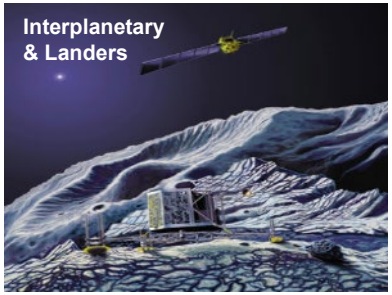
LG Chem MJ1 Cell Space Qualification



POWERED *by*

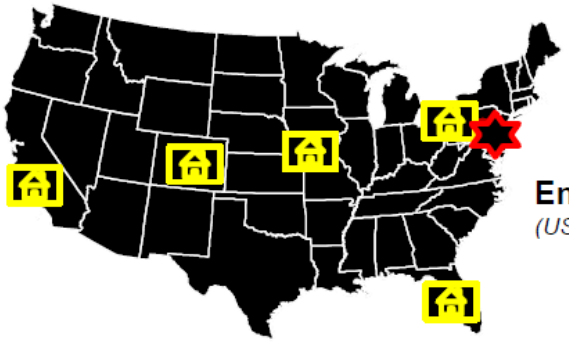
ABSL QUALLION

Tyler Lefholz
and Lindsey Bienvenu

EnerSys Advanced Systems / ABSL
Longmont, Colorado

Manufacturing Facilities

- Sylmar, CA
- Santa Clarita, CA
- Longmont, CO
- Warrensburg, MO
- Horsham, PA
- Tampa, FL
- Culham Oxfordshire, UK



EnerSys Headquarters: Reading, PA
(US Owned Company)

Five EAS Engineering Locations Serving Six Markets

Business Line	Brands	Technology	Location
Space	ABSL/Quallion	Lithium-Ion Materials, Cells, and Batteries	Longmont, CO Sylmar, CA Culham, UK
Aviation	Hawker/Quallion	Lead Acid (Thing Plate), Ni-Cd & Li-Ion	Warrensburg, MO and Sylmar, CA
Medical	Quallion	Cells and Batteries	Sylmar, CA
Munitions	EAS	Lithium Primary and Liquid Reserve	Horsham, PA
Land & Sea	Armasafe / Hawker	Lead Acid (Thin Plate & Flooded/Tubular)	Warrensburg, MO

Celebrating
over **2.5 Billion** Cell Hours in Space Without a Failure

Cell Suite Information

Cell	Cell Format	Cell Capacity	Max Discharge Current	Energy Density	Notable Characteristics
Sony - HCM	18650	1.5Ah	1.95A	130 Wh/Kg	Long Cycle Life
E-Moli One - C	18650	2.0Ah	20A	160 Wh/Kg	High Rate
E-Moli One - M	18650	2.8Ah	5.6A	217 Wh/Kg	Low Temp Operation
LG Chem - MJ1	18650	3.5Ah	10A	257 Wh/Kg	High Energy
QL075KD	Large Prismatic	72Ah	70A	147 Wh/Kg	Long Cycle Life

18650MJ1 Qualification Plan

Qualification Test Groups

- Build Quality
- Electrical Qualification
- Environmental Testing
- Safety Device Verification
- Endurance Testing

Initial Screening

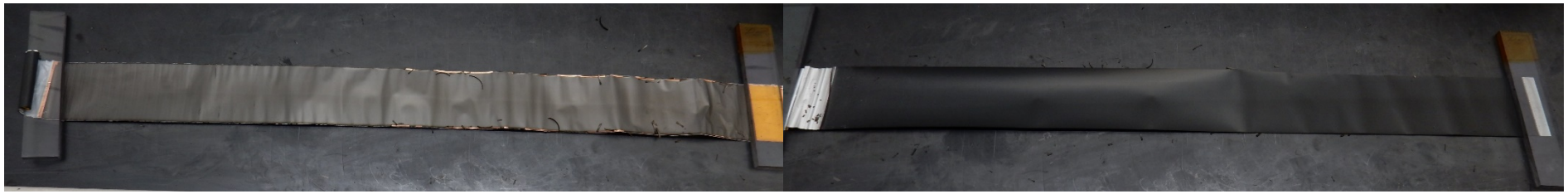
- **Cells cycled at C/14 (0.25A) between 4.2V and 2.5V**
  - Tested at approx. 20°C
  - AC impedance measured at 50% SoC, 1kHz

Parameter	Average	Max	Min
Initial OCV (V)	3.606	3.855	3.586
AC Impedance (mΩ)	29	32	27
Charge Capacity (mAh)	3431	3454	3403
Discharge Capacity (mAh)	3427	3454	3382

Build Quality

Mechanical Analysis

- Cells passed with no notable anomalies



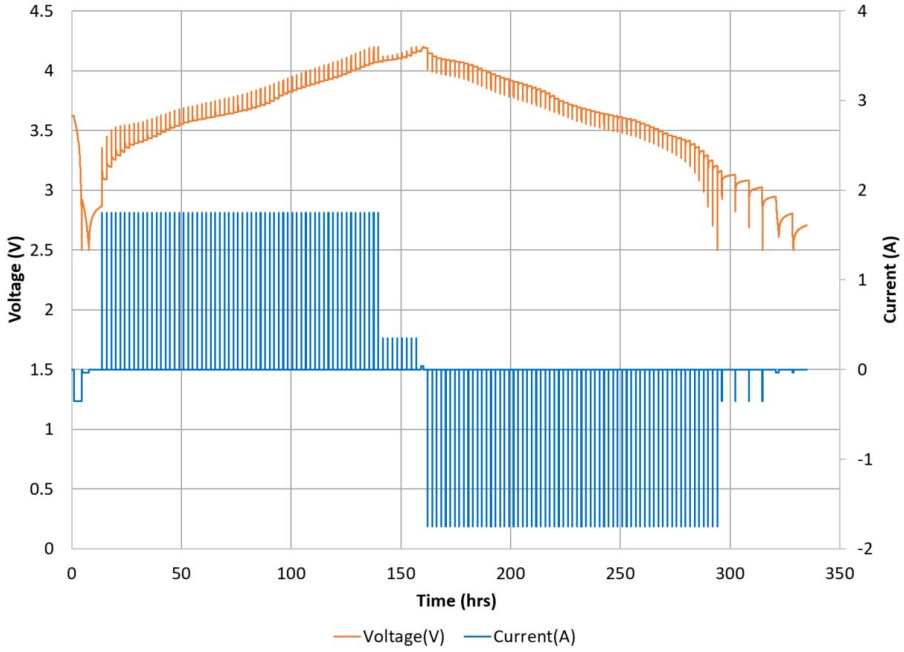
Chemical Analysis

- X-Ray Diffraction Analysis
- Scanning Electron Microscopy (SEM) and Energy-Dispersive X-Ray Spectroscopy (EDX) Analysis
- Gas Chromatography-Mass Spectrometry (GCMS) Analysis
- Fourier Transform Infrared Spectroscopy (FTIR) Analysis

Electrical Testing

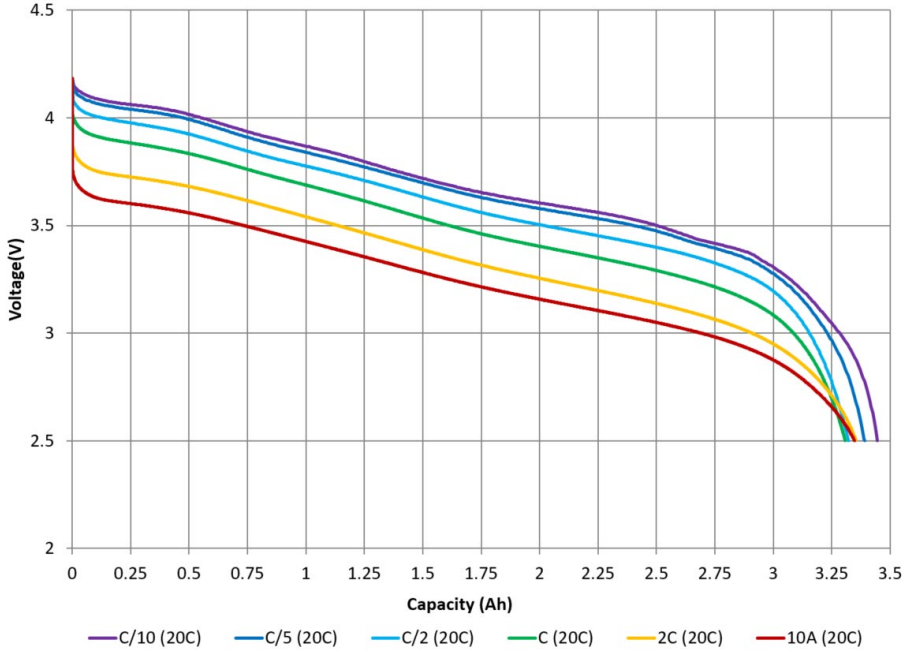
Electrical (BEAST) Testing

- Cells tested at -15°C – 60°C
- Cycled at C/2, C/10, and C/100



Rate Characterization

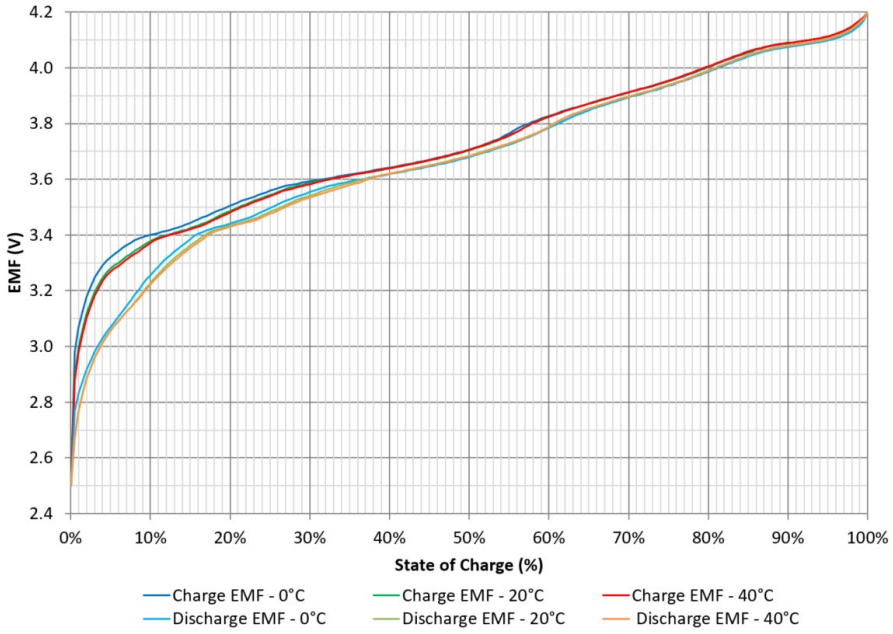
- Cells tested at -15°C – 60°C
- Discharge Rates: C/10, C/5, C/2, C, 2C, and 10A



Electrical Testing (cont.)

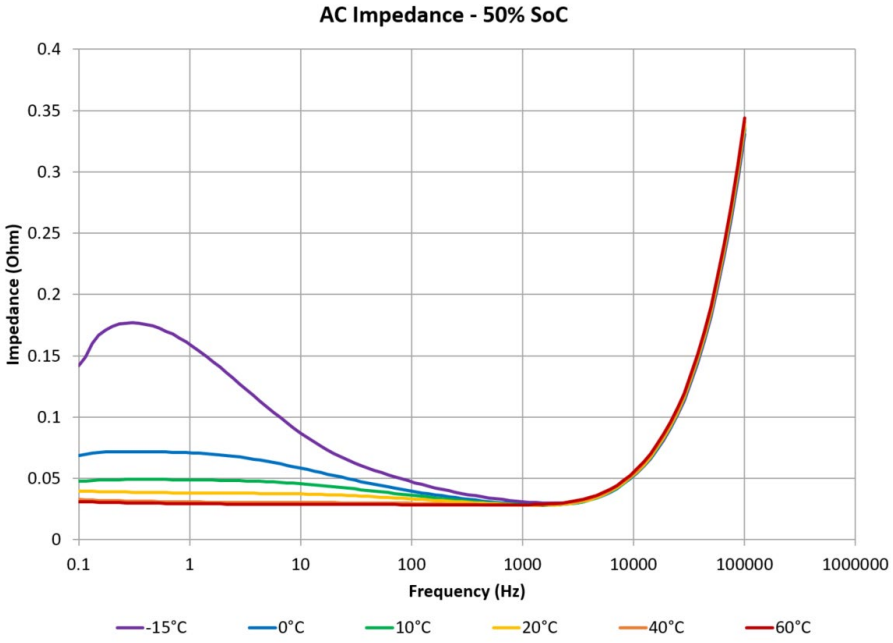
EMF Testing

- Cells tested at 0°C, 20°C, and 40°C
  - 100% and 50% capacity charges and discharges



AC Impedance

- Cells tested at -15°C – 60°C
  - SoC: 5%, 20%, 40%, 50%, 60%, 80%, 100%
  - 100mHz – 100kHz



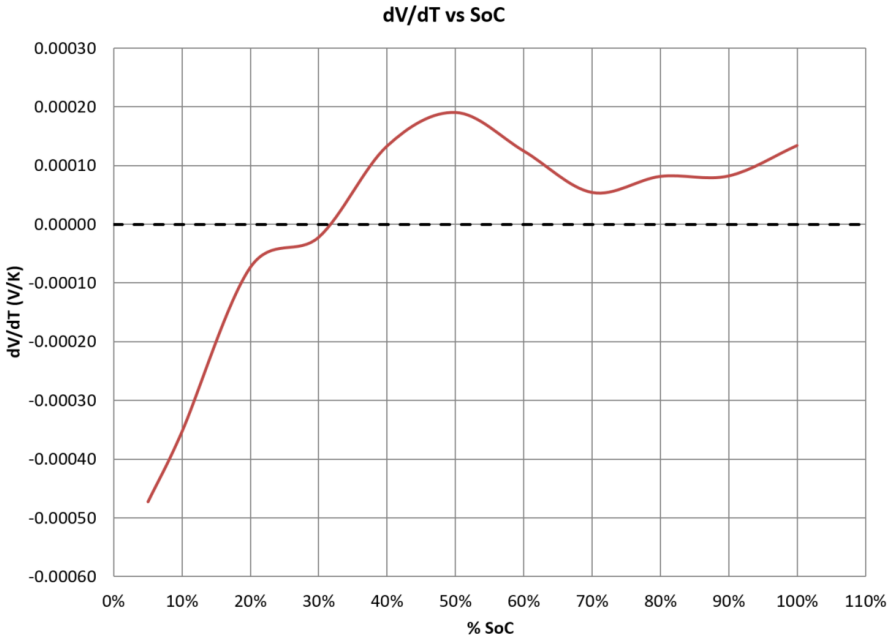
Electrical Testing (cont.)

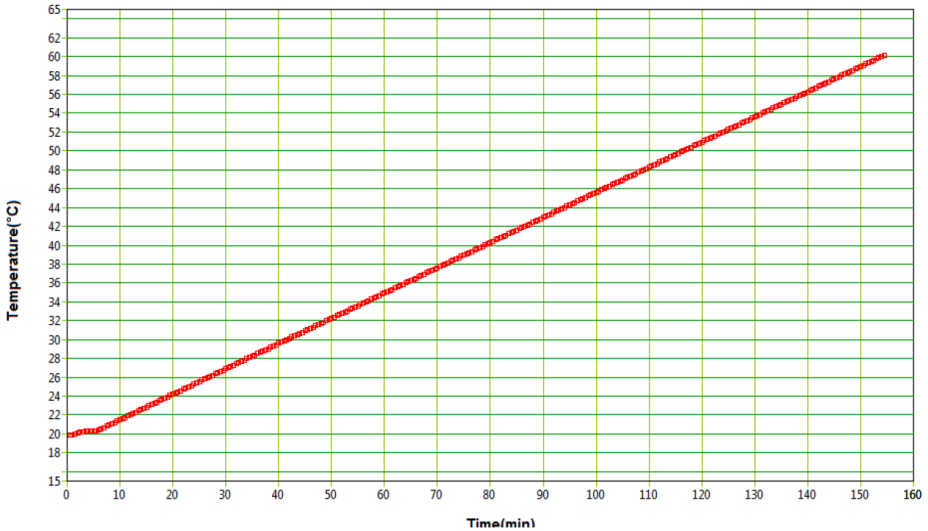
TNP Testing

- Cells cycled from -20°C – 60°C
  - SoC: 5% – 100%

Heat Capacity

- Cells tested off-site
  - 20°C – 60°C temperature range

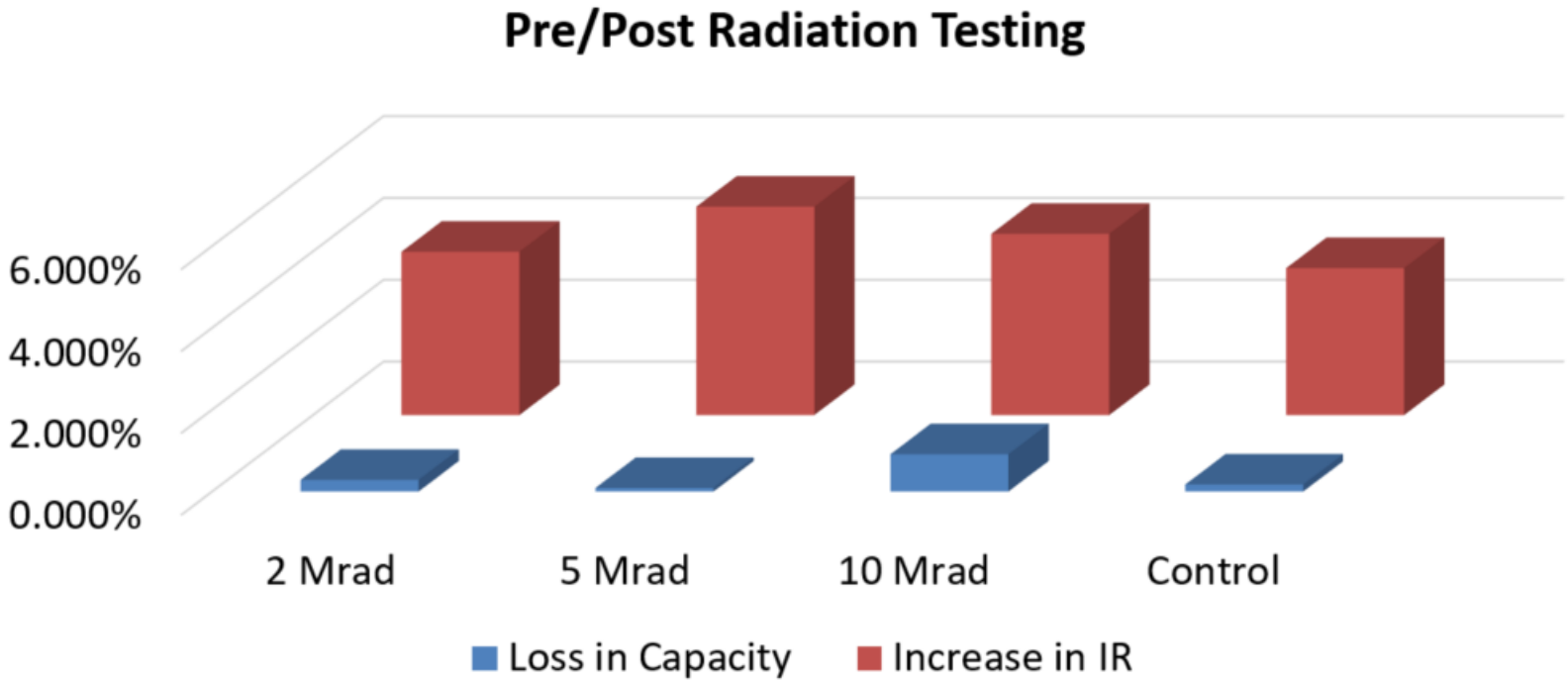




Environmental Testing

Radiation Testing

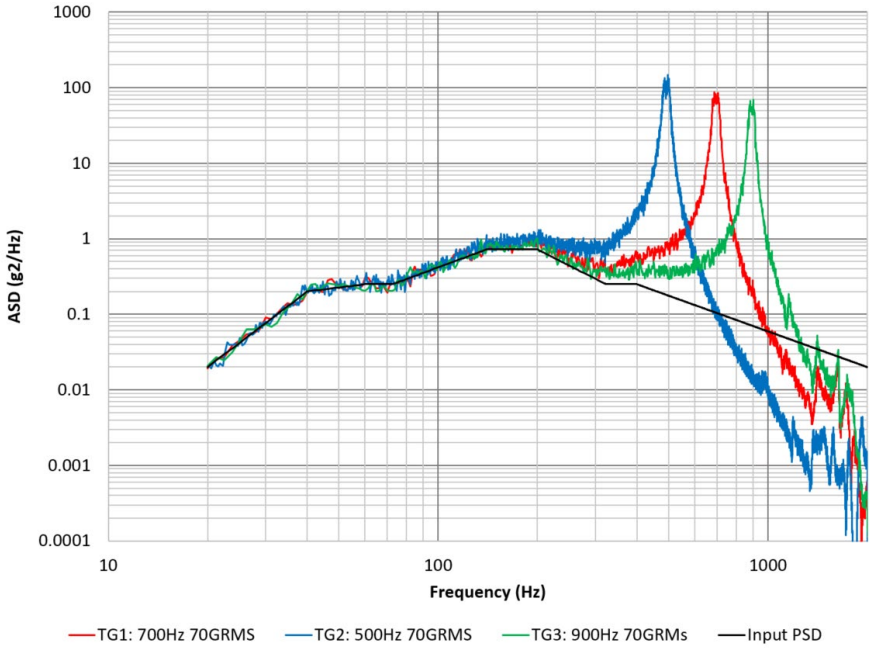
- Radiation Levels: 2Mrad, 5Mrad, and 10Mrad
- Pre/post radiation



Environmental Testing (cont.)

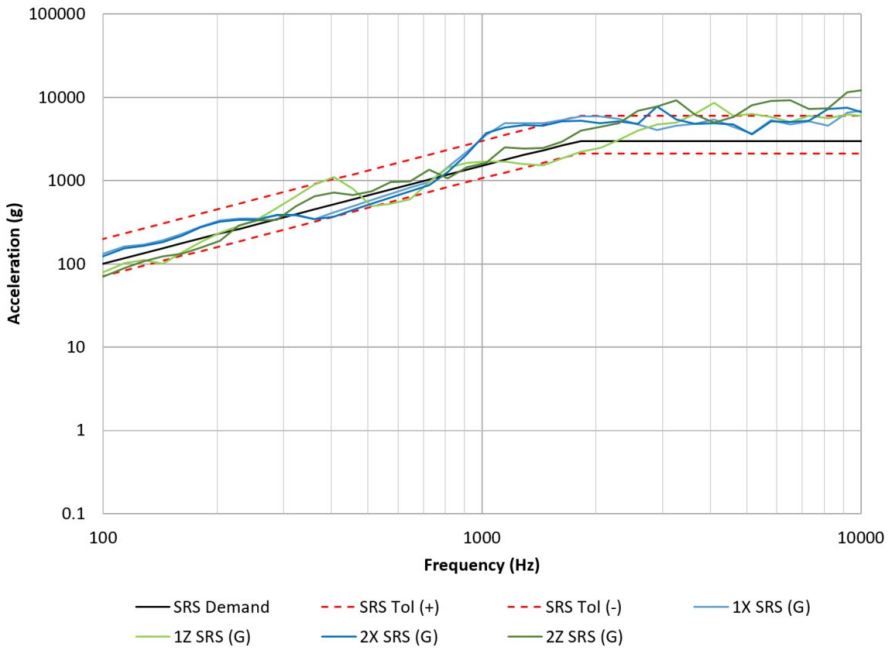
Vibration Testing

- Cells tested to 70Grms
  - TG1 tested at 700Hz resonance
  - TG2 tested at 500Hz resonance
  - TG3 tested at 900Hz resonance



Shock Testing

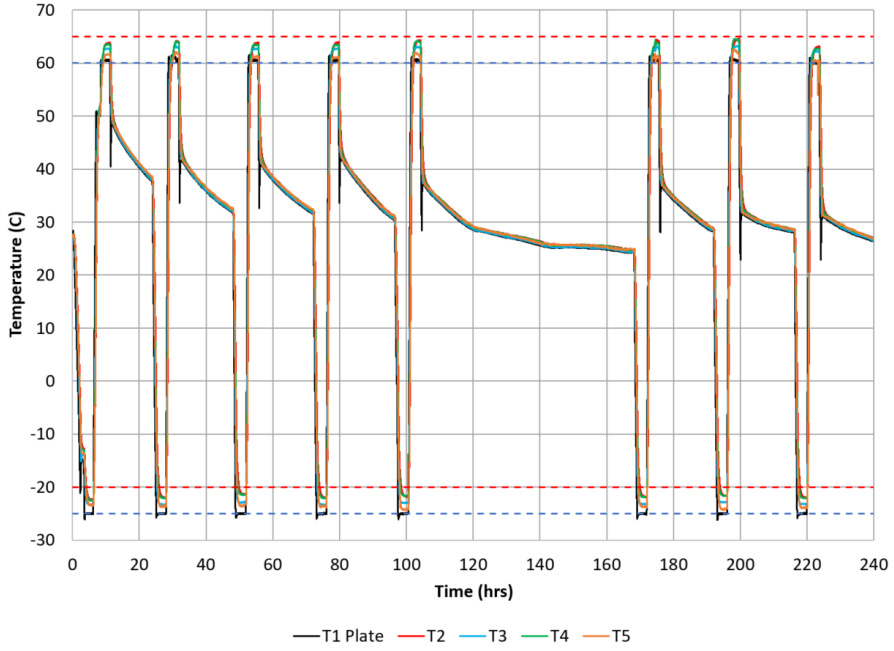
- Cells tested to 3000g
  - Taken from vibe TG1, TG2, and TG3



Environmental Testing (cont.)

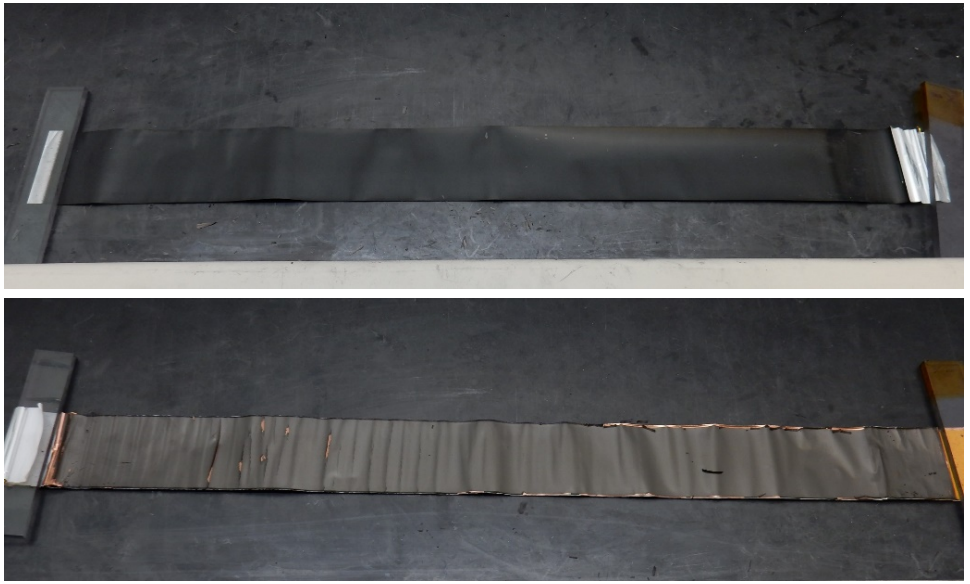
TVAC Testing

- Cells from vibe/shock testing
  - 8 thermal cycles with dwells at -20° and 60°C
  - RGA scans every 30 min showed no signs of electrolyte leakage



Post Environmental DPA

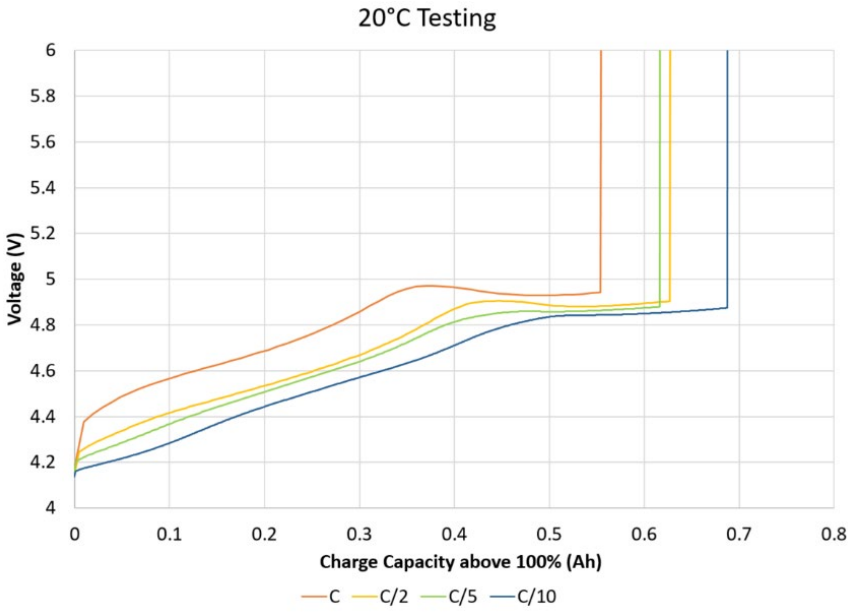
- Cells from vibe/shock/TVAC testing
  - No signs of damage or leakage
  - Results consistent with mechanical analysis results

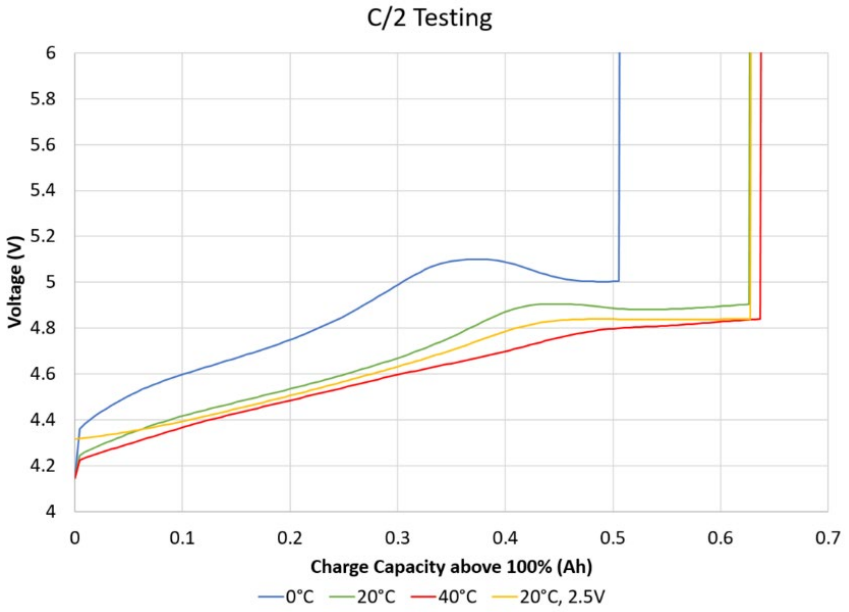


Safety Device Verification

Overcharge Testing

- Cells from vibration, shock, TVAC, and radiation tested in addition to fresh cells
- Test Temperatures: 0°C, 20°C, and 40°C
- Charge Rates: C/10, C/5, C/2, and C
- Starting Voltages: 2.5V and 4.2V

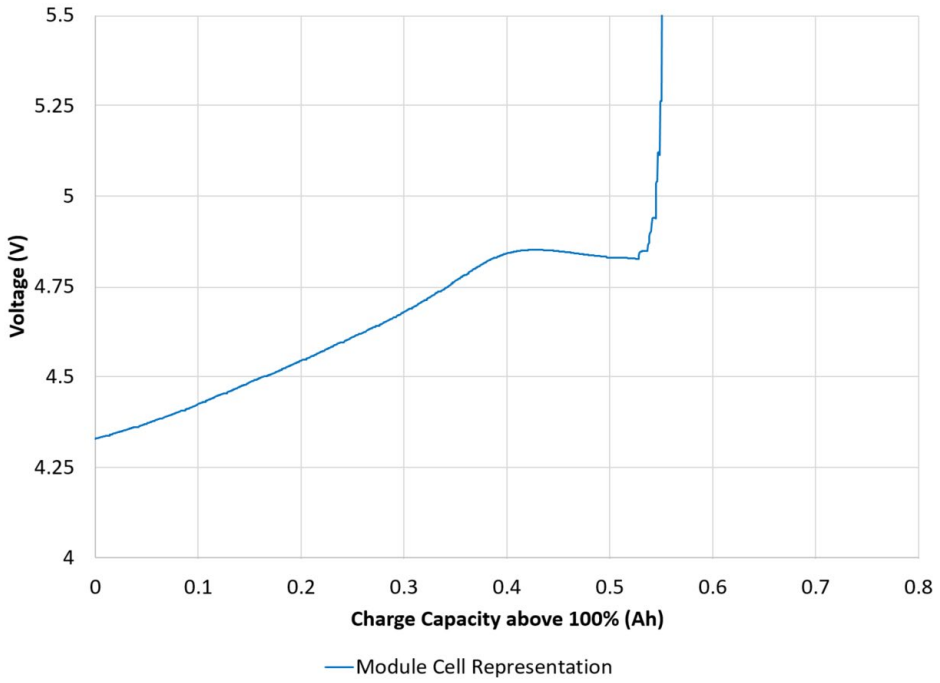




Safety Device Verification (cont.)

Module Overcharge Testing

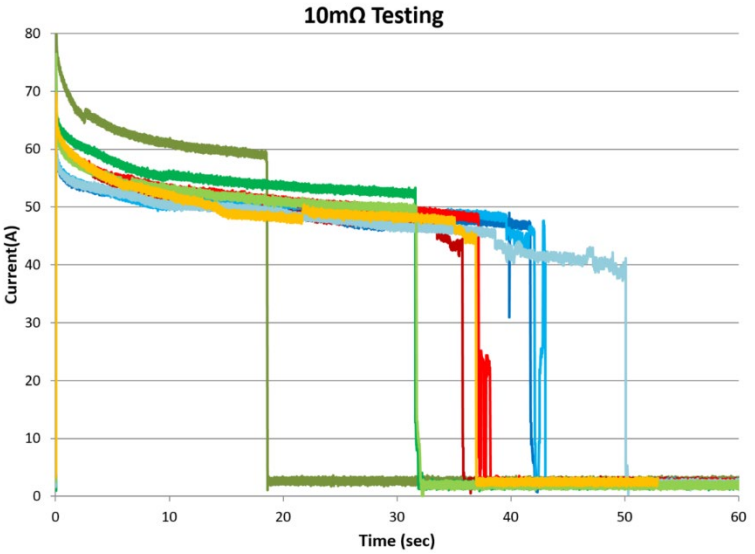
- 8s10p configuration
  - Successful CID activation in all cells
  - No venting or visible signs of damage throughout cell block
  - C/2 (17.5A) charge rate from min. voltage
  - Voltage at CID Activation = 38.6V
    - Cell voltage of 4.83V
  - Max Temperature = 62.3°C

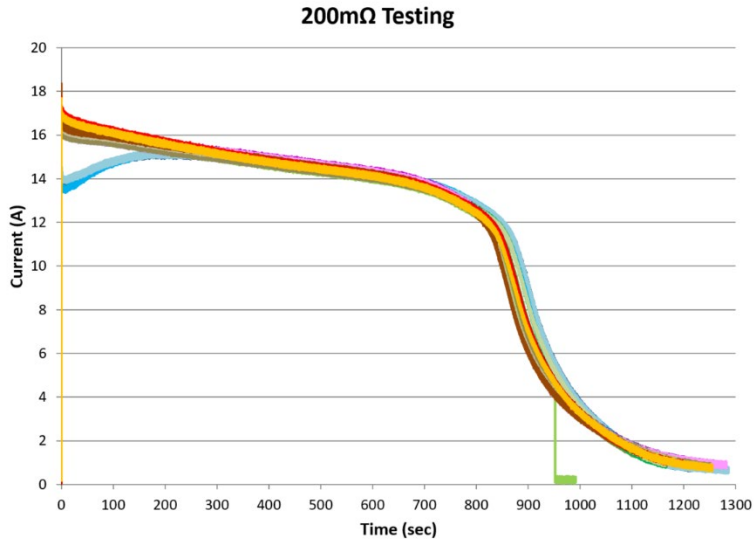


Safety Device Verification (cont.)

Overcurrent Testing

- Fresh and post-environmental cells tested
  - Test Temperatures: 0°, 20°, and 40°
  - Short Resistance: 10mΩ – 200mΩ
- No venting when tested at resistance of 50mΩ and higher.
- Cells tested at lower resistances saw collapses in voltage and current prior to full discharge

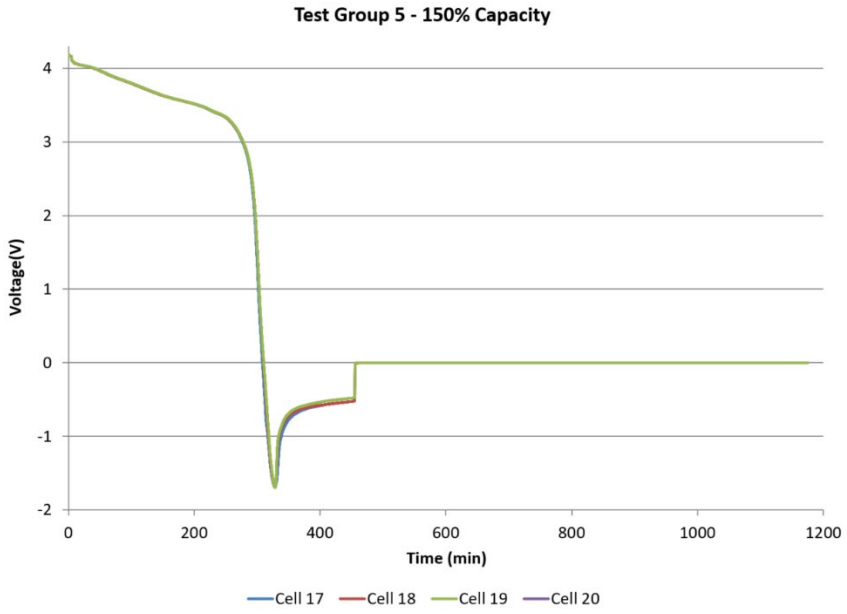




Safety Device Verification (cont.)

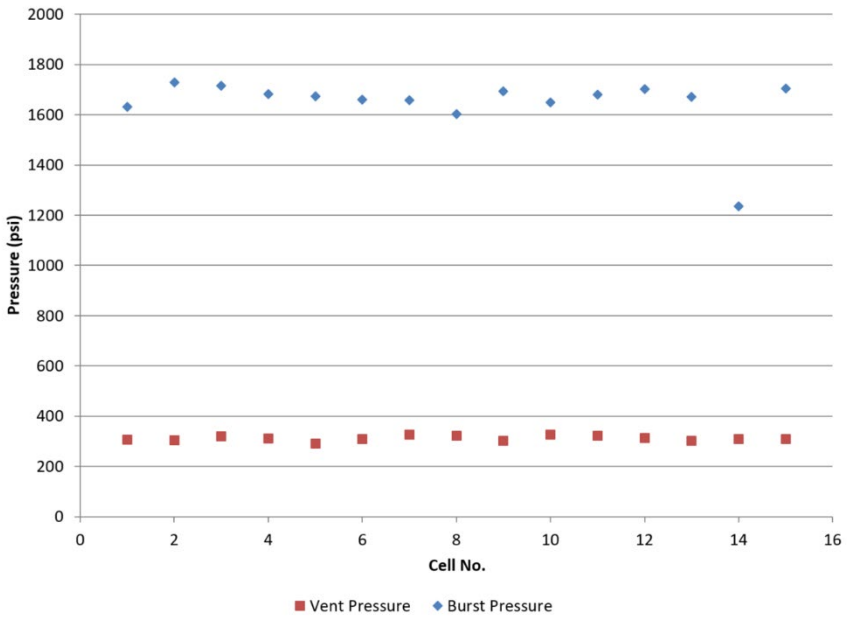
Over-Discharge Testing

- Cells tested at 20°C
  - Test scenarios:
    - End-stop voltages of 1.5V –150% capacity
  - No damage or leakage observed



Burst:Vent Pressure Testing

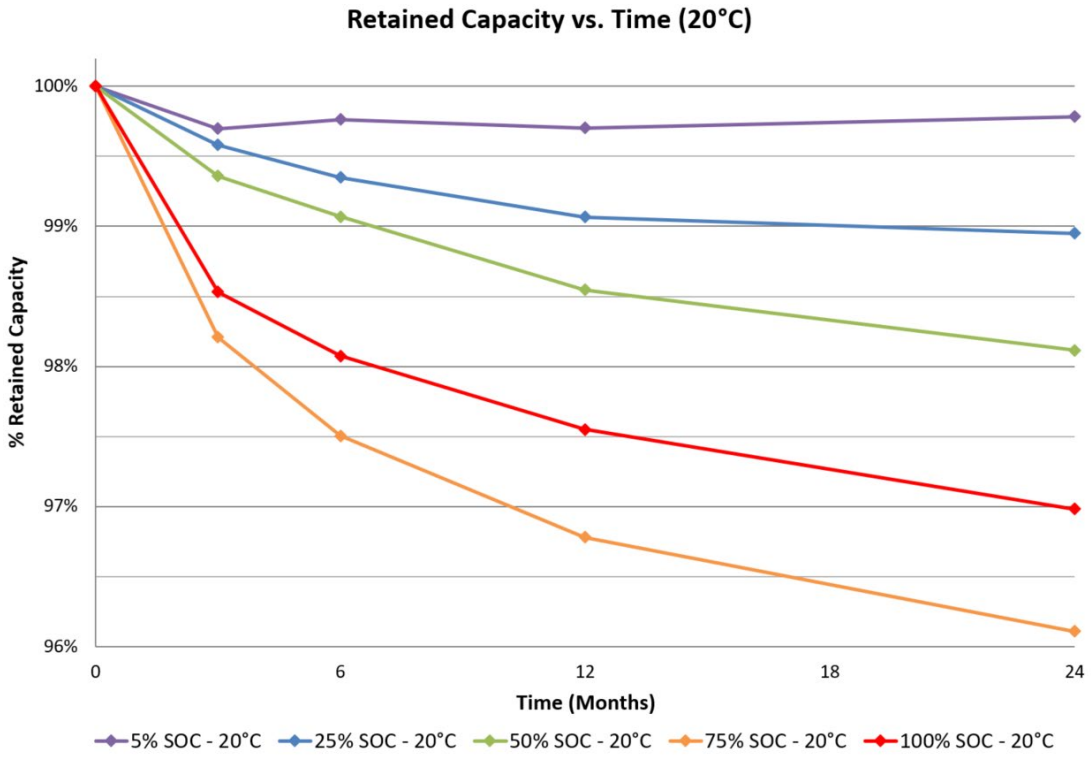
- Fresh cells tested
  - Min. Burst:Vent = 3.77
  - Avg. Burst:Vent: 5.28
    - P_{burst} = 1646 psi
    - P_{vent} = 312 psi



Endurance Testing

Storage Testing

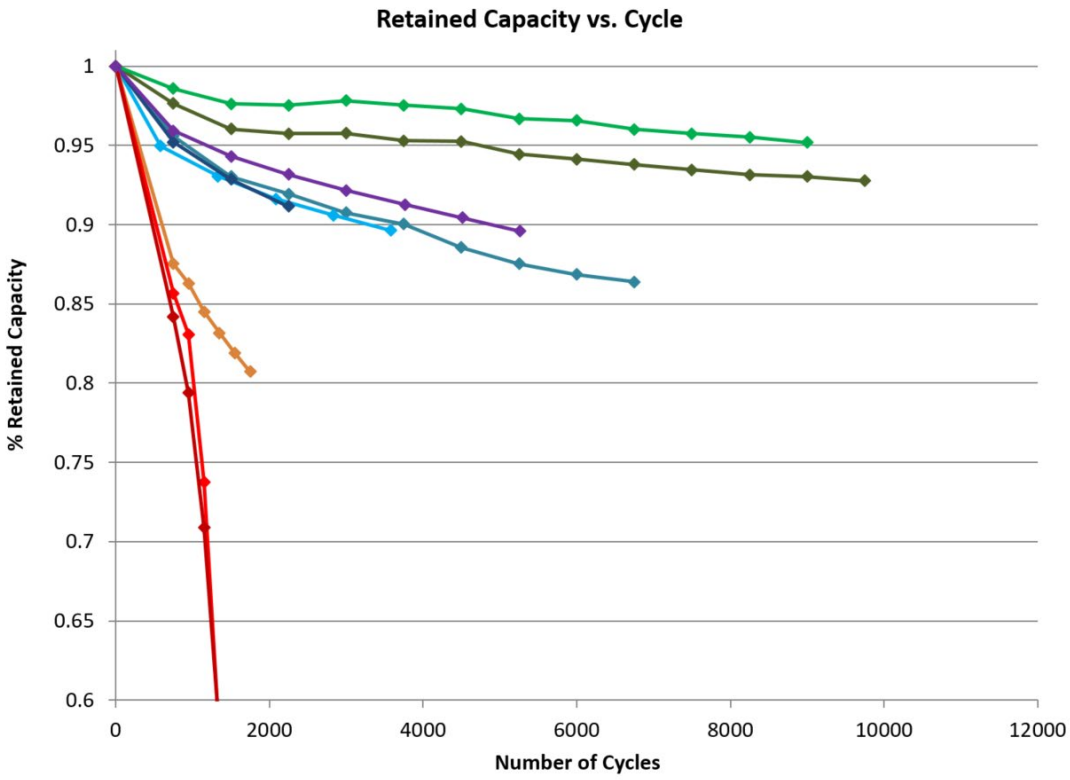
- Test conditions:
  - Temp: 0°C – 40°C
  - SoC: 5% – 100%
- Fade is consistent across cells tested under same conditions
- 24 month capacity measurement completed August 2020.



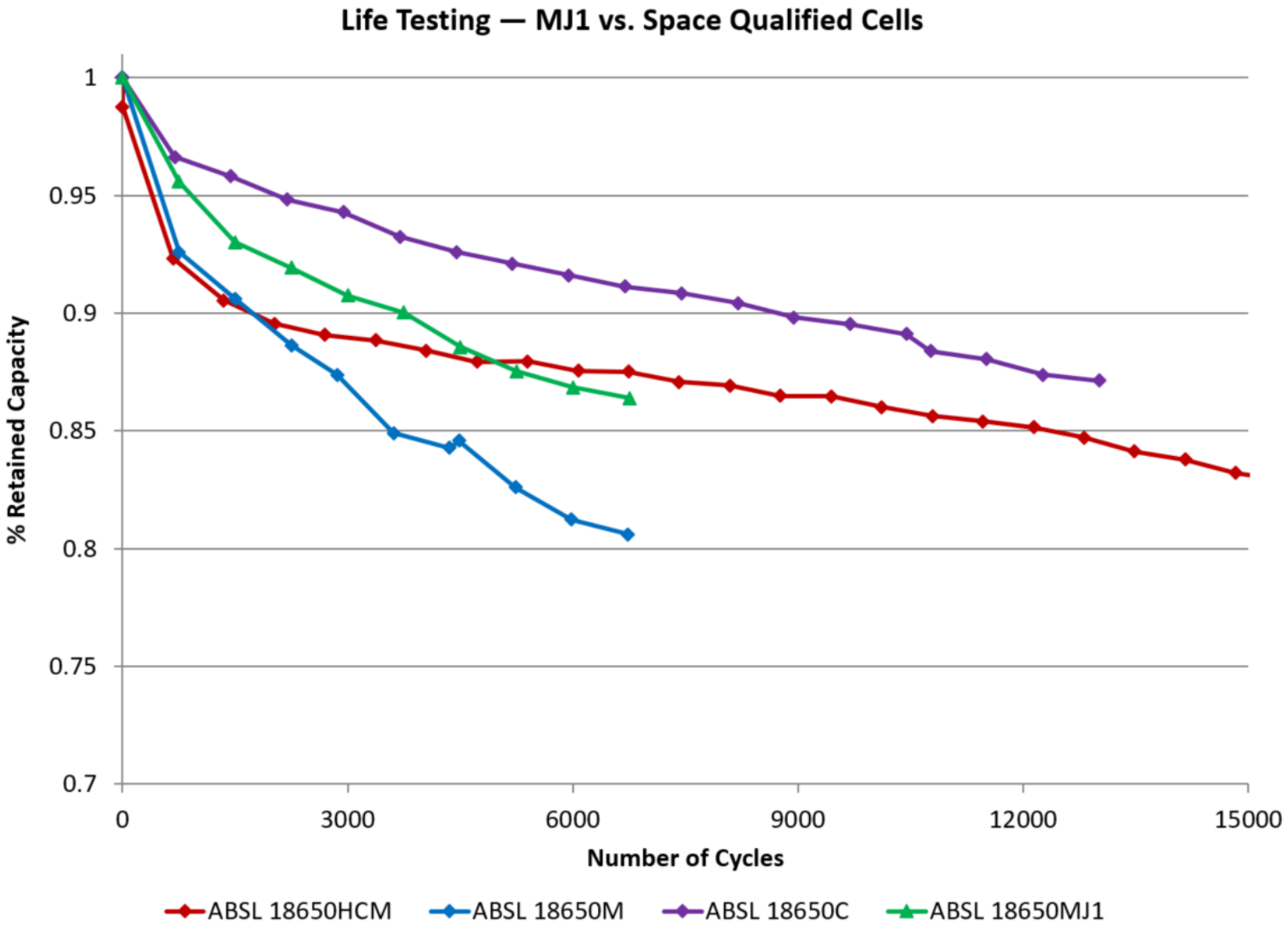
Endurance Testing (cont.)

Life Testing

- Varying Test Conditions:
  - DOD
  - EOC Voltage
  - Discharge Rates
  - Temperature
- Lower DOD tests result in less fade over time
- MJ1 shows favorable performance compared to other qualified cells



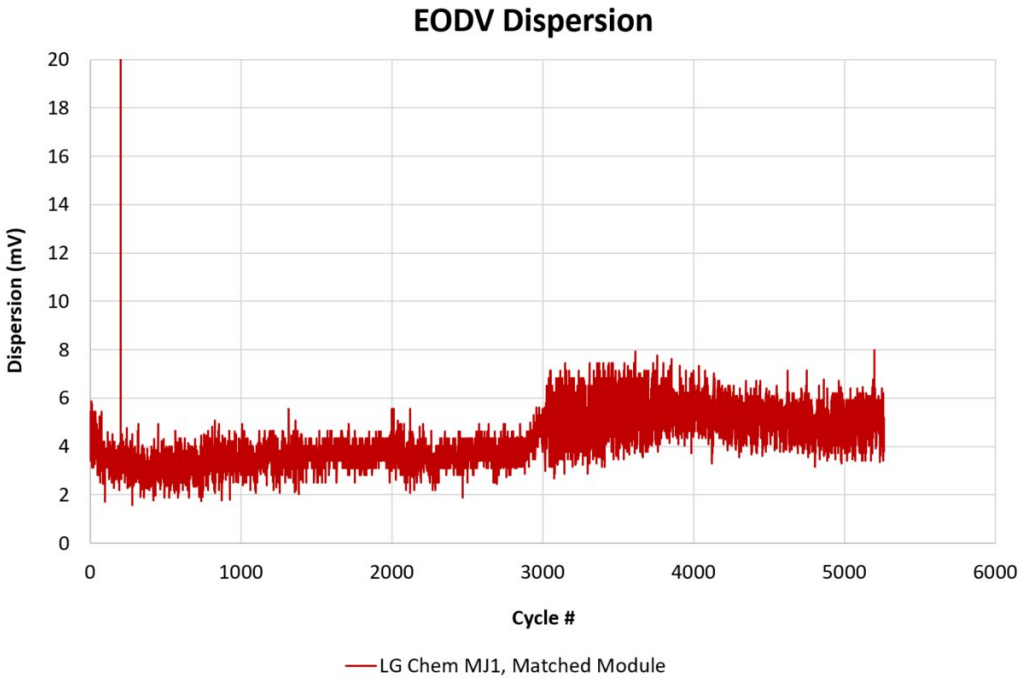
Endurance Testing (cont.)



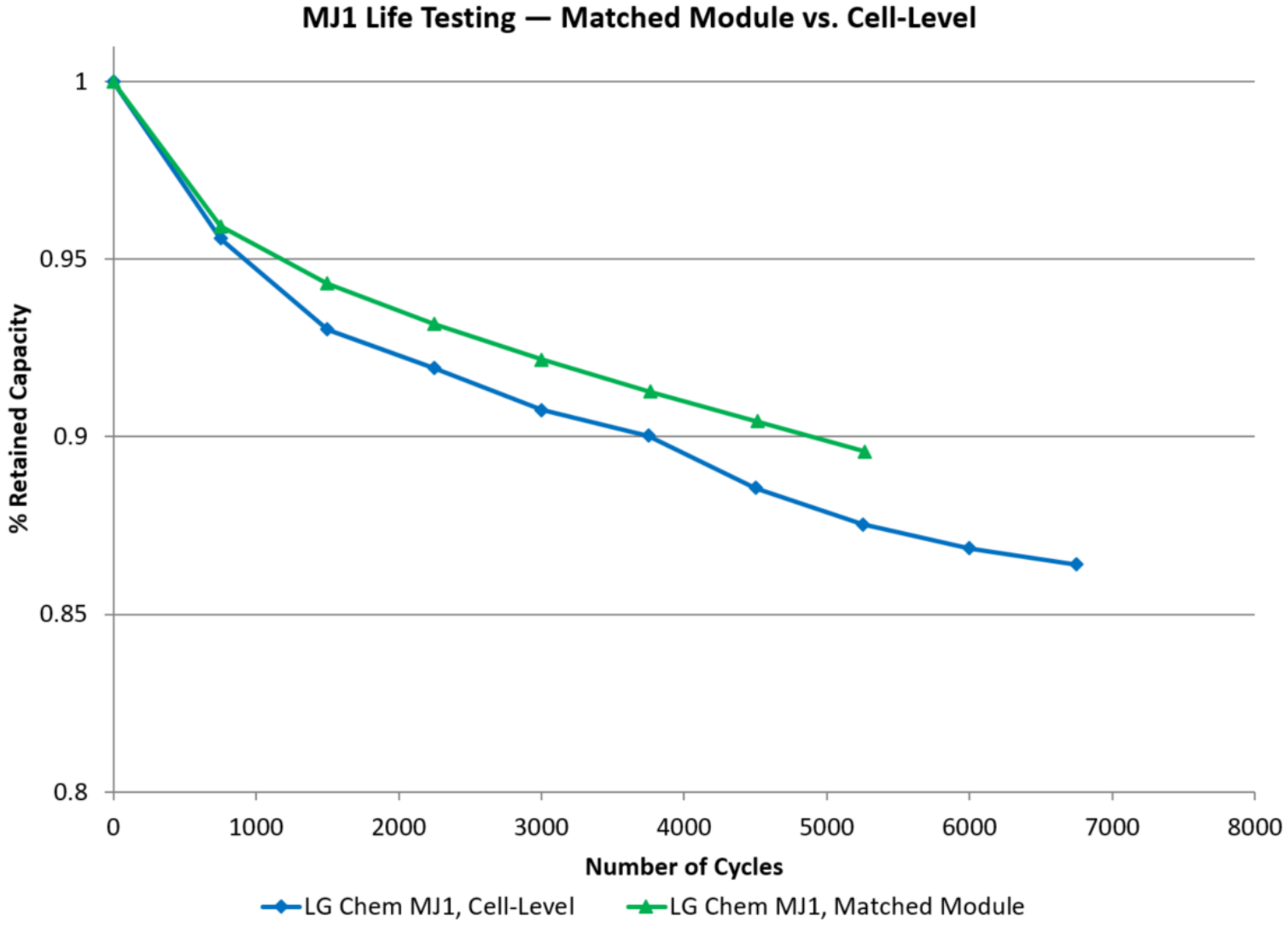
Endurance Testing (cont.)

8s Module Matched Life Testing

- Cells in string matched using ABSL's proprietary process
- Dispersion between cells in string is minimal and consistent through 5250 cycles
- 8s module exhibits slightly better fade compared to cell-level tests under the same conditions



Endurance Testing (cont.)



18650MJ1 – Qualified

- LG Chem MJ1 Cell is fully qualified
- Latest revision of Qualification Report released March 2020
- Storage and Life testing to be continued indefinitely
- LG Chem MJ1 Cell has been selected for multiple missions

Questions?