Calendar Life Aging of Two Models of 18650 Lithium Ion Cells

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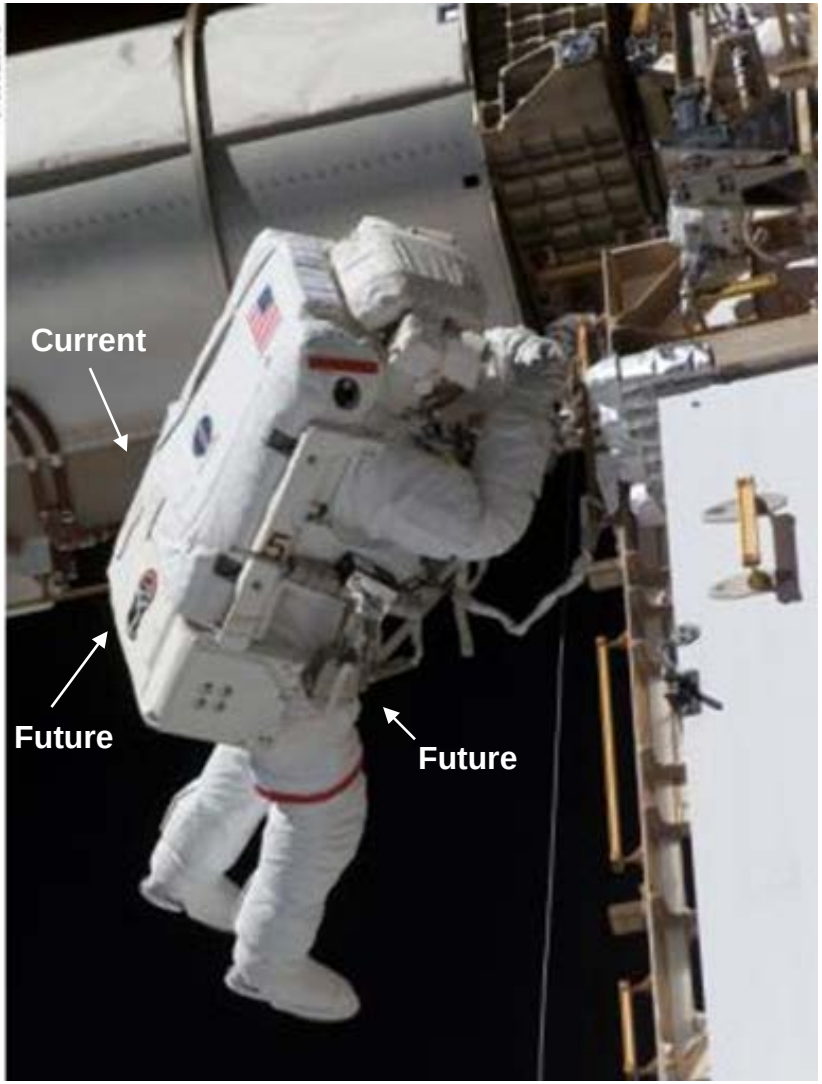
Introduction

- Interim calendar life test results for two models of 18650 lithium ion cell used in Human Spaceflight
  - Test conditions derived from low rate, low cycle, extended storage application requirements
  - Test cells selected from date code traceable populations
    - Moli ICR18650J, Apr 2007
    - Samsung ICR18650-26F, Dec 2013
- This work is administered by NASA Johnson Space Center in support of the EVA Office and the International Space Station
- Test is performed by Symmetry Resources Inc, Arab AL



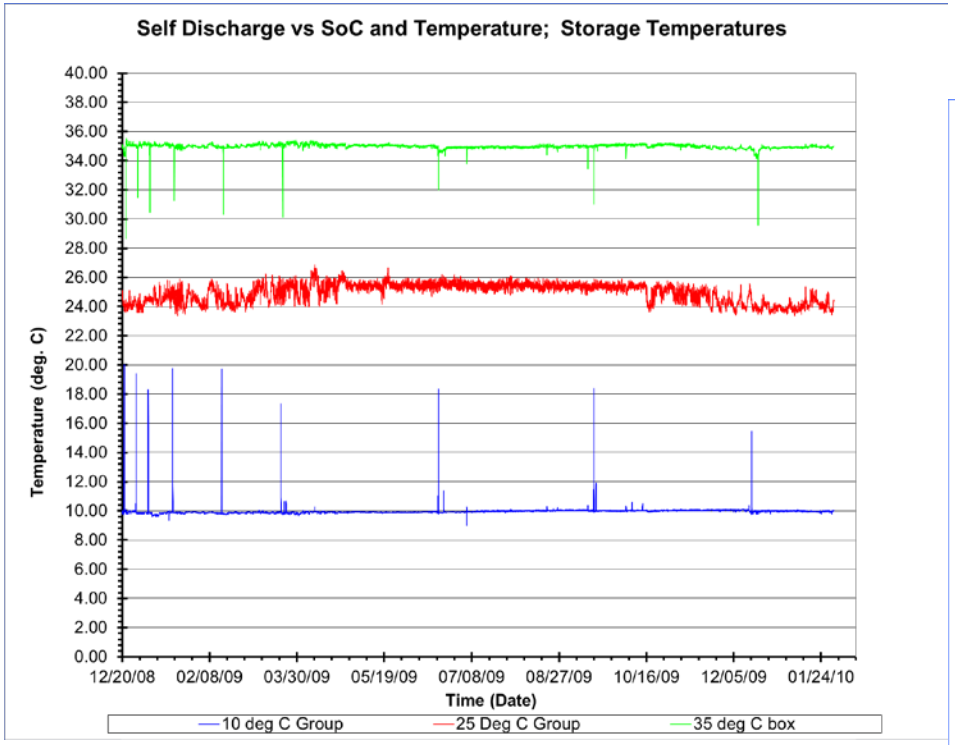
Test Protocol

- **Calendar Life Test is an on-going, full factorial, self discharge and irreversible capacity loss experiment of twelve conditions with 3 groups of 3 cells per condition for a total of 108 cells**
  - **Storage Conditions:**
    - **Cells stored in sealed, dry containers**
    - **SOC: 0%, 30%, 100%, 110%**
    - **Temperature: 10°C, 25°C, 35°C**
  - **Cycle Protocol: C/2 cycling between 3.2-4.2V**
    - **During discharge pulse at 2C for 1s every 10% SOC**
    - **Terminate final charge cycle at storage condition**
  - **Test Protocol: Measure OCV and/or cycle at ambient conditions**
    - **Year 1: cycle at 90, 180, 270, and 365 day intervals**
    - **Year 2+: cycle at 182, 365, and 730 day intervals**
    - **Group 4 (spare cells) to be tested with 730 day interval if not used**
    - **When cell group average fails to deliver 1.66 Ah (~70%)**
      - **Charge at C/2, discharge at 563mA for 5s then 238 mA to 3.2V**
      - **If unable to deliver 1.66 Ah, terminate storage**

SOC Definition (Moli/eSDI):
0% = 3.2/3.2V
30% = 625/720 mAh charge input
100% = 4.12/4.1V, taper to 60mA
110% = 4.2/4.2V, taper to 60mA

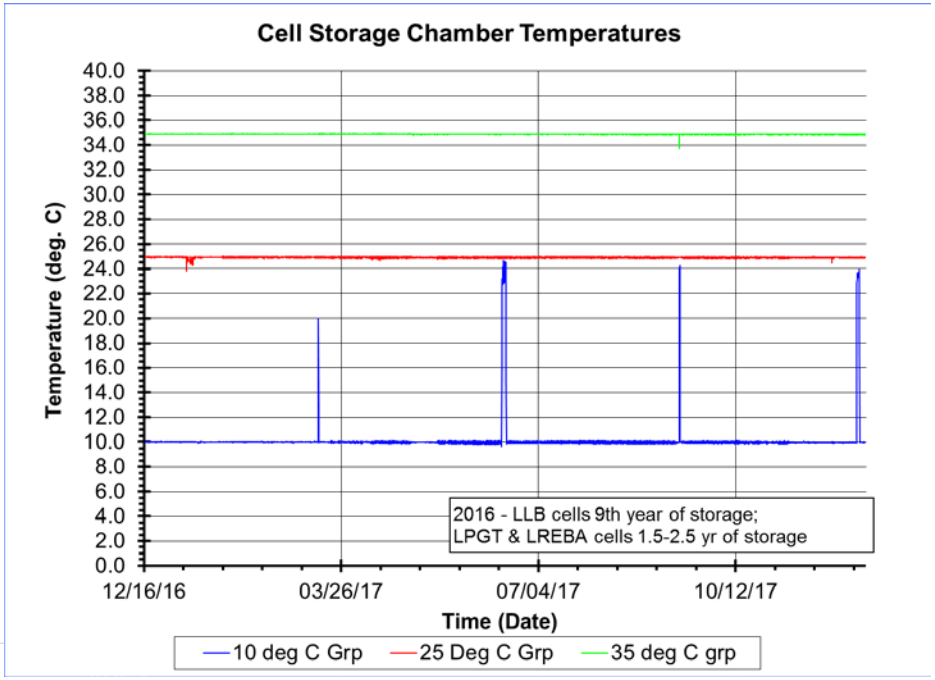
Storage Environment

- **Test Temperature has been maintained within +/- 2 ºC since 2008 except during periods of cell access or extended power outage (interim years not shown)**



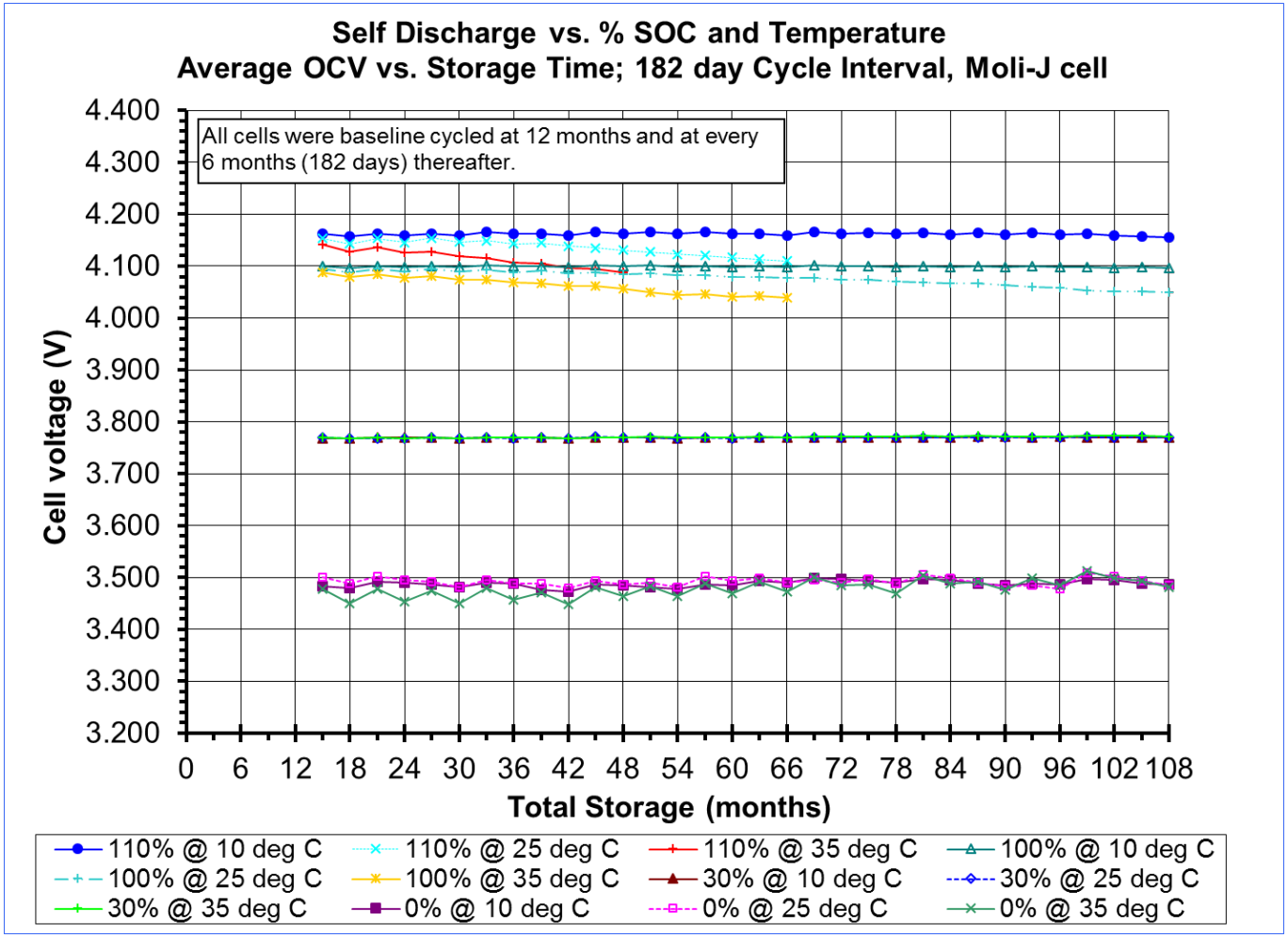
Chamber Temperatures, 2008-2010

Chamber Temperatures, 2017



Self Discharge

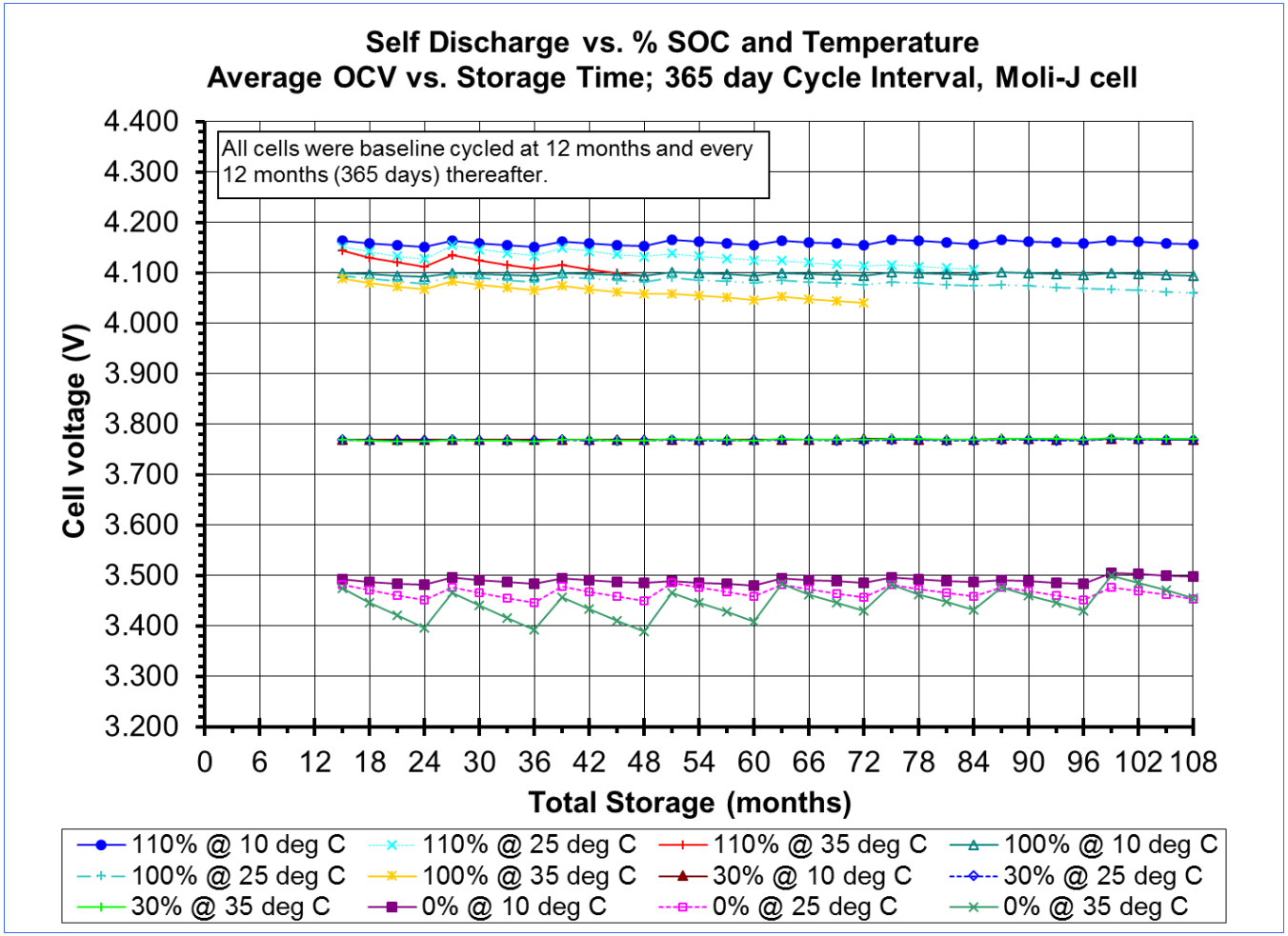
- **108 month self discharge results for the Moli cell, 182 day cycle group**



Lithium Ion Cell Calendar Life Testing, SRI Job# 53H & 86A, Feb 20, 2018

Self Discharge

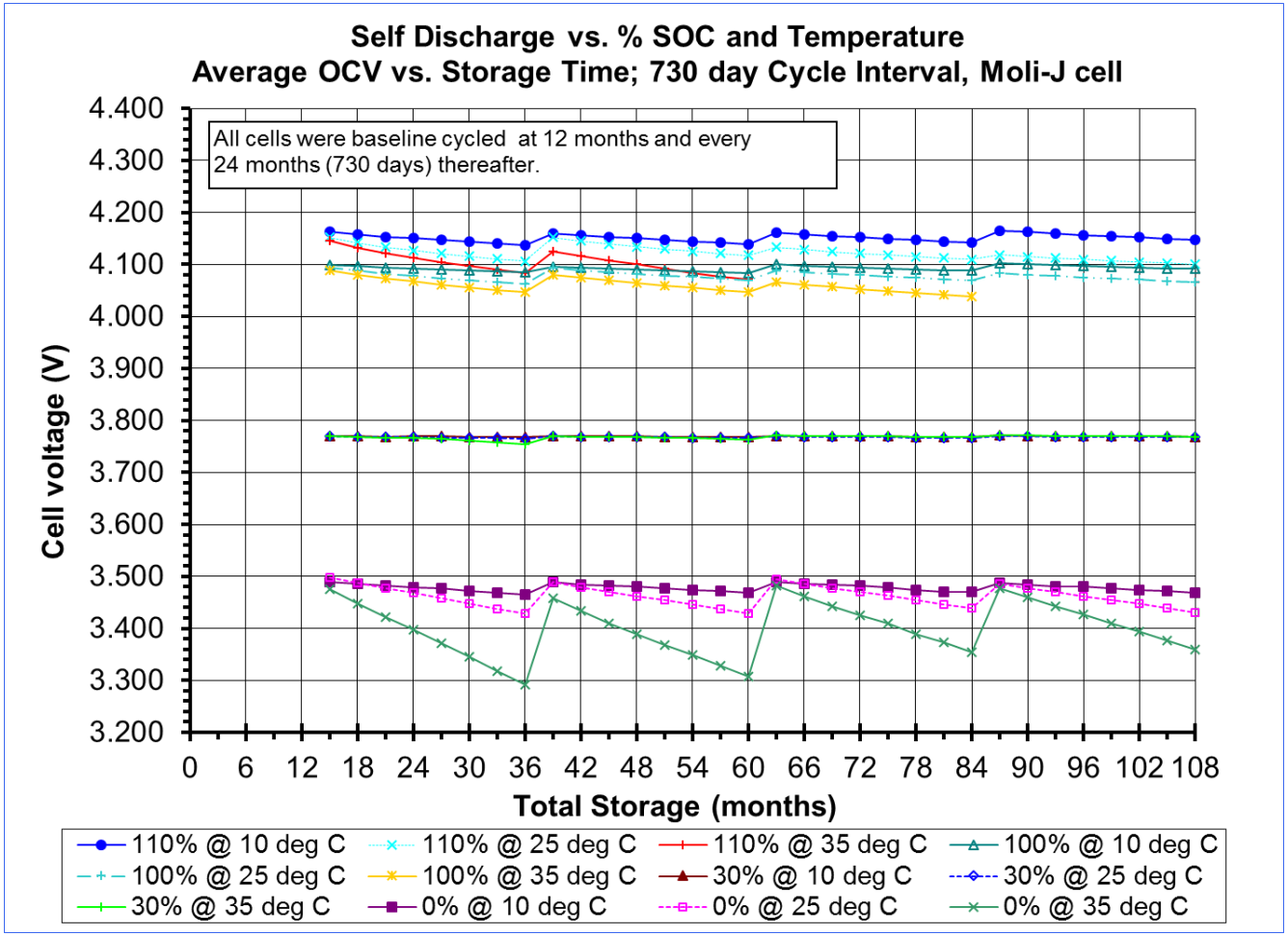
- **108 month self discharge results for the Moli cell, 365 day cycle group**



Lithium Ion Cell Calendar Life Testing, SRI Job# 53H & 86A, Feb 20, 2018

Self Discharge

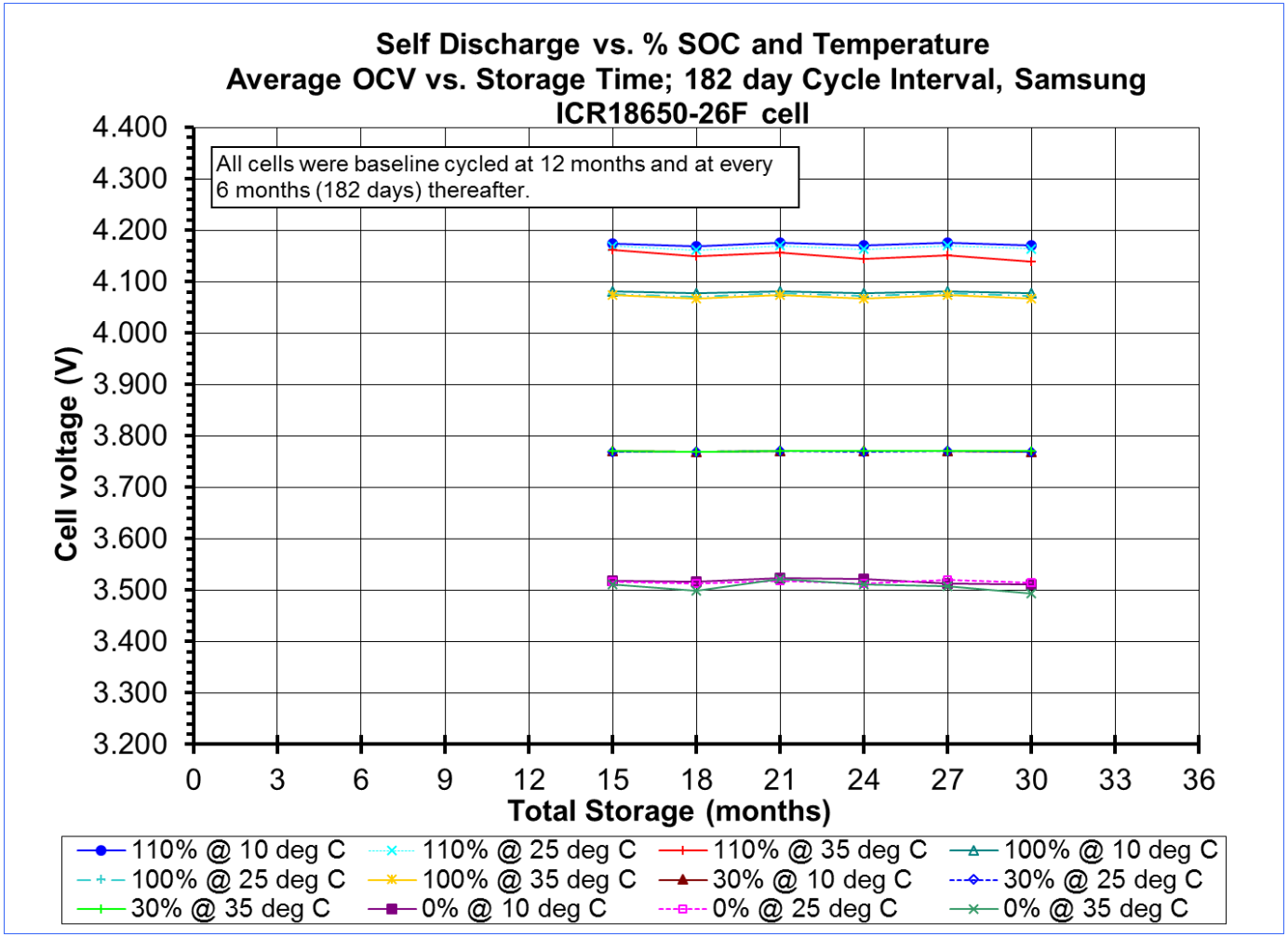
- **108 month self discharge results for the Moli cell, 730 day cycle group**



Lithium Ion Cell Calendar Life Testing, SRI Job# 53H & 86A, Feb 20, 2018

Self Discharge

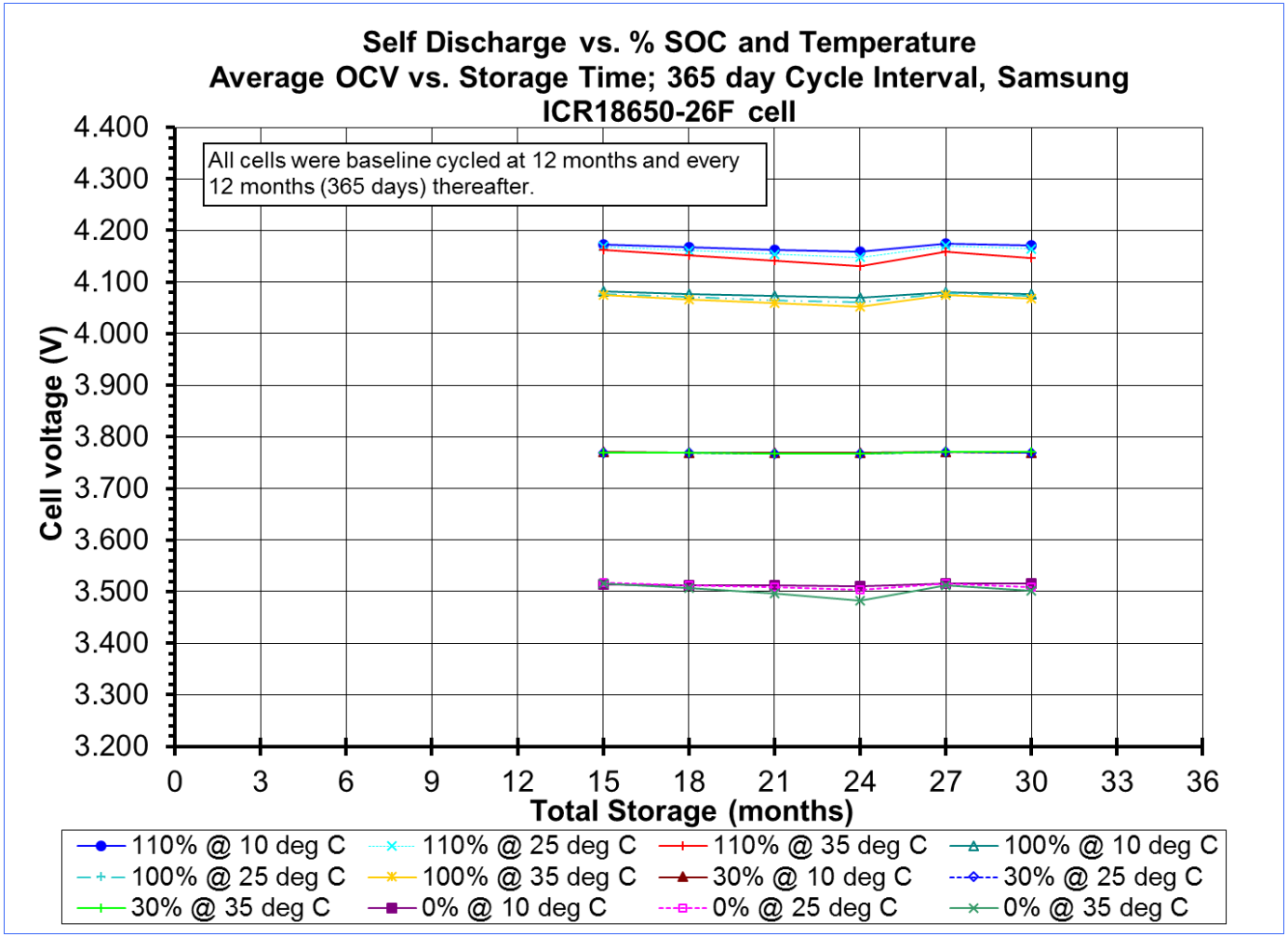
- **30 month self discharge results for the Samsung cell, 182 day cycle group**



Lithium Ion Cell Calendar Life Testing, SRI Job# 53H & 86A, Feb 20, 2018

Self Discharge

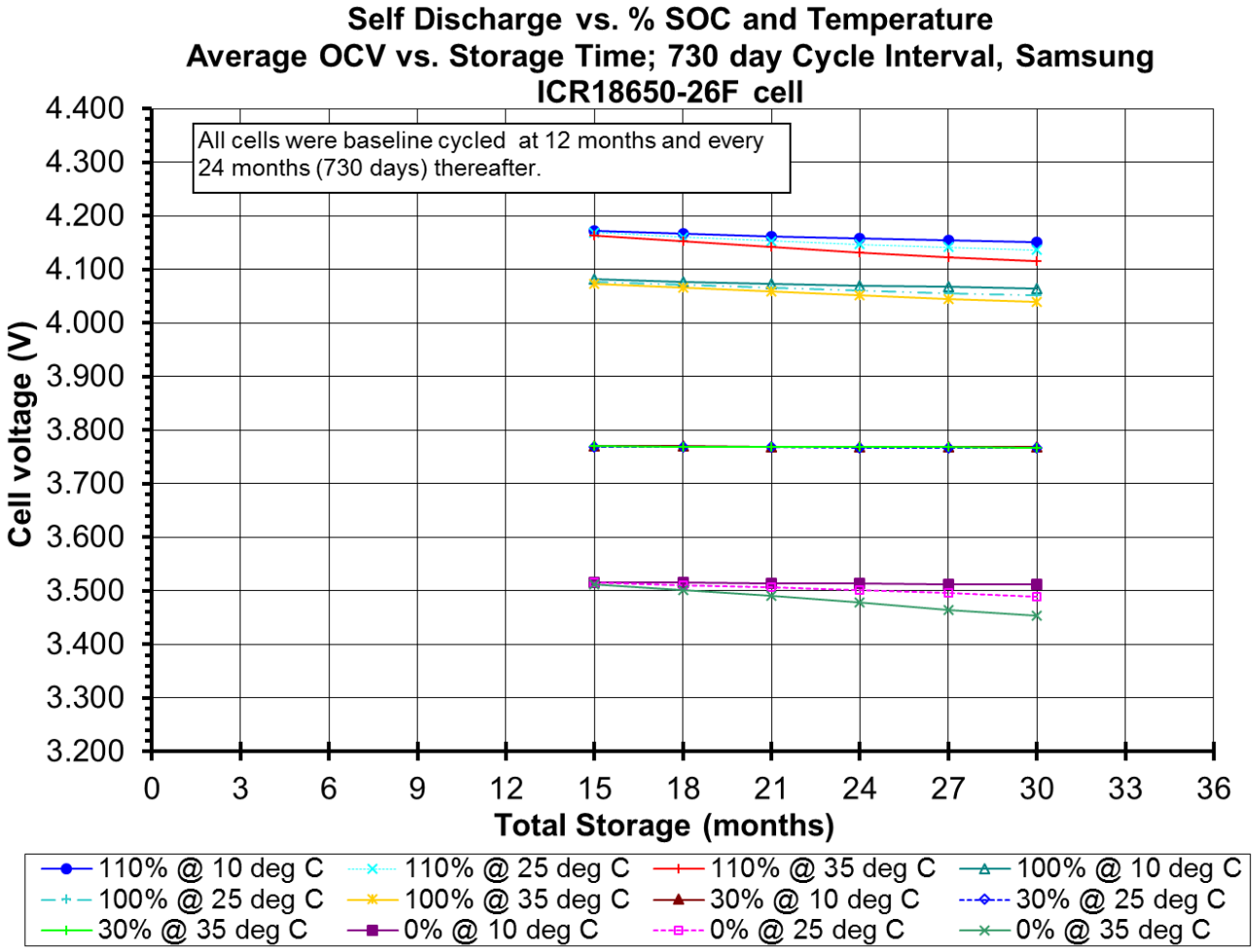
- **30 month self discharge results for the Samsung cell, 365 day cycle group**



Lithium Ion Cell Calendar Life Testing, SRI Job# 53H & 86A, Feb 20, 2018

Self Discharge

- **30 month self discharge results for the Samsung cell, 730 day cycle group**



Lithium Ion Cell Calendar Life Testing, SRI Job# 53H & 86A, Feb 20, 2018

Cell Failures

- **Initial Findings**
  - **None of the 216 cells have failed anomalously**
  - **Several high temperature and/or high SOC groupings have failed**

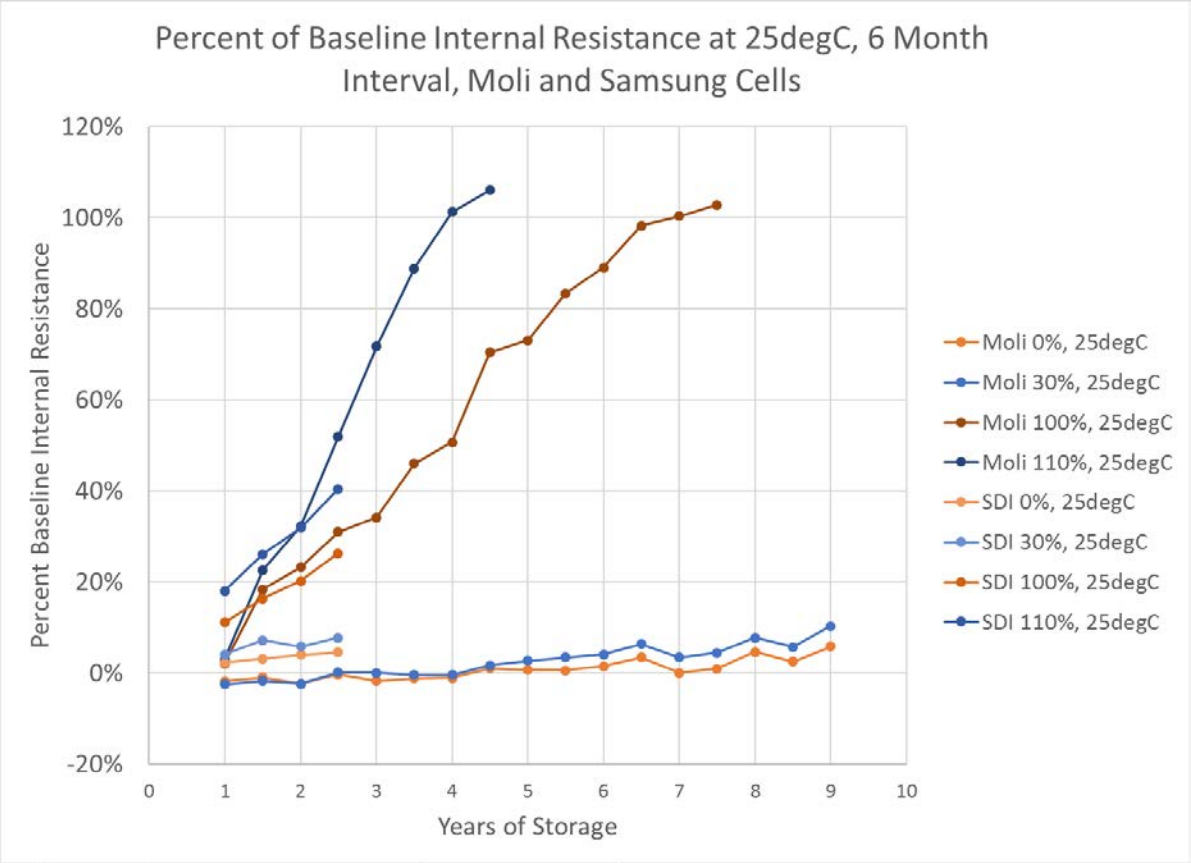
Moli J Cell Group Failure Chronology

Storage Temp. (°C)	SoC (%)	Cycle Interval (mo.)	Total Storage Time to Group Capacity Failure	
			C/2 Discharge	0.238A Discharge
35	110	6	24 months	36 months
35	110	12	36 months	48 months
35	110	24	36 months	60 months
35	100	6	42 months	66 months
25	110	6	42 months	66 months
35	100	12	48 months	72 months
25	110	12	48 months	84 months
35	100	24	60 months	84 months
25	110	24	60 months	108 months
25	100	6	72 months	
25	100	12	96 months	
25	100	24	108 months	

Lithium Ion Cell Calendar Life Testing, SRI Job# 53H & 86A, Feb 20, 2018

Internal Resistance

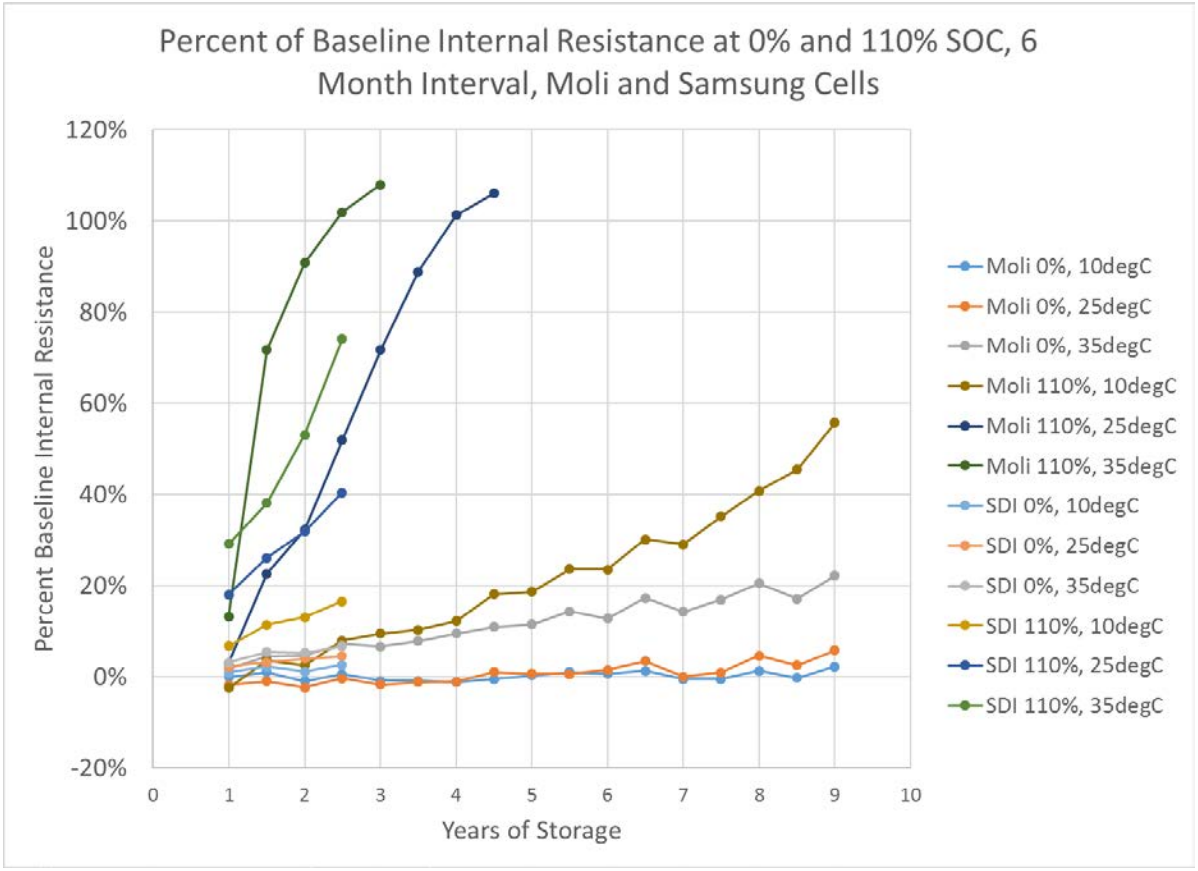
- **Internal Resistance growth provides a clear indication of cell degradation**
  - **Effect of SOC at 25 degree C for both Moli and Samsung cell**



Data provided by Lithium Ion Cell Calendar Life Testing, SRI Job# 53H & 86A, Feb 20, 2018

Internal Resistance

- **Internal Resistance growth provides a clear indication of cell degradation**
  - **Effect of temperature at 0% and 110% SOC for both Moli and Samsung cell**



Data provided by Lithium Ion Cell Calendar Life Testing, SRI Job# 53H & 86A, Feb 20, 2018

Capacity Decay

- **Mechanism does not appear to be strongly coupled to cycling**
  - **Maximum number of cycles shown on plot are 17**

Cycle Life Test Results Shown for Reference Only

5S Moli Cell Cycling

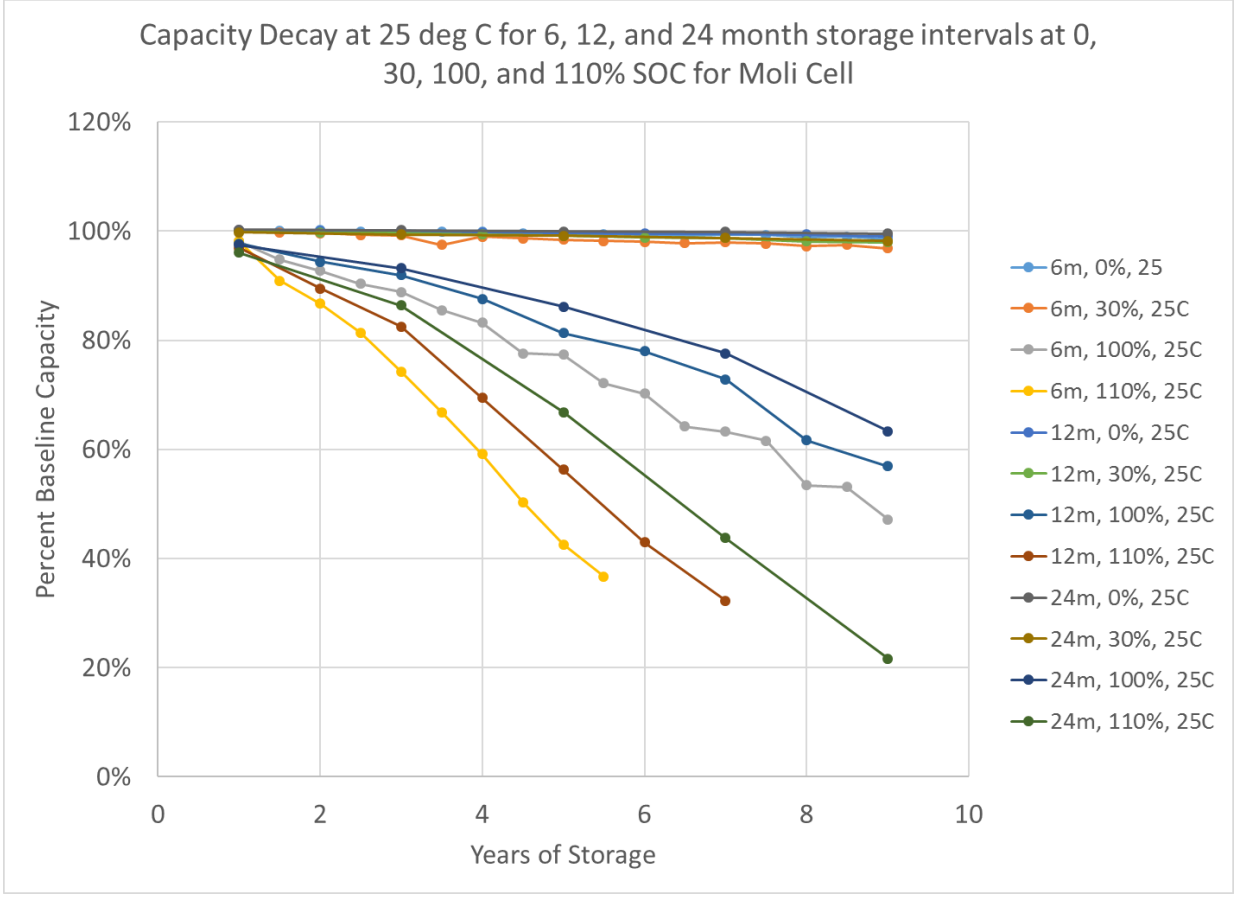
Cycle	Cap	% Cap
1	2.199	100.00%
10	2.198	99.98%
50	2.197	99.94%
100	2.196	99.88%
150	2.195	99.83%
200	2.194	99.78%

SRI Job# 86A, Oct 20, 2009

4S Samsung Cell Cycling

Cycle	Average	% Cap
1	2.381	100.00%
10	2.354	98.85%
50	2.317	97.32%
100	2.273	95.47%
150	2.244	94.24%
200	2.225	93.44%

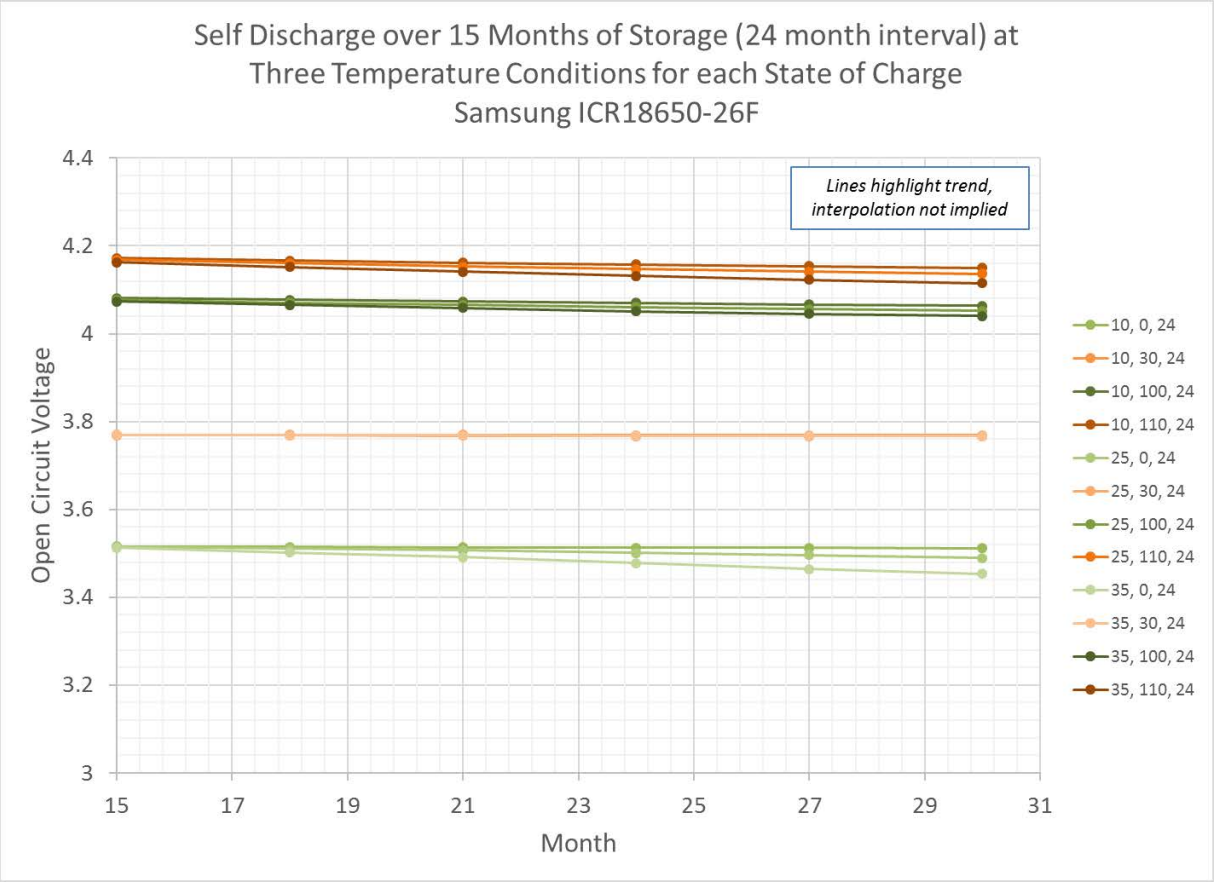
PCTest Job# 4M1702100015-2, Jan 17, 2018



Data provided by Lithium Ion Cell Calendar Life Testing, SRI Job# 53H & 86A, Feb 20, 2018

Self Discharge

- **24 Month Interval test provides insight into Self Discharge Rate**
  - **Rate is minimized at 30% SOC for tested temperatures**



SELF DISCHARGE RATE mV/mon

First Interval (Month 15-36*)

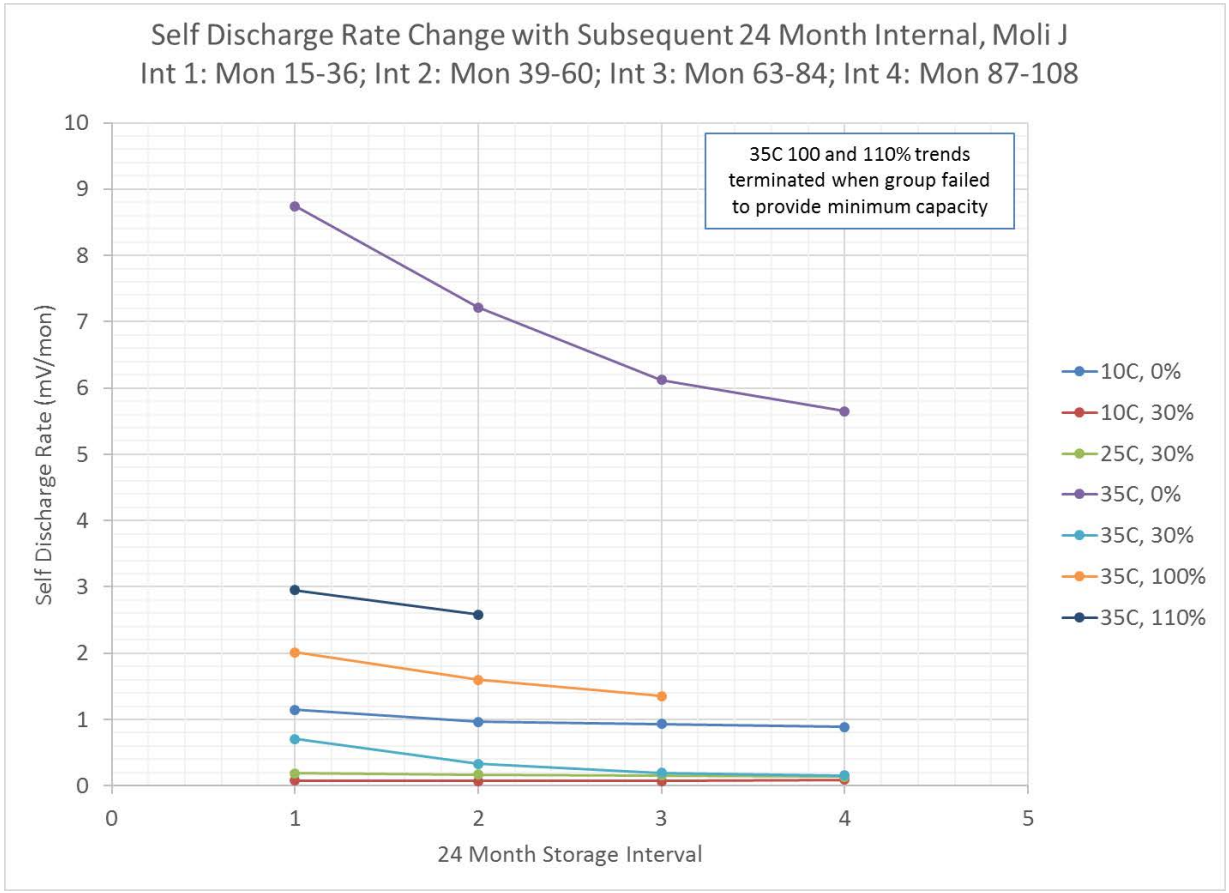
	0%	30%	100%	110%
10C	0.3	0.1	1.2	1.5
25C	1.7	0.2	1.7	2.2
35C	4.0	0.2	2.2	3.1

Rate is calculated by subtracting final OCV from initial OCV and dividing by 15 months.
**Note, interval is incomplete.*

Data provided by SRI Job# 53H

Self Discharge

- **Extended 24 month interval testing offers insight into Self Discharge Rate change with continued storage (30% is still preferred)**



SELF DISCHARGE RATE (mV/mon)

First Interval (Month 15-36)

	0%	30%	100%	110%
10C	1.1	0.1	0.7	1.2
25C	8.7	0.2	1.5	2.2
35C	8.7	0.7	2.0	3.0

Fourth Interval (Month 87-108)

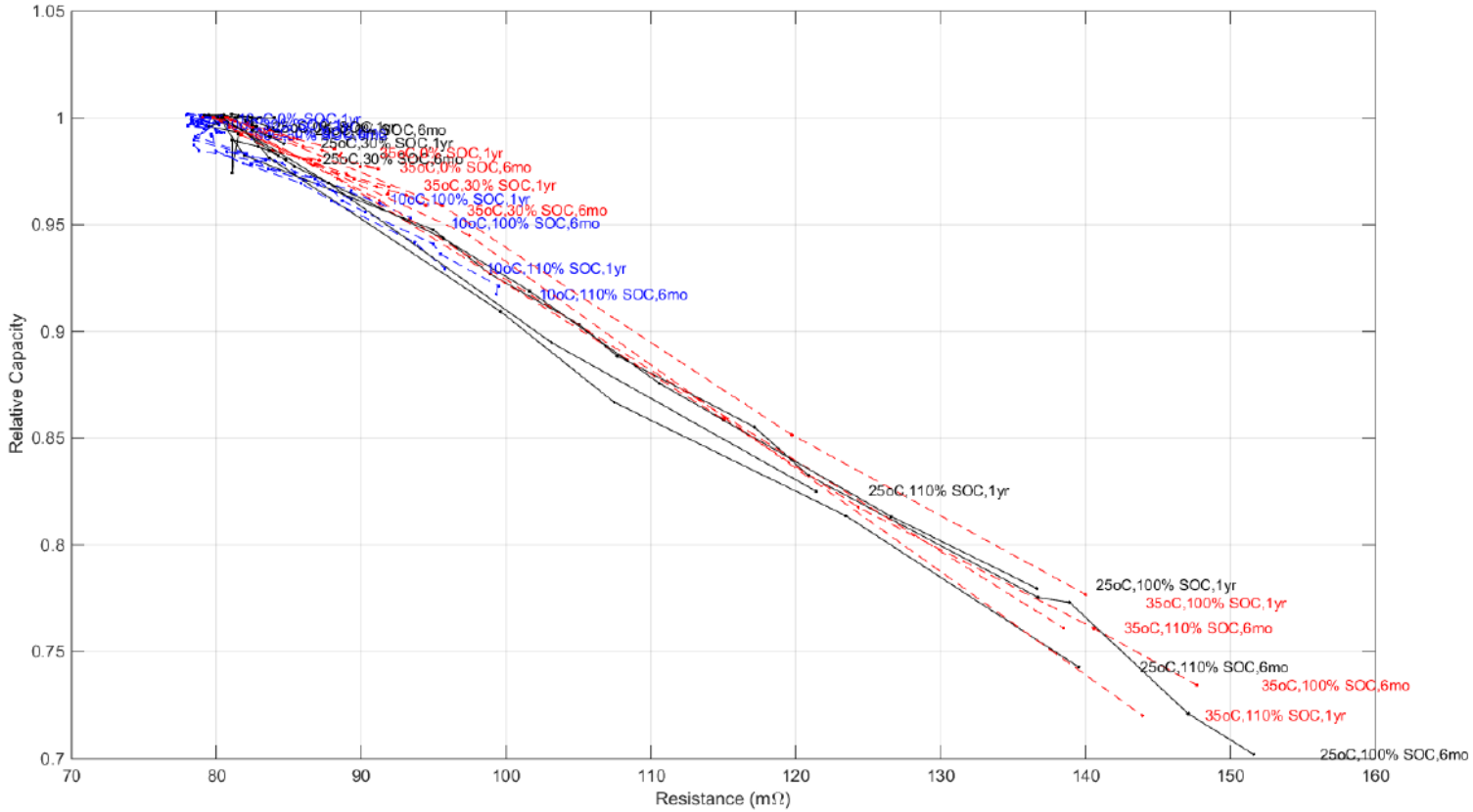
	0%	30%	100%	110%
10C	0.9	0.1	0.5	0.8
25C	2.6	0.1	0.8	0.9
35C	5.6	0.2	0.2	0.1

Rate is calculated by subtracting final OCV from initial OCV and dividing by 21 months

Data provided by SRI Job# 83A

Degradation Mechanism

- **Initial review by National Renewable Energy Laboratory suggests a single mechanism dominates observed degradation, Moli cell only**



Preliminary Look at NASA Cell-Life Data, NREL, K. Smith, Sep 18, 2015

Summary

- Temperature and SOC storage conditions are being assessed on two models of commercial lithium ion cell
  - Test protocols derived from low rate, low cycle, extended life application
  - Test offers insight into self discharge rate and effect of storage condition
  - Results used to validate operational storage conditions and approximate end of asset life
    - Mechanistic modeling has been considered as forward work
    - Current method assumes observed degradation is linear and mathematically averages degradation based on time at condition

$$X(t) = X(t-1) * \left[1 +/- \left(Annual\ Cycle\ Loss * Annual\ Cycles + \frac{\sum Condition\ Loss * days\ at\ Condition}{365 days}\right)\right]$$

- Acknowledgements:
  - Brad and Katy Strangways, Symmetry Resources Inc
  - Kandler Smith, NREL
  - Eric Darcy and the EVA Office of the NASA Johnson Space Center
- Questions?