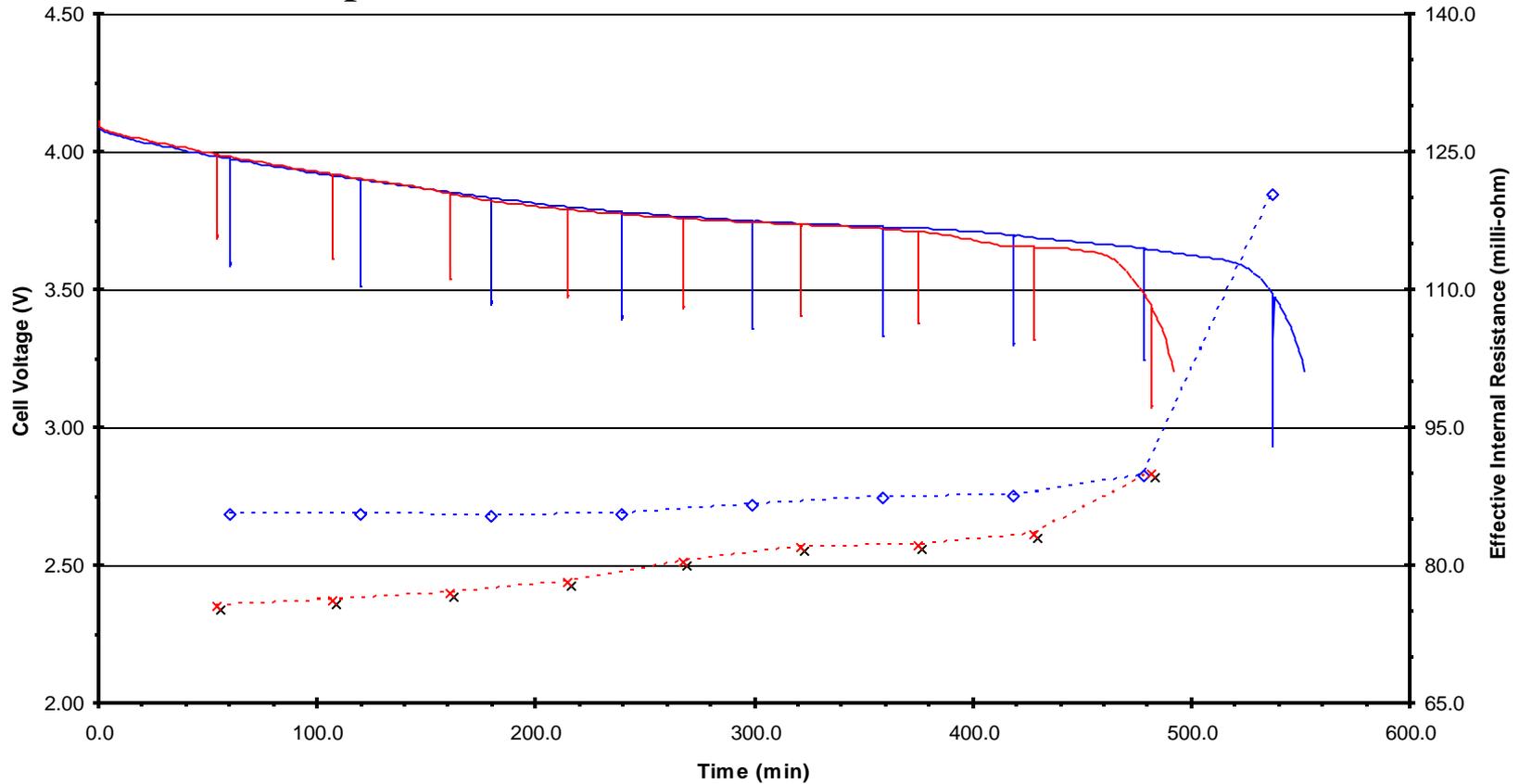
- Randomly select 16 cells from each lot
- Perform Ah vs T (10, 25, and 35°C)
- Split each lot sample into on two equal groups (30%, 100% SoC) for the environmental exposure testing
- Environmental Exposure
  - Depress to < 7 torr in 7.5 min, hold for 15 min, and repress within 15 min to ambient pressure. Complete 15 cycles.
  - 24 thermal cycles with 3hr dwells at +54 °C and -24 °C
  - Vibration at 0.146 g<sup>2</sup>/Hz from 20 to 750 Hz for 7.5 min/axes (axial and radial) for a total of 13.25 grms
  - Shock – 40g, 11 msec saw tooth pulse in 6 orthogonal directions
  - Repeat Ah vs T characterization vs temperature (same as pre-test)
  - -50 °C exposure to the 30% SoC group
  - Repeat Ah vs T only at room temperature

## Figure : LLB Cell Lot Certification

Capacity charge/discharge vs. Temperature

Discharge - 240mA w/ 1s-2C Pulse @ 10% SoC intervals, 25°C

LLB runtime predict: > 60 min with MoliJ than with LV cells at 25 C

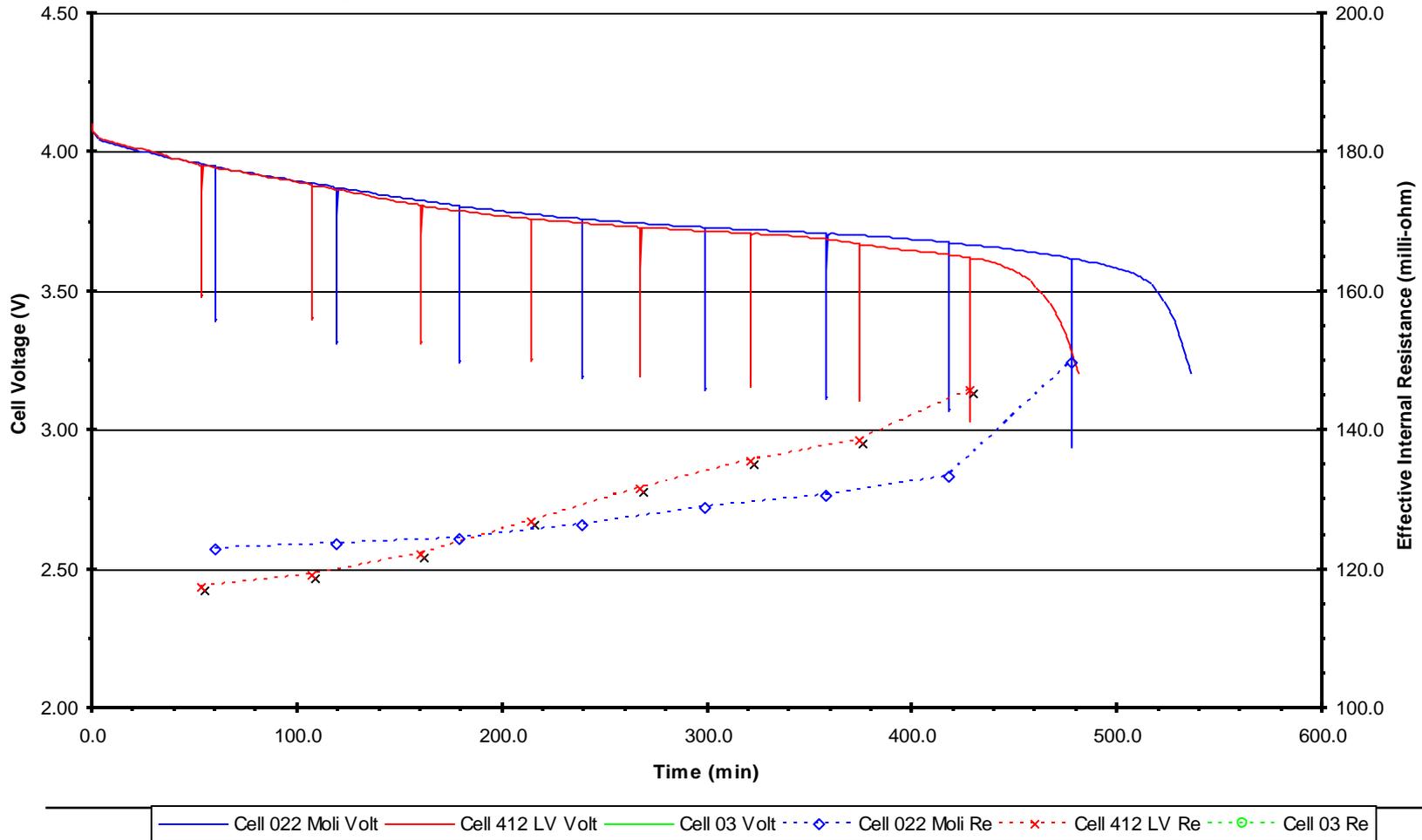


### Figure : LLB Cell Lot Certification

Capacity charge/discharge vs. Temperature

Discharge - 240mA w/ 1s-2C Pulse @ 10% SoC intervals, 10°C

## LLB runtime predict: > 55 min with MoliJ than with LV cells at 10 C



### Figure : LLB Cell Lot Certification

Capacity charge/discharge vs. Temperature

Discharge - 240mA w/ 1s-2C Pulse @ 10% SoC intervals, 35°C

LLB runtime predict: > 62 min with MoliJ than with LV cells at 35 C

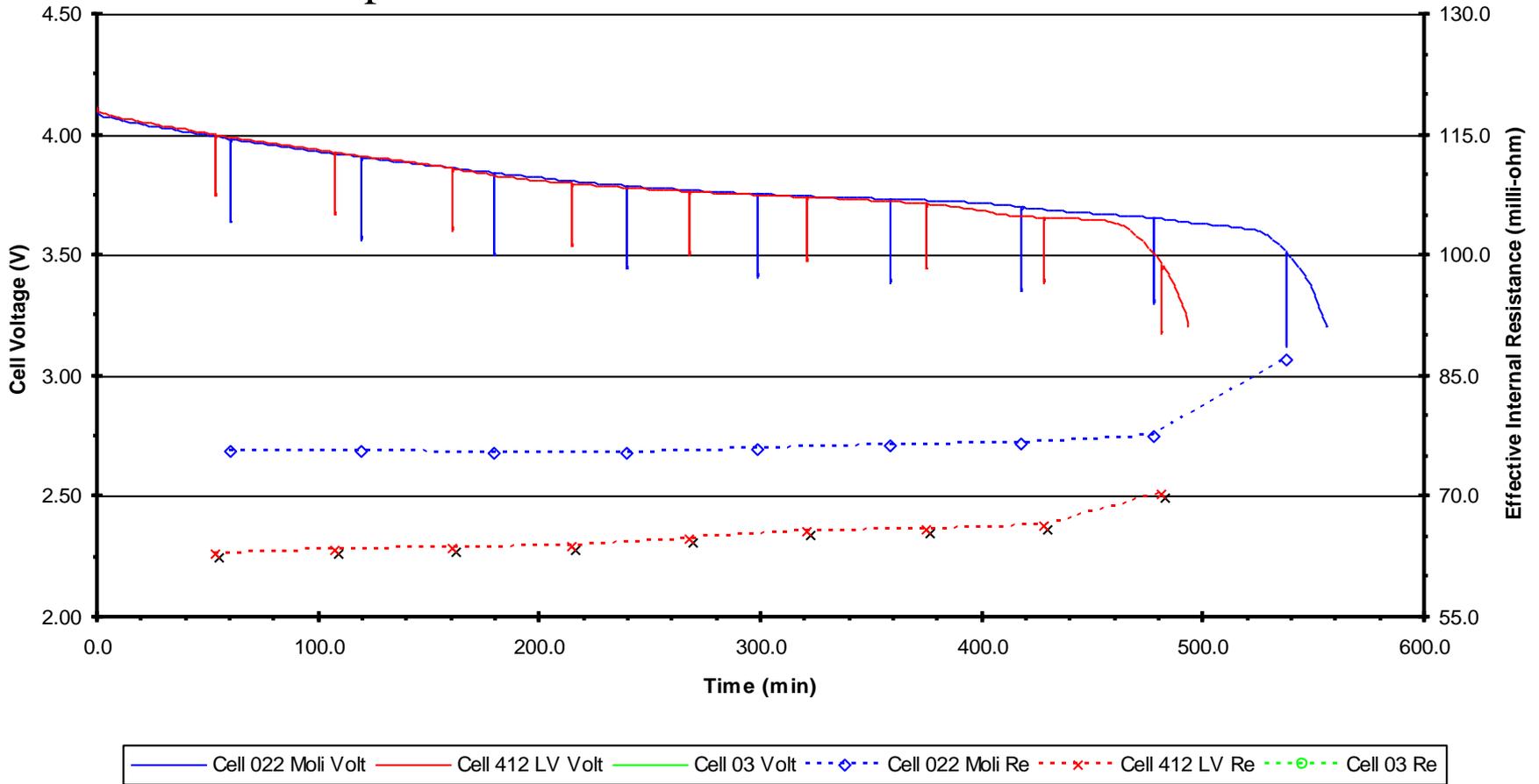


Table 2: Capacity versus Temperature Statistical Summary

| <b>Moli J</b> | <b>Capacity at Temperature (A-h)</b> |             |             | <b>R<sub>e</sub> at 50% SoC (mohms)</b> |             |             |
|---------------|--------------------------------------|-------------|-------------|---|-------------|-------------|
|               | <b>25°C</b>                          | <b>10°C</b> | <b>35°C</b> | <b>25°C</b>                             | <b>10°C</b> | <b>35°C</b> |
| average       | 2.2135                               | 2.1460      | 2.2312      | 85.6                                    | 128.4       | 75.4        |
| std           | 0.0161                               | 0.0186      | 0.0143      | 1.0                                     | 1.8         | 0.8         |
| max           | 2.2418                               | 2.1777      | 2.2575      | 86.7                                    | 131.5       | 76.7        |
| min           | 2.1937                               | 2.1190      | 2.2110      | 83.3                                    | 125.2       | 74.0        |
| range         | 0.0481                               | 0.0586      | 0.0465      | 3.4                                     | 6.3         | 2.7         |
| <b>LV</b>     |                                      |             |             |   |             |             |
| average       | 1.9755                               | 1.9300      | 1.9821      | 78.7                                    | 131.0       | 63.9        |
| std           | 0.0030                               | 0.0043      | 0.0030      | 1.5                                     | 2.6         | 1.1         |
| max           | 1.9792                               | 1.9378      | 1.9856      | 81.0                                    | 135.9       | 65.4        |
| min           | 1.9698                               | 1.9238      | 1.9761      | 76.1                                    | 126.4       | 62.1        |
| range         | 0.0094                               | 0.0140      | 0.0095      | 4.8                                     | 9.5         | 3.4         |

Capacity performance is only slightly influenced by temperature  
 Cell internal resistance is much more influenced by temperature

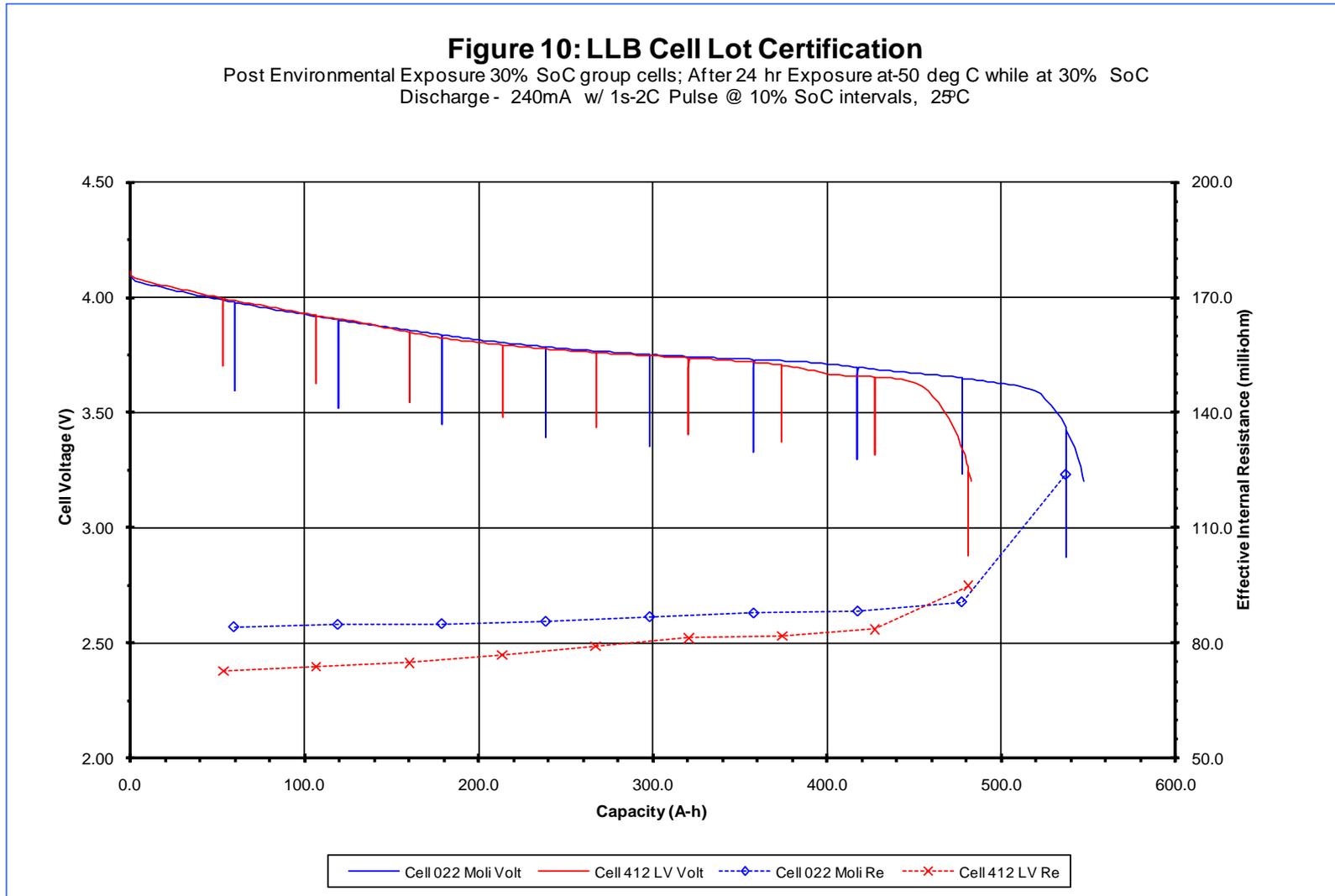
# Effects of pressure, thermal, vib, and shock

| Pre & Post Environmental Capacity Loss and Resistance Growth |         |            |         |            |         |            |
|--|---------|------------|---------|------------|---------|------------|
|  | 10 degC |            | 25 degC |            | 35 degC |            |
|  | mAh     | Re (mohms) | mAh     | Re (mohms) | mAh     | Re (mohms) |
| MoliJ 30%  | 8.1     | 2.3        | 12.3    | 0.4        | 12.0    | 0.6        |
| MoliJ 100%   | 48.3    | 9.6        | 52.6    | 5.9        | 34.0    | 3.7        |
|  |         |            |         |            |         |            |
| LV 30%   | 29.7    | 7.1        | 30.2    | 0.4        | 25.0    | 0.7        |
| LV 100%  | 36.1    | 4.8        | 47.7    | 2.2        | 34.2    | 1.8        |

Overall capacity losses were very low (< 53 mAh, 2.4%)

Room temperature capacity performance suffered most

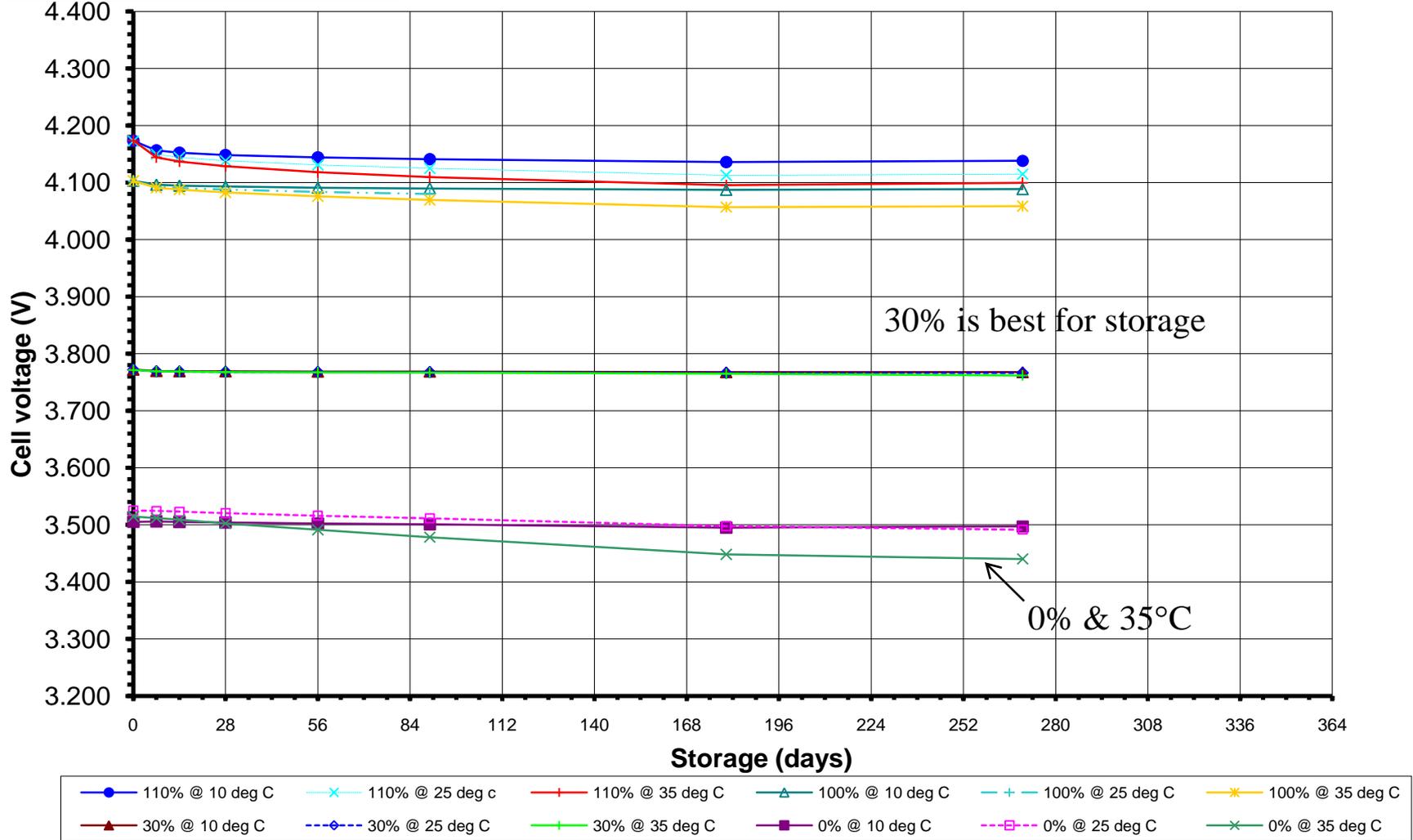
Largest cell resistance growth detected at low T, 100% SoC



Negligible capacity loss (<10 mAh) after 24hr exposure to -50°C while at 30% SoC

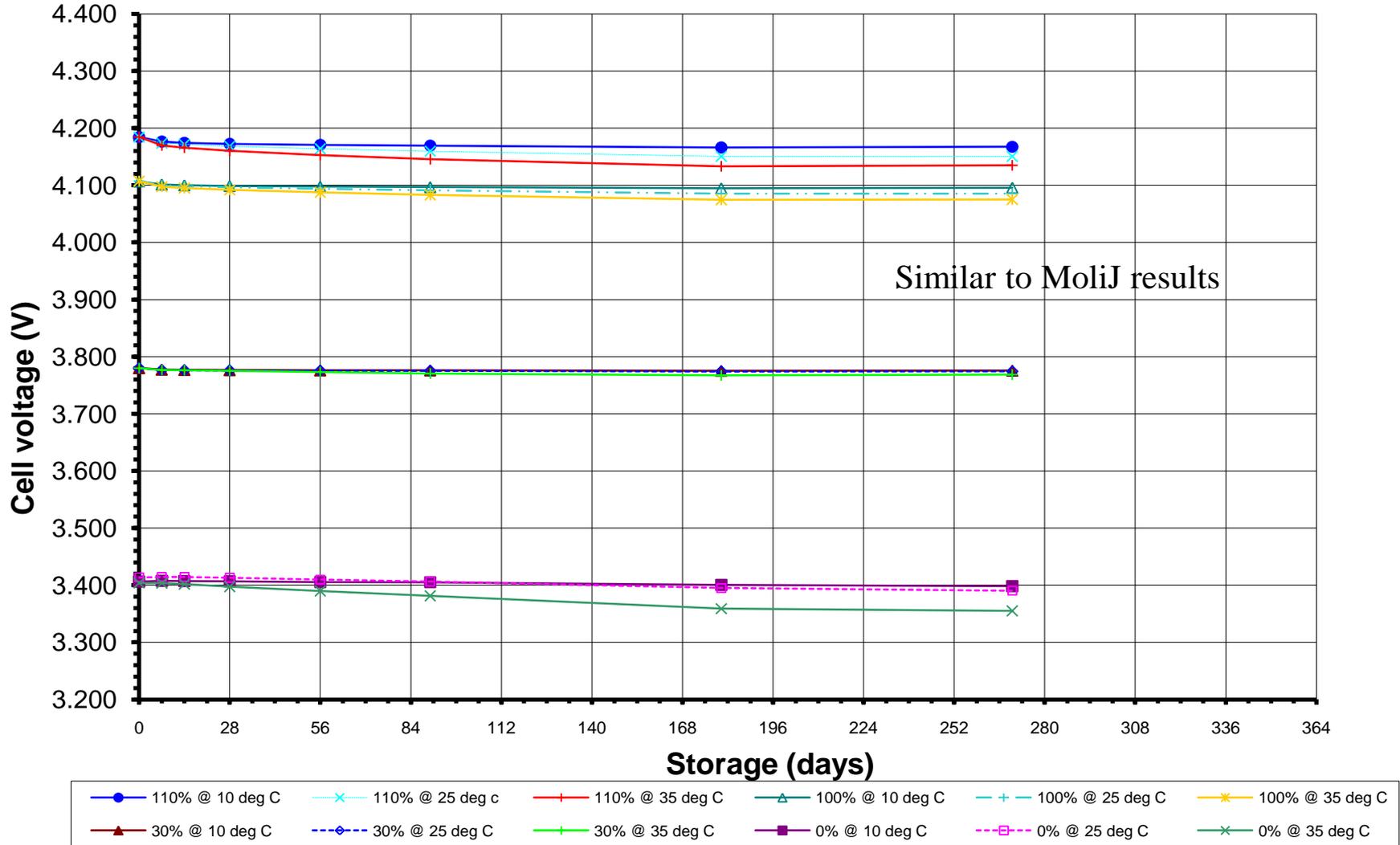
### Self Discharge vs SOC (as %), at Temperature; Group Average OCV, Moli-J cell

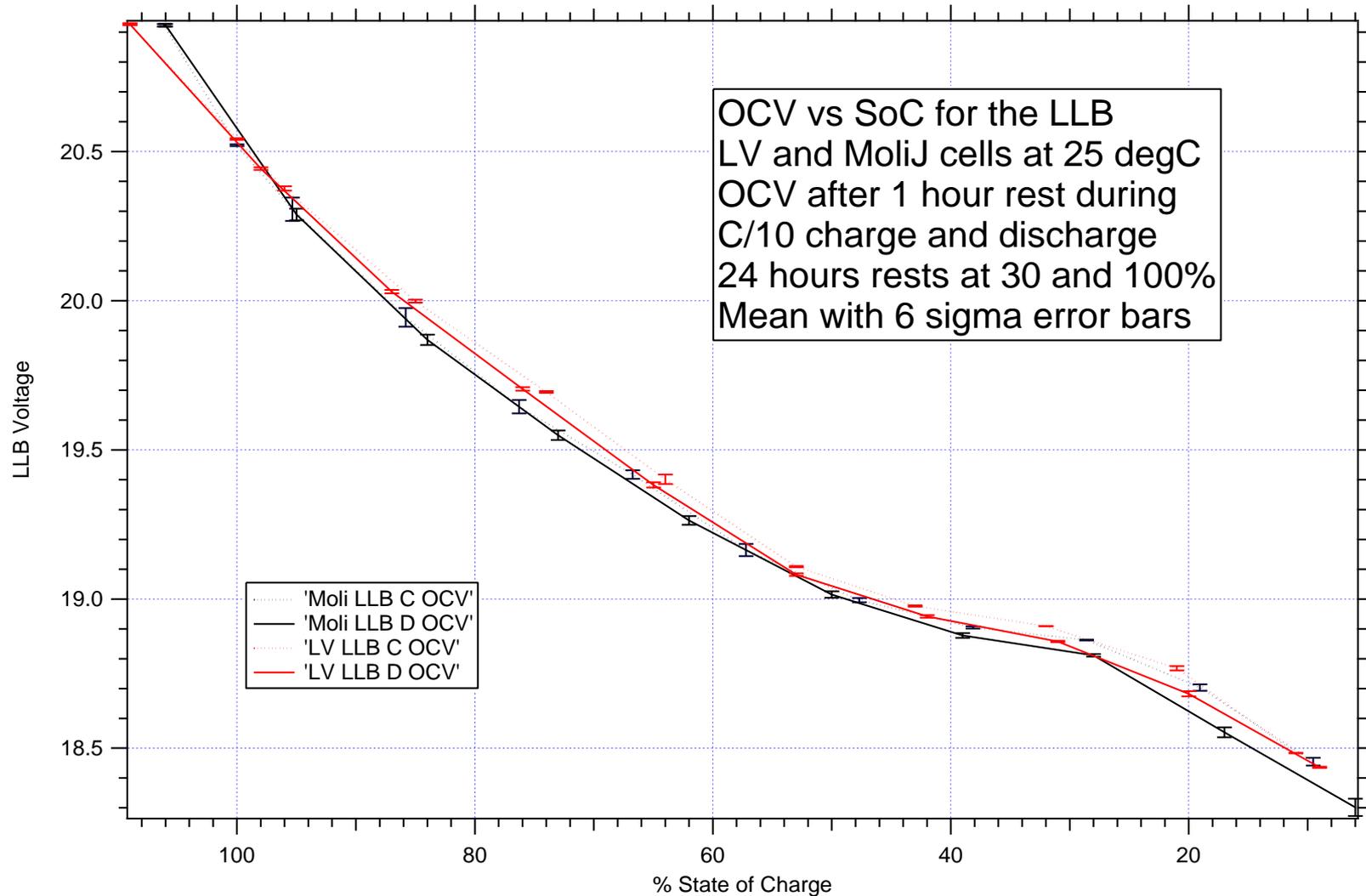
Record days 0, 7, 14, 28, 56, 90, 180, and 270



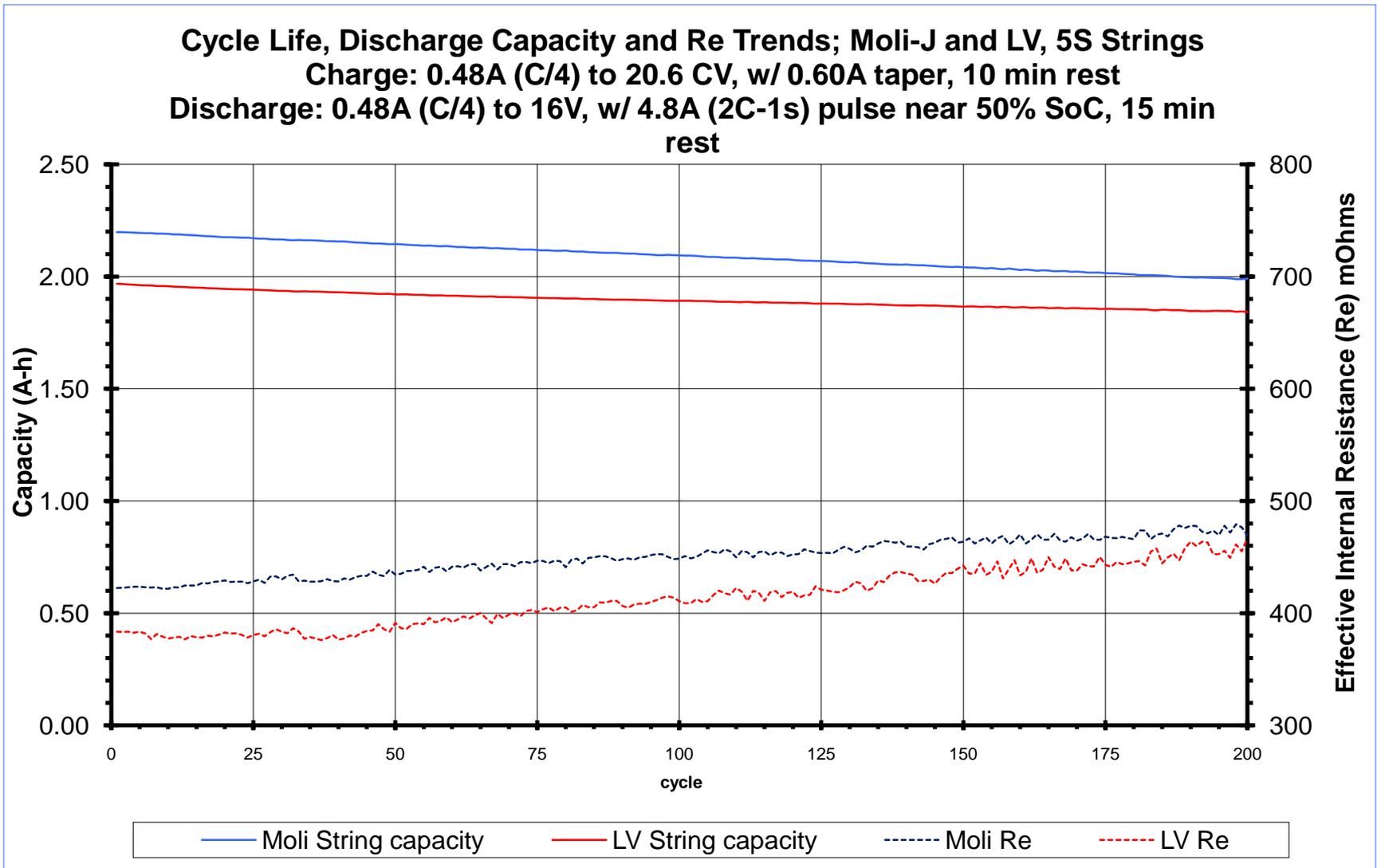
Record days 0, 7, 14, 28, 56, 90, 180, and 270

**Self Discharge vs SOC (as %), at Temperature; Group Average OCV, LV cell**





LLB OCV can be used to indicate State-of-Charge (SoC)  
 Hysteresis between charge and discharge is small



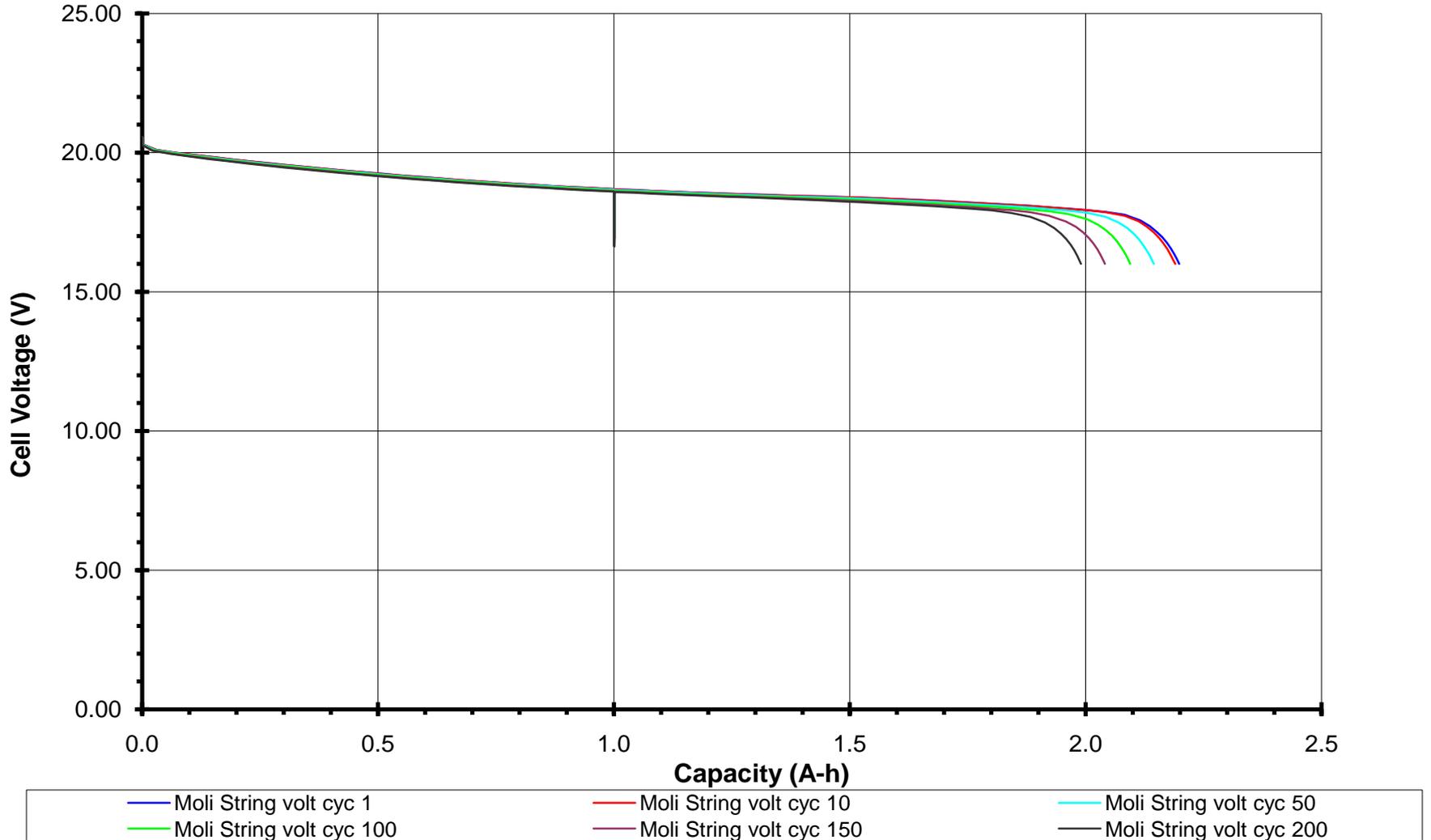
Capacity fade and resistance growth after 200 cycles are < 13% with MoliJ

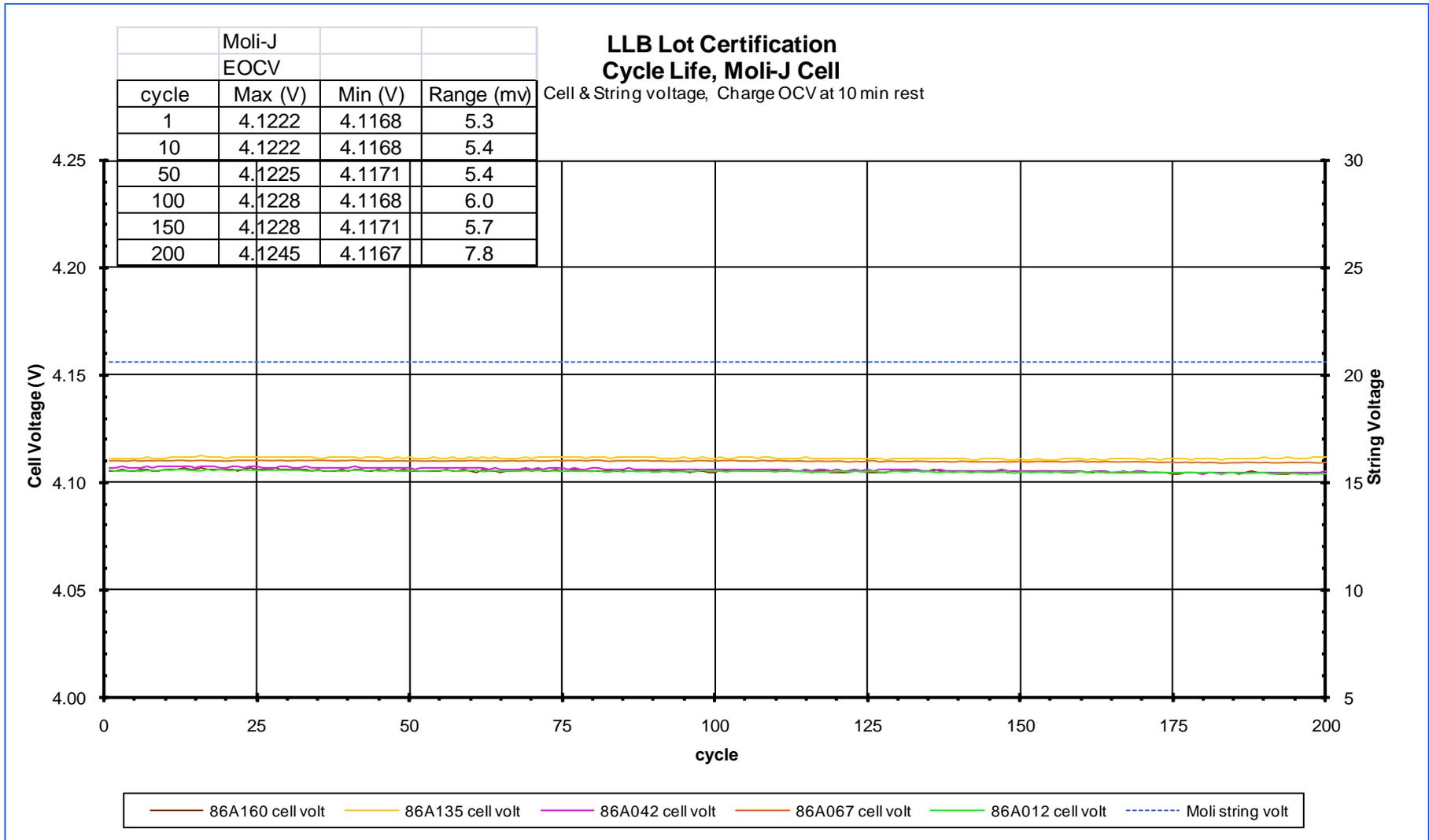
15% capacity margin exists over the 1.67Ah/cell is required to meet 26.6Ah/LLB

## Cycle Life, Discharge Moli-J Cell; 5S Battery

Discharge - 600mA (C/4) w/ 1s-4.8A (2C) Pulse near 50% SoC, Room Temperature

Voltage profiles of the 5S MoliJ test string only deviate at the end of charge with increasing cycles





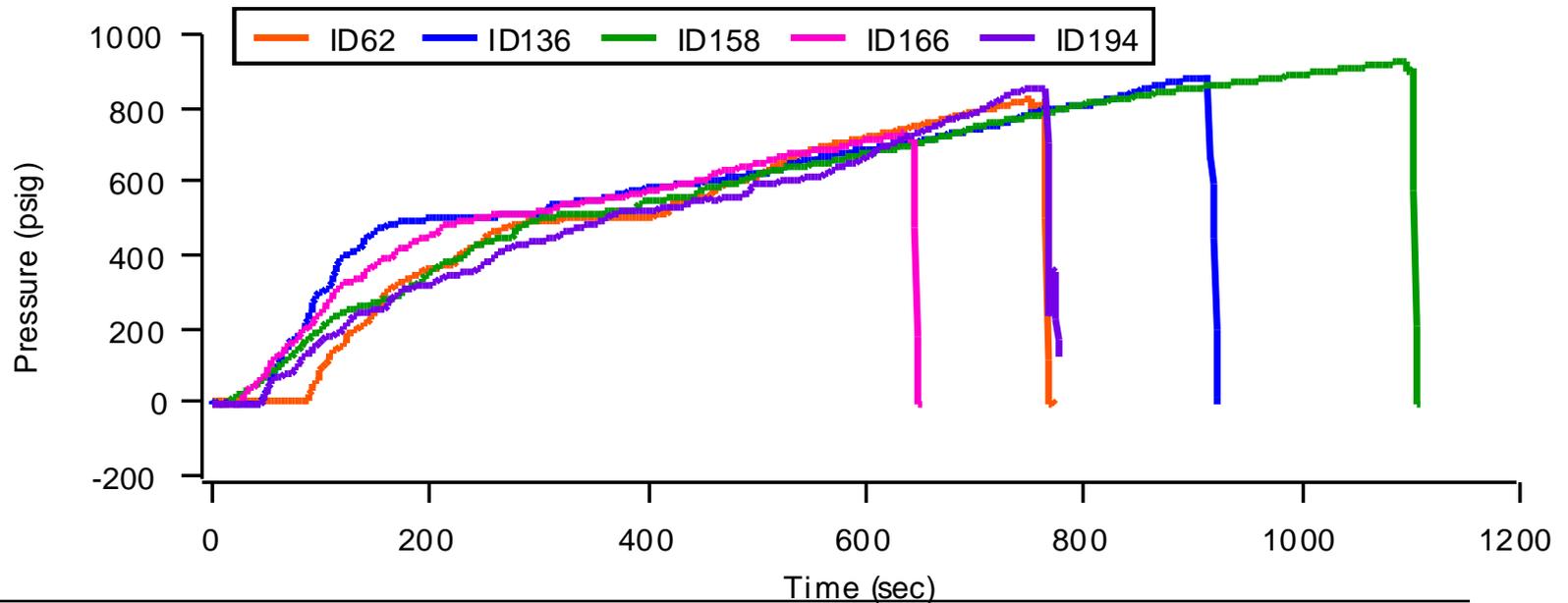
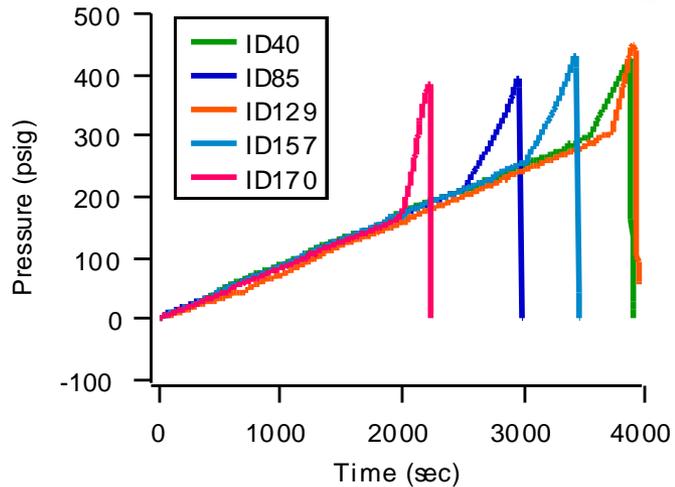
Without balancing, cell voltages at the end of string charge deviated  $< 8$  mV during the cycling

# Cell Vent/Burst Pressure Determination

- Vent test performed by discharging cell, drilling small hole in bottom of can, and epoxing cell to A/N pipe fitting
- Hydraulic method was attempted first, but higher vent pressures and greater variability than expected occurred
- Retested new cells with pneumatic method and got less variability but same average vent pressures
- Burst test is done the same way except that the cell vent in cell header is filled with epoxy to disable it
- Ratio of average vent:burst pressure is 1:1.9 which on surface violates our fracture control requirement > 1:2.5 ratio of vent-to-burst
- Even if the anomalous low burst pressure result of S/N 194 is thrown out because of suspicion that its vent was not fully blocked, the ratio only improves to 1:2.0
- The rationale for accepting lower ratio, which has precedent, is if the bursts are not violent and act as a secondary leak before burst feature
- Unfortunately, one cell (S/N 136) appears to have burst violently, while the other 4 burst “vented” benignly
- The cap of S/N 136 blew out along with the cell’s jellyroll
- Test method improvements are being investigated

| MoliJ    |               |          |                |
|----------|---------------|----------|----------------|
| Cell S/N | Vent P (psia) | Cell S/N | Burst P (psia) |
| 40       | 425           | 62       | 826            |
| 85       | 392           | 136      | 885            |
| 129      | 448           | 158      | 926            |
| 157      | 433           | 166      | 730            |
| 170      | 386           | 194      | 553            |
| Average  | 417           |          | 784            |
| sdev     | 27            |          | 149            |
| sdev%    | 6%            |          | 19%            |
| Min      | 386           |          | 553            |
| Max      | 448           |          | 926            |
| Range    | 62            |          | 373            |
| Range%   | 15%           |          | 48%            |
| -3sigma  | 336           |          | 338            |
| +3sigma  | 497           |          | 1230           |
| 3sRange  | 160           |          | 892            |
| 3sRange% | 38%           |          | 114%           |

# MoliJ Vent and Burst Pressure Plots



## After pictures of burst pressure test for MoliJ #136

### Cell separated from fitting

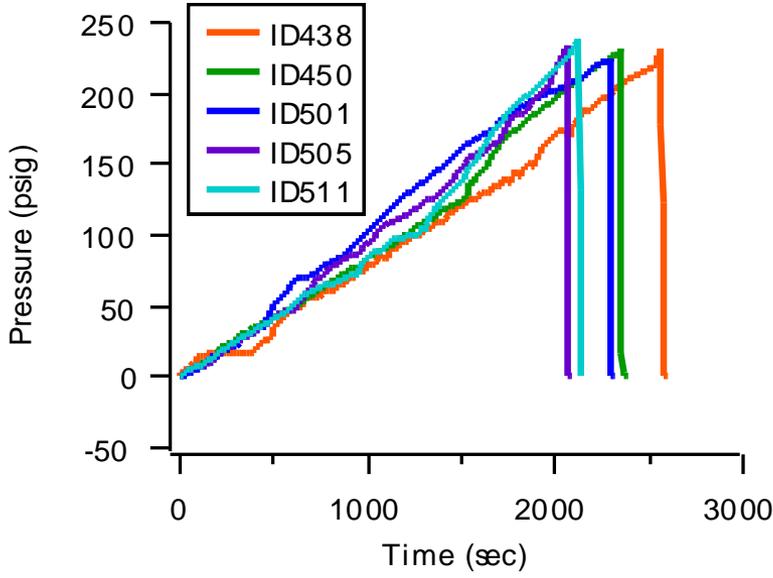


### Fitting, cell can and contents



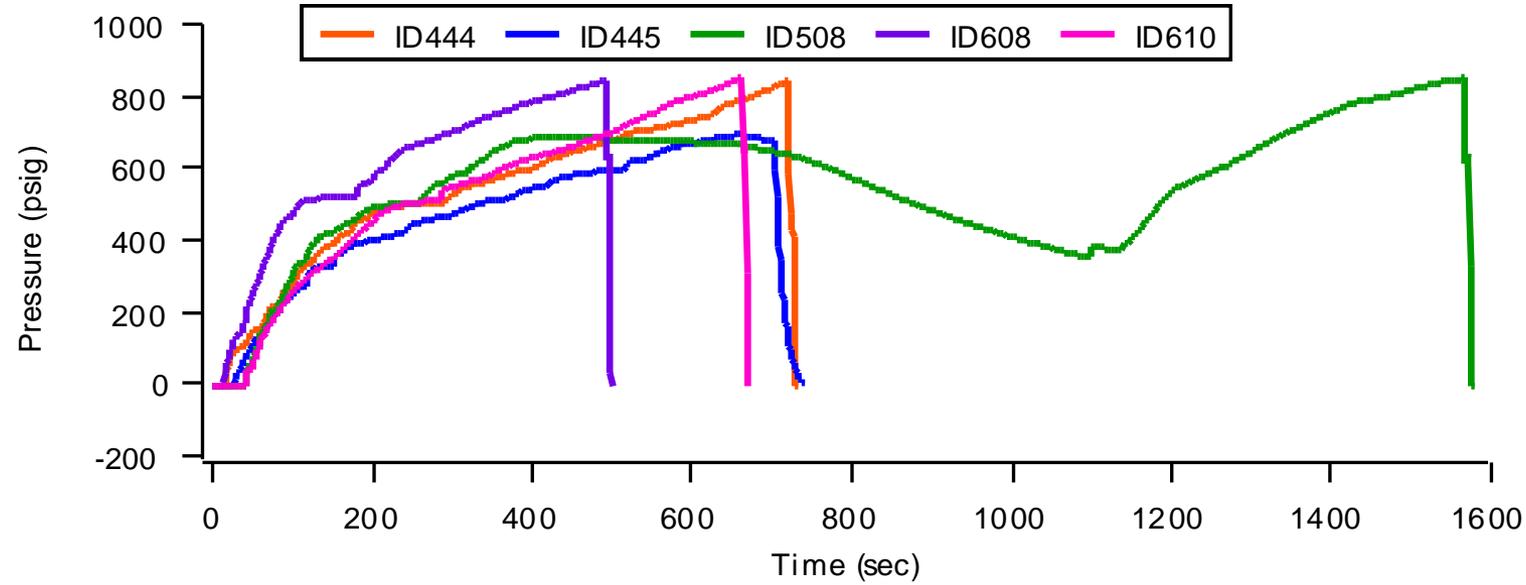
### Proposed improvements to test methods

- Cut the entire bottom of the cell can off instead of drilling a small hole
- Etch the can walls to better adhere the can to the fitting with epoxy
- Insert the epoxy inside the cell header with narrow syringes to ensure a complete fill



Vent-to-Burst P  
Ratio is 1: 3.5  
and  
4 of 5 cells burst  
violently

| Cell S/N | Vent P (psia) | Cell S/N | Burst P (psia) |
|----------|---------------|----------|----------------|
| 438      | 231           | 444      | 844            |
| 450      | 231           | 445      | 694            |
| 501      | 224           | 508      | 850            |
| 505      | 233           | 608      | 843            |
| 511      | 238           | 610      | 856            |
| Average  |               | 232      | 817            |
| sdev     |               | 5        | 69             |
| sdev%    |               | 2%       | 9%             |
| Min      |               | 224      | 694            |
| Max      |               | 238      | 856            |
| Range    |               | 14       | 163            |
| Range%   |               | 6%       | 20%            |
| -3sigma  |               | 217      | 609            |
| +3sigma  |               | 247      | 1026           |
| 3sRange  |               | 30       | 417            |
| 3sRange% |               | 13%      | 51%            |



# Overcharge Testing

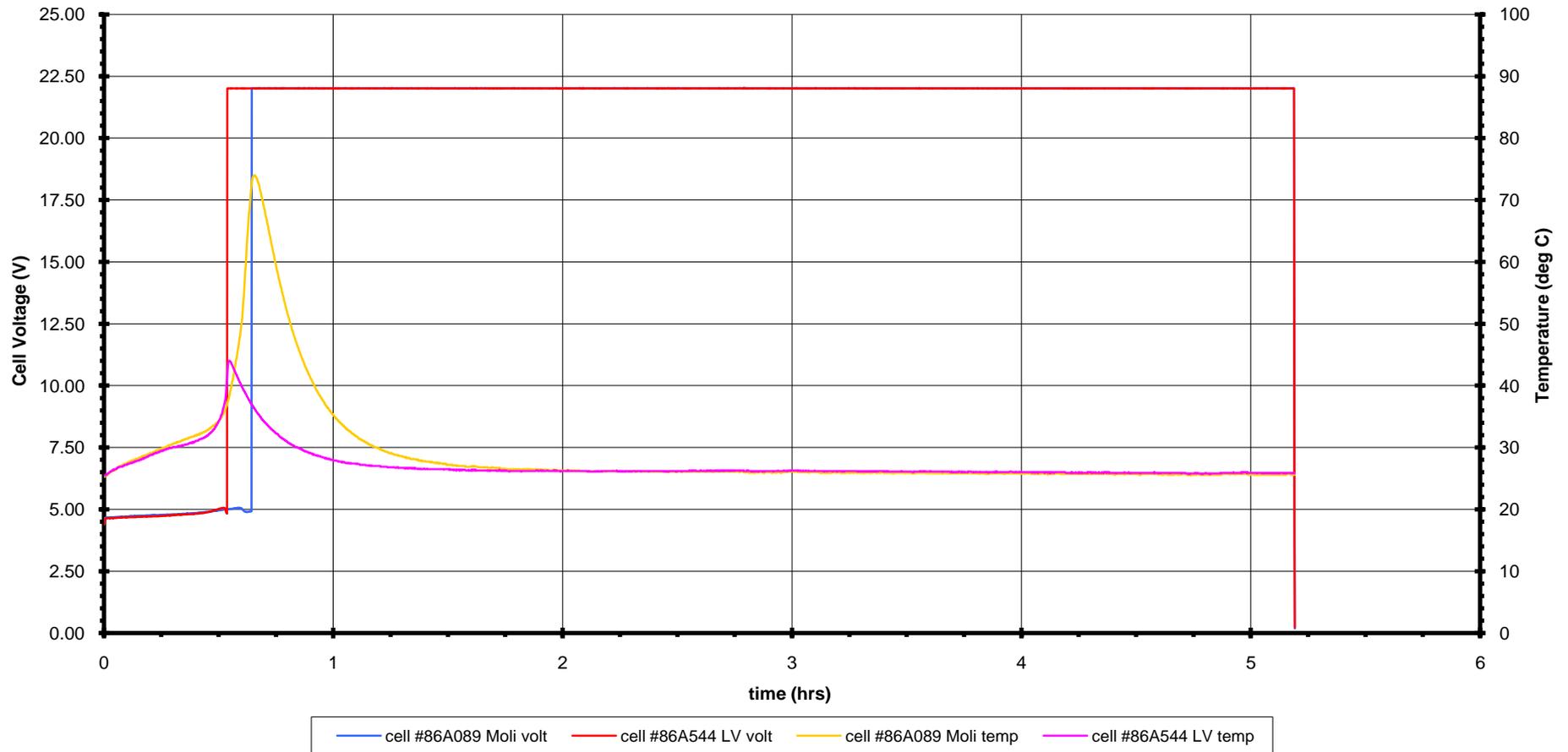
- Overcharge Test Method (all starting at 25°C)
  1. Charge 9 cells per design at C/20 to 4.4V for 48 hours to simulate Shuttle Ag/Zn battery charger left on too long (21.8V)
  2. Split the cells in (1) into 3 groups and charge them to 22V with current limited to 0.1A, 0.6A, and 2.4A, respectively, to test the cell Current Interrupt Device (CID)
- Results
  1. Both cell designs tolerated the 4.4V overcharge with no detectable temperature rise
  2. MoliJ CID activated at all 3 rates, reaching a maximum temperature of 74 °C, 56 °C, and 34 °C at 2.4A, 0.6A, and 0.1A, respectively.
  3. LV CID activated only at the 2.4A and 0.6A rates, getting to maximum temperatures of 45 °C and 46 °C, respectively.
  4. Interestingly, at 0.1A overcharge, the LV cell does not require CID activation to show 48 hours of tolerance, reaching maximums of 4.6V and 33 °C. Subsequent discharge of the cell yielded 3.349Ah!
  5. Both cell design tolerated all overcharge tests without mass loss (< 50 mg), venting, sparks, smoke, flames, or explosion.

**Figure 23: LLB Cell Lot Certification**

Overcharge at 2.4A

Charge @ C/20 to 4.4V, 4.4V x 48 hrs

Rest 24 hours, Charge @2.4A to 22V for 48hr or &gt; 1hr after CID Trip

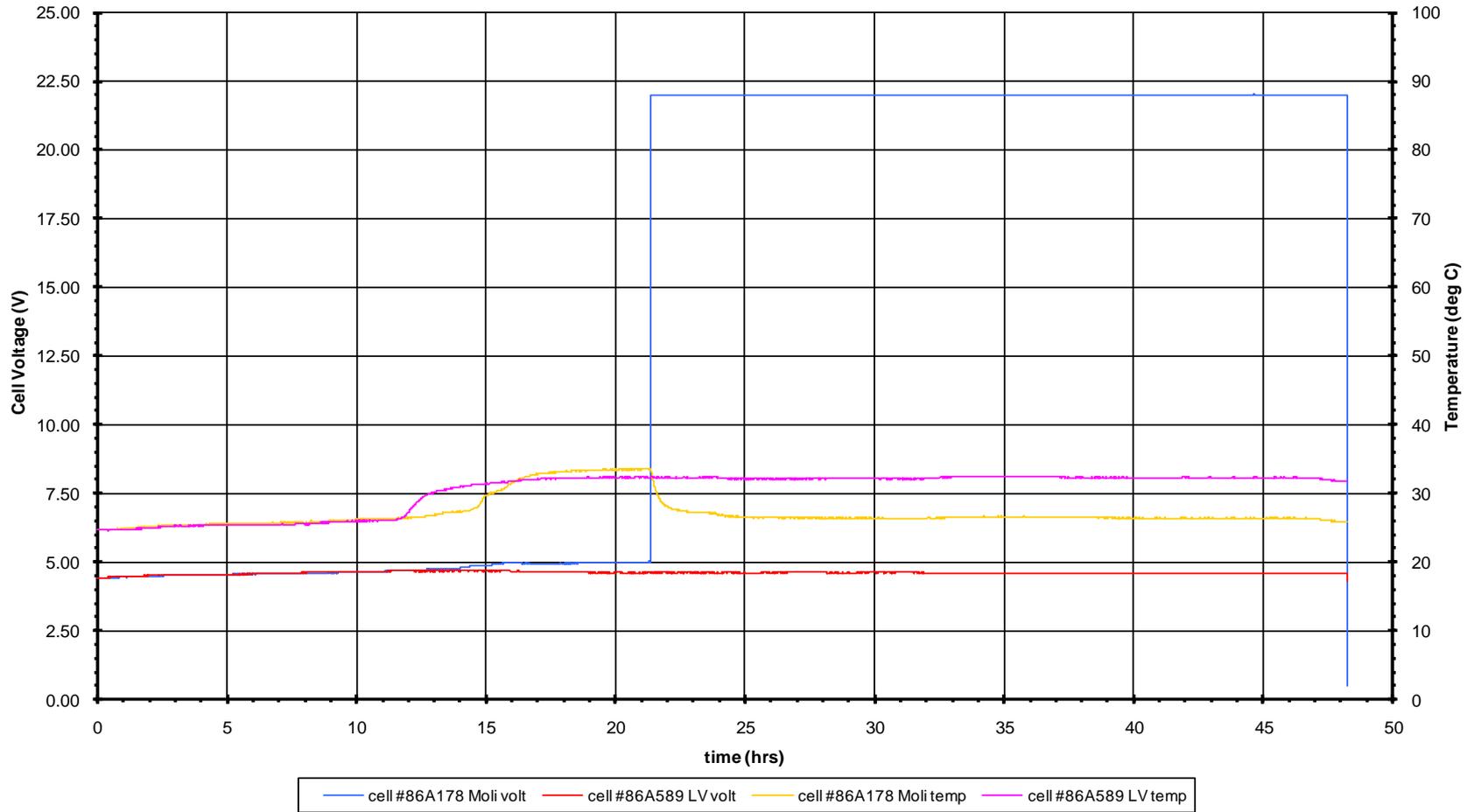


**Figure 25: LLB Cell Lot Certification**

Overcharge at 0.1A

Charge @ C/20 to 4.4V, 4.4V x 48 hrs

Rest 24 hours, Charge @ 0.10A to 22V for 48hr or &gt; 1hr after CID Trip



# External Short Circuit



- Method
  - Evaluate the effectiveness of the cell PTC current limiter
  - 3 cells from each design tested at each of three resistances (44-46 mohms, 98-100 mohms, and 298-303 mohms)
  - Same standardize cell heat sink was used for each test
  - All tests started at 25°C.
- Results
  - All cells demonstrated tolerance without mass loss (< 50 mg), venting, sparks, smoke, flames, or explosion
  - All cell PTCs activated nominally and regulated the maximum cell temperatures to ~70C.

## External Short Circuit Detailed Results

| <u>Moli-J</u><br>Cell # | Circuit<br>(mohms) | Mass<br>loss<br>(mg) | In-rush<br>Current<br>(A) | Trip<br>Time<br>(s) | Max.<br>Cell<br>Temp<br>(°C) | <u>LV</u><br>Cell # | Mass<br>loss<br>(mg) | In-rush<br>Current<br>(A) | Trip<br>Time<br>(s) | Max.<br>Cell<br>Temp<br>(°C) |
|-------------------------|--------------------|----------------------|---------------------------|---------------------|------------------------------|---------------------|----------------------|---------------------------|---------------------|------------------------------|
| 090                     | < 50               | 5.4                  | 35.58                     | 1.66                | 71                           | 411                 | 2.9                  | 40.75                     | 1.62                | 69                           |
| 167                     |                    | 8.5                  | 34.36                     | 1.73                | 70                           | 597                 | 3                    | 41.67                     | 1.57                | 69                           |
| 048                     |                    | 4.2                  | 35.23                     | 1.65                | 72                           | 492                 | 2.4                  | 41.91                     | 1.71                | 69                           |
| 149                     | ≈100               | 3.1                  | 23.46                     | 4.31                | 70                           | 427                 | 1.4                  | 26.48                     | 6.02                | 69                           |
| 046                     |                    | 1.8                  | 23.63                     | 4.5                 | 69                           | 580                 | 6                    | 26.36                     | 5.79                | 71                           |
| 192                     |                    | 2.3                  | 23.15                     | 4.31                | 71                           | 527                 | 2.2                  | 26.35                     | 5.57                | 70                           |
| 021                     | ≈300               | 6.5                  | 10.97                     | 97.9                | 69                           | 470                 | 0.5                  | 11.52                     | 201.4               | 71                           |
| 057                     |                    | 3.8                  | 11.01                     | 85.3                | 68                           | 599                 | 14.1                 | 11.54                     | 203.4               | 69                           |
| 198 (*)                 |                    | 1.7                  | 11.07                     | 101.8               | 70                           | 549                 | 0.7                  | 11.55                     | 201.6               | 72                           |

(\*) A slight electrolyte odor was detected from cell 198

## MoliJ

**Heat-to-Vent Test****Purpose**

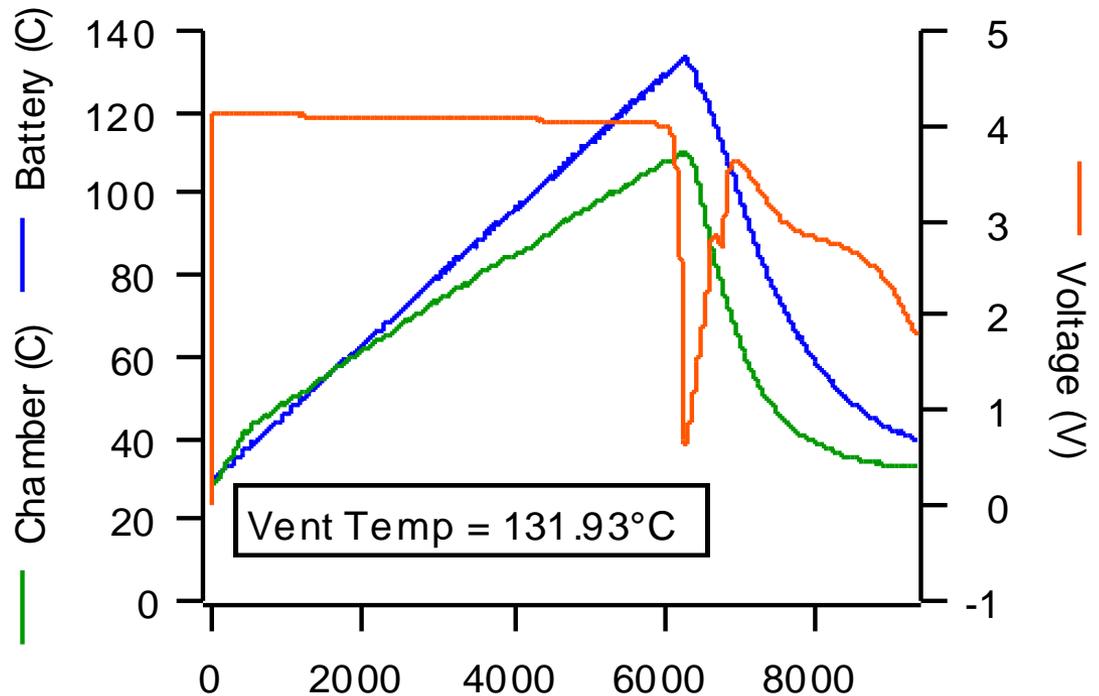
- Induce venting to verify vent function

**Method**

- 5 Cells were fully charged
- Placed in toaster oven and stabilized at 60°C for 24 hours
- Cell was removed, and weighed for mass loss detection
- Cell was then connected to a 40 ohm load and replaced in oven for thermal ramp to 150 °C for a 1-hr hold.

**Results**

- All MoliJ cells had no mass loss at 60 °C.
- All MoliJ cells vented before getting to 150 °C



LV

## Heat-to-Vent Test

### Purpose

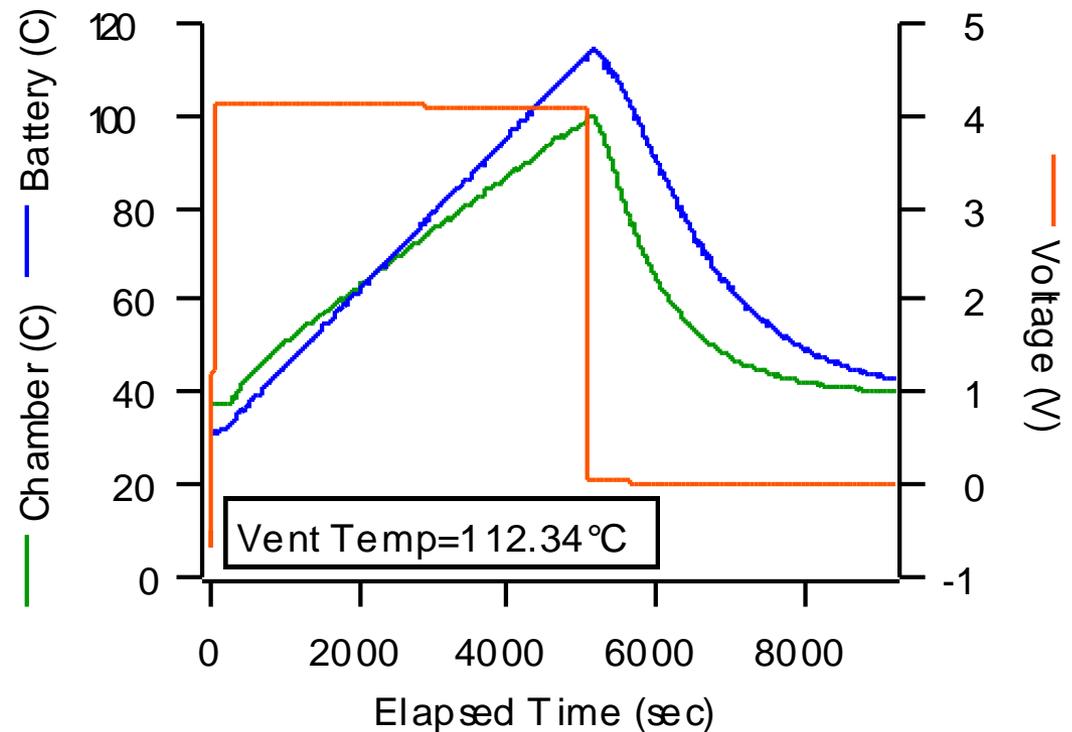
- Induce venting to verify vent function

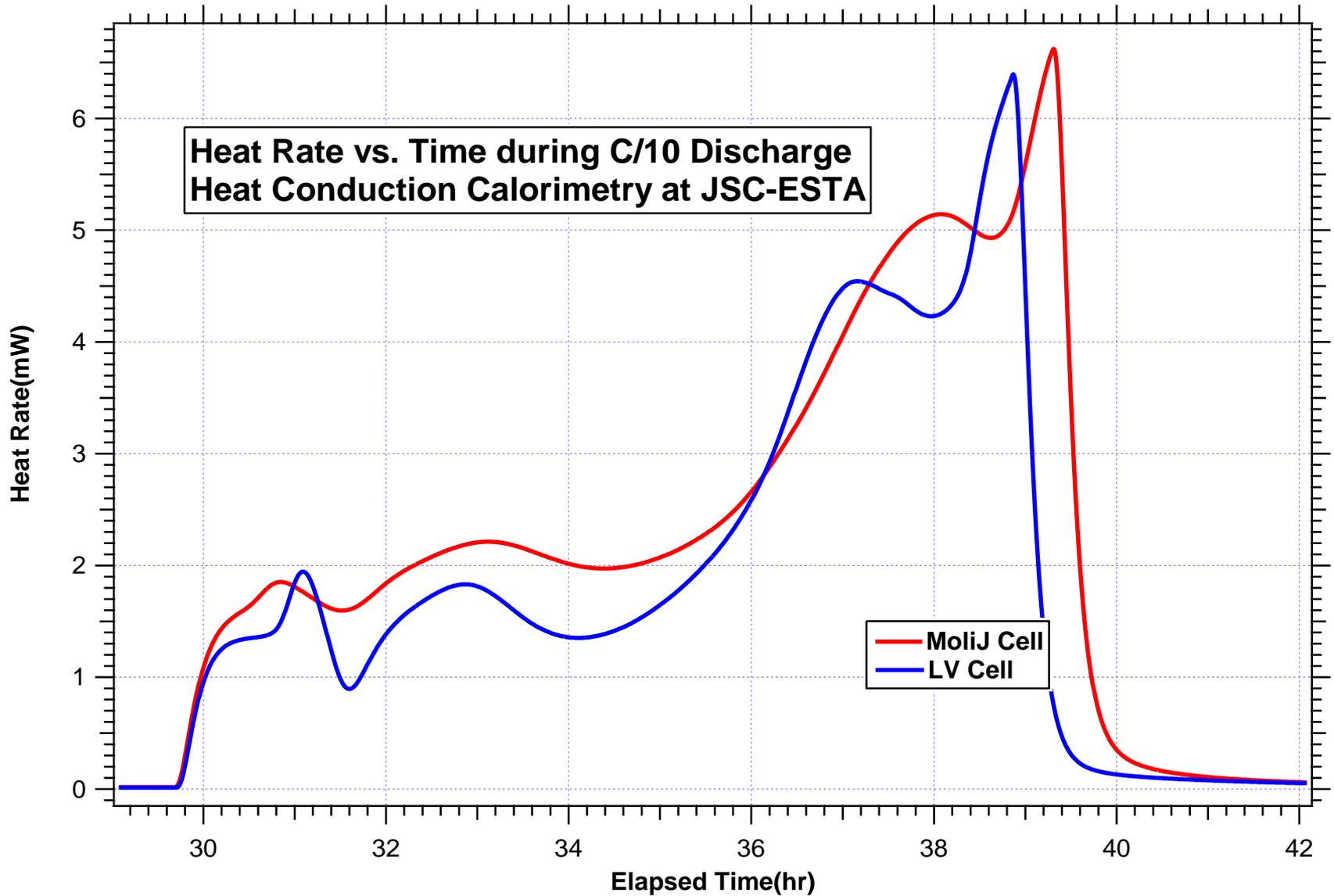
### Method

- 5 Cells were fully charged
- Placed in toaster oven and stabilized at 60°C for 24 hours
- Cell was removed, and weighed for mass loss detection
- Cell was then connected to a 40 ohm load and replaced in oven for thermal ramp to 150 °C for a 1-hr hold.

### Results

- All LV cells had no mass loss at 60 °C.
- All LV cells vented before getting to 150 °C





## Summary Conclusions

- COTS cell acceptance testing revealed tight performance uniformity
  - Only 1.5% of ~3600 MoliJ cell OCVs found outside a 6 sigma range of **6 mV** after > 27 months at ~40% SoC and mostly room temperature storage
- Both cells designs performed nominally during nearly all performance and abuse tests
  - An LLB using the MoliJ cell will provide ~ 1 hour more runtime for the Spacesuit than one using the LV cell over the entire relevant temperature range
  - Calendar and cycle life data suggest potential useful service to 2020
  - Only outstanding issue is MoliJ burst pressure testing resulted in 1 or 5 violent burst event for reasons not fully understood
  - Possible test improvements identified will be verified
- Content of certification tests, adapted for this low rate, cycle life, long calendar life application, fully characterized the cell designs and provides a good model for future crew spacecraft Li-ion batteries
- NDE/DPA of cell samples from each lot was very revealing and will be presented on Thursday by Exponent