

Space Qualification of the Quallion 72Ah Li-ion Cell



POWERED by
ABSL  **QUALLION**

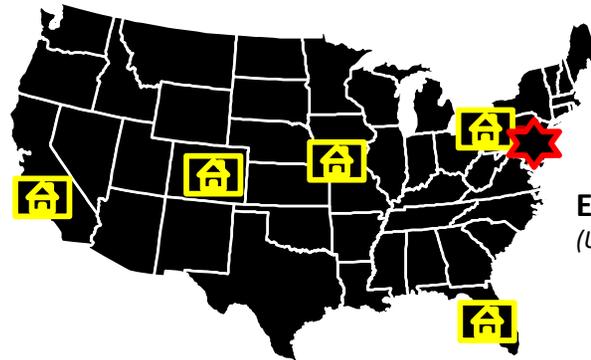
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Jake Dembeck

EnerSys Advanced Systems / ABSL
Longmont, Colorado

EnerSys Advanced Systems - Facility Locations

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 (Thin 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

Value Proposition – Space

- **Heritage**

- ABSL supplied the 1st rechargeable Lithium-ion battery flown in space
- ABSL delivered the longest serving Lithium-ion spacecraft battery
- ABSL is the most demonstrated Lithium-ion space battery supplier with more Li-ion heritage than any other vendor



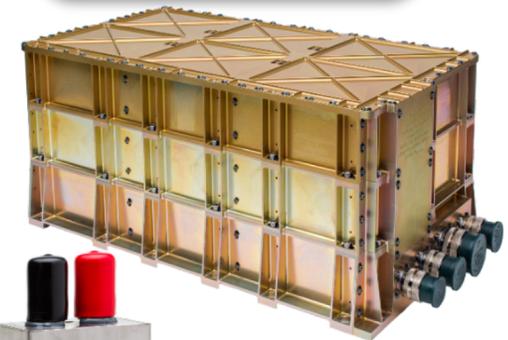
- **Flexibility, Simplicity, and Performance**

- Small cell approach is uniquely scalable for voltage and capacity
- No cell balancing electronics or cell bypass required



- **Reliability**

- ABSL batteries have never had a failure on orbit with over 2.5 billion cells hours of operation
- Able to meet the demanding safety requirements of human spaceflight



- **Vertical Integration with Domestic Supply**

- Complete battery manufacturing process from raw materials to finished batteries, enabling a unique level of configuration control and security of supply

- **Turn-Key Space Engineering Services**

- Engineering services include: design, modeling, analysis, manufacturing, space qualification, environmental & electrical testing



Quallion 72Ah Cell Specifications

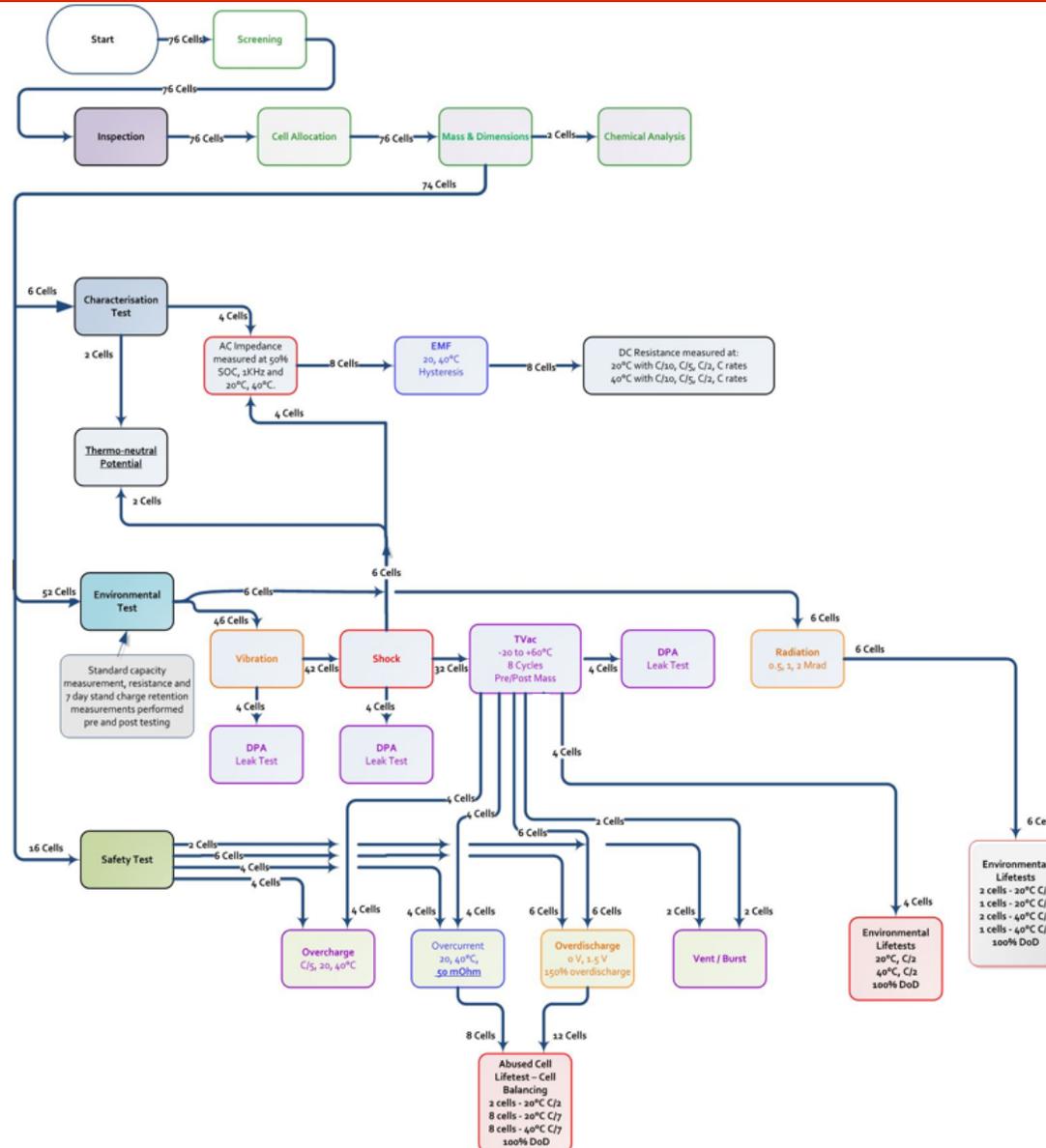
- Cell Characteristics

Capacity	Typical	72,000 mAh 259 Wh
	Minimum	68,000 mAh 245 Wh
Voltage	Nominal	3.6 V
	Charge	4.1 V
	Discharge	2.7 V
	Minimum Discharge	0 V
Charge Current	Standard	7.0 A
	Maximum	70 A
Charge Time	Standard	10 hrs
Discharge Current	Maximum	70 A
Temperature	Charge	-20°C to 50°C
	Discharge	-20°C to 50°C
Energy Density	Gravimetric	143 Wh/kg



72Ah Qualification Plan

Cells Tested
76



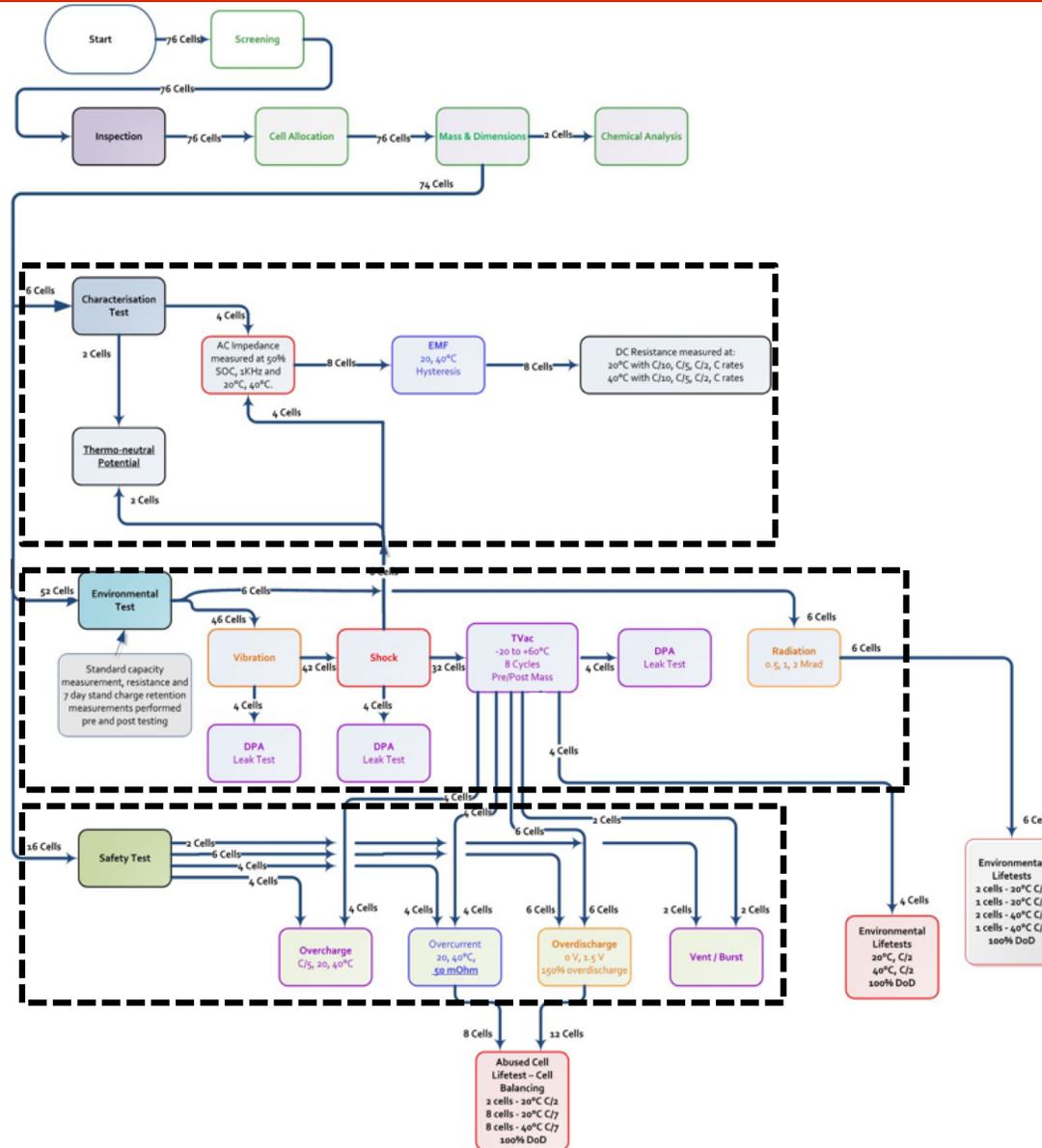
72Ah Qualification Plan

Cells Tested
76

Electrical
Characterization

Environmental
Testing

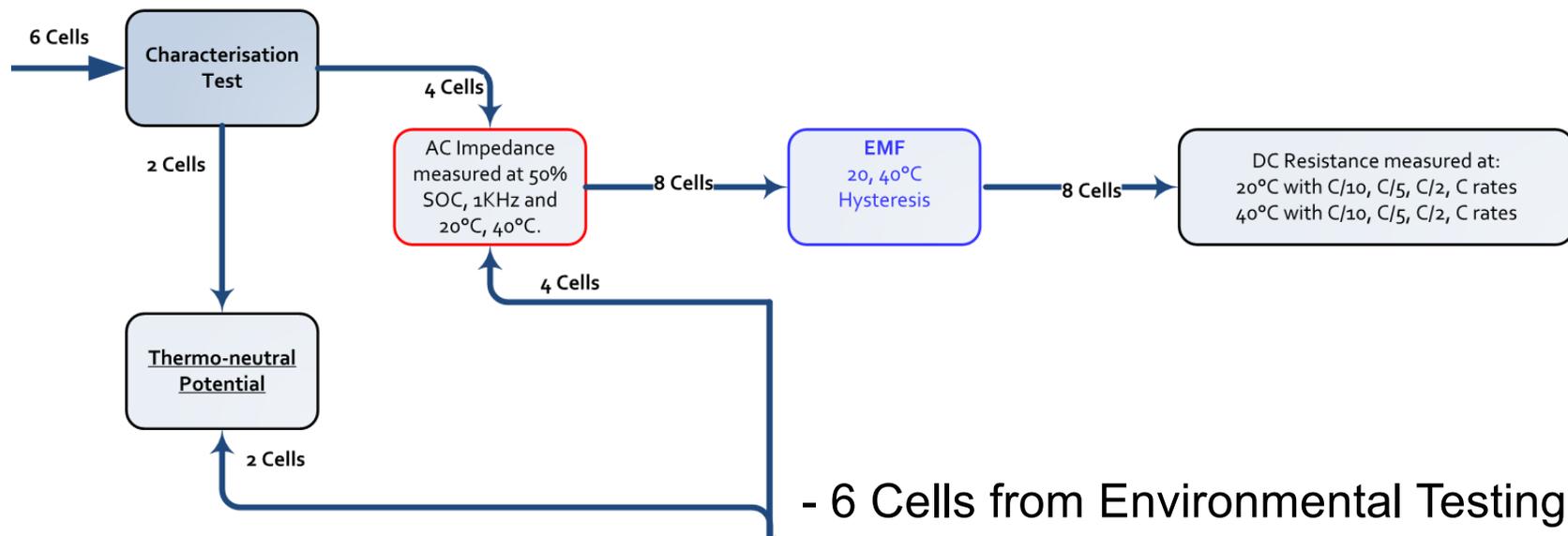
Safety Testing



72Ah Qualification Plan

Cells Tested
12

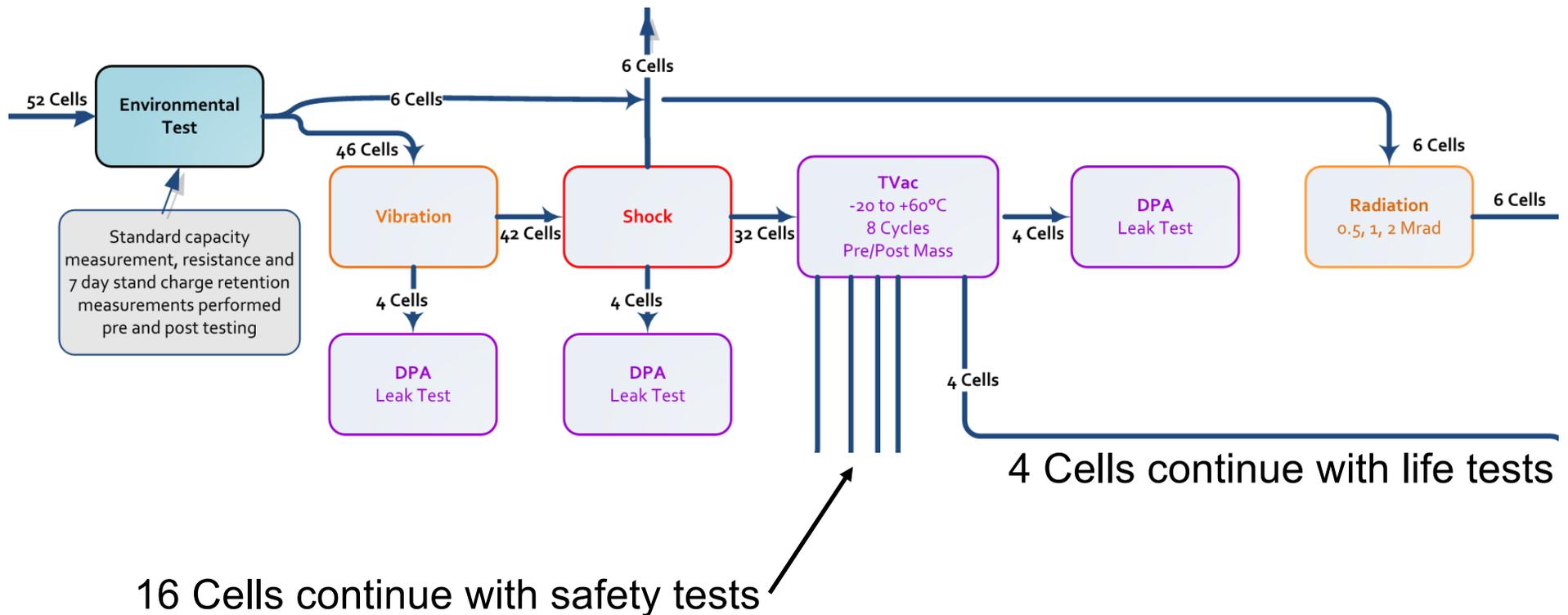
Electrical Characterization



72Ah Qualification Plan

Cells Tested
52

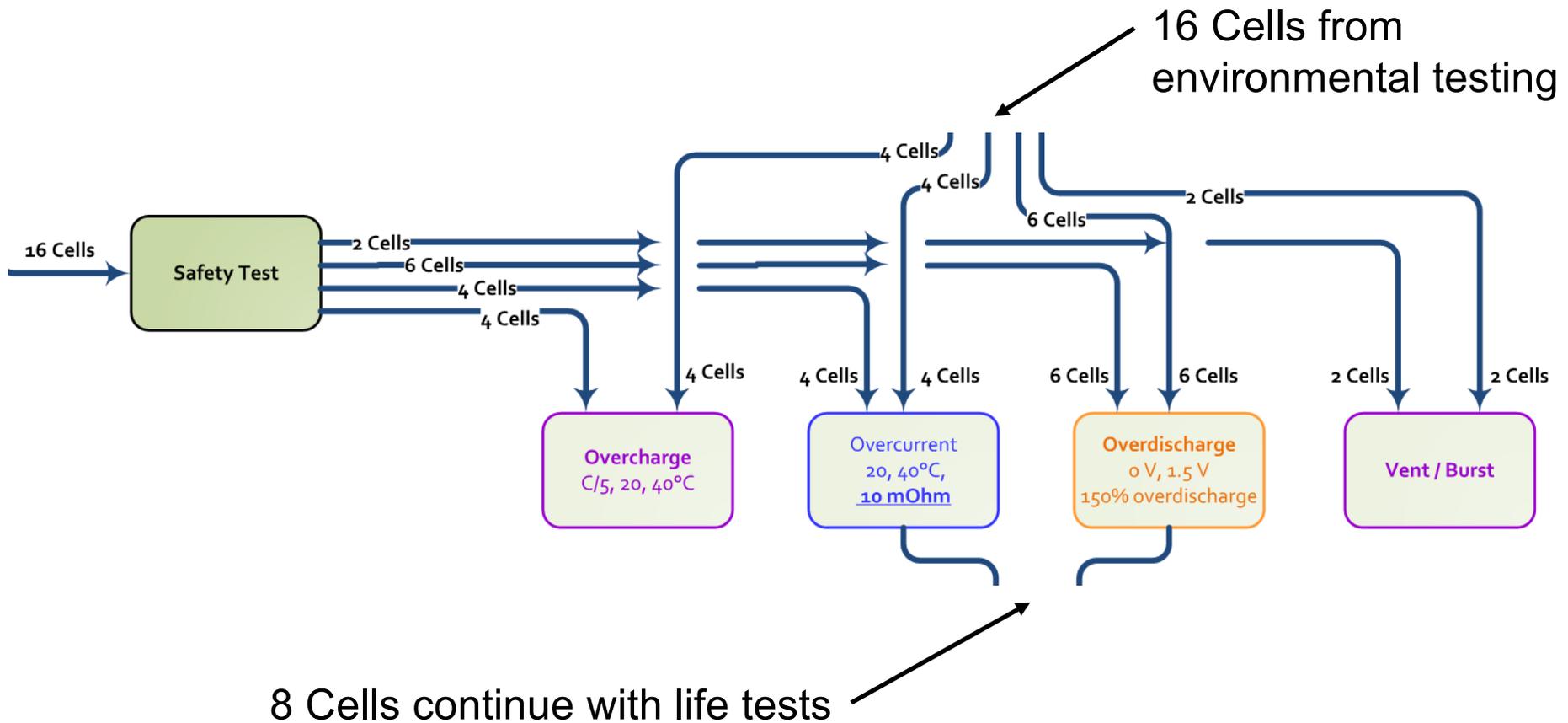
Environmental Testing



72Ah Qualification Plan

Safety Testing

Cells Tested
32

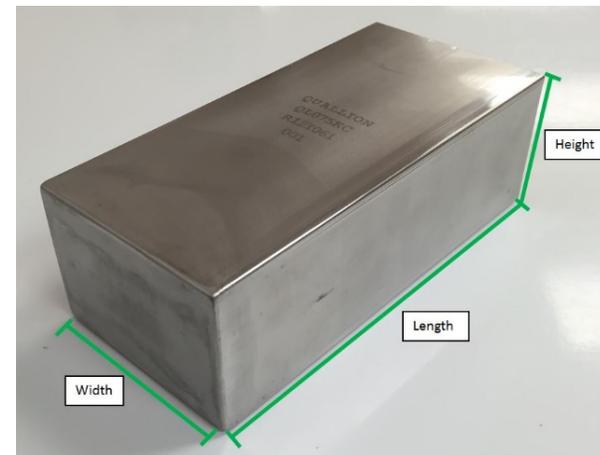


Initial Inspection and Screening

Cells Tested
76

- **Visual Inspection**

- Each cell from foreign and domestic lots screened against:
 - Rust or other contamination
 - Scratches, gouges, dents
 - Marring on terminal threads



- **Mass and Dimensional**

- Average measurements for each material source:

Group	Mass (lbs)	Std. Dev. (lbs)	Length (in)	Std. Dev. (in)	Width (in)	Std. Dev. (in)	Height (in)	Std. Dev. (in)
Foreign	4.012	0.006	6.757	0.009	3.182	0.011	2.210	0.001
Domestic	4.019	0.006	6.762	0.010	3.186	0.004	2.229	0.019

Initial Inspection and Screening

Cells Tested
76

• Electrical Cycling

- Standard Capacity Measurements (SCM) were completed at 20°C
- SCM performed at:
 - Charge: C/2
 - Discharge C/2 and C/5

Parameter	Domestic			Foreign		
	Average	Max	Min	Average	Max	Min
AC Impedance (mΩ)	1.567	1.682	1.419	1.586	1.654	1.529
Initial OCV (V)	4.100	4.103	4.096	4.102	4.106	4.097
Discharge Capacity (Ah)	71.579	74.737	66.854	70.310	71.118	69.351
DCIR at 50% SoC (mΩ)	4.144	9.242	2.635	3.274	3.483	3.155
DCIR at Min Voltage (mΩ)	11.396	14.210	9.881	11.458	11.761	11.173

Electrical Characterization: ACIR

Cells Tested
8

– Test objective/method

- Resistance data measured at 1kHz
- ACIR data used as baseline measurement for comparison in future testing
- 8 cells tested:

	20°C	40°C
Domestic Cells	2	2
Foreign Cells	2	2

– Test Results

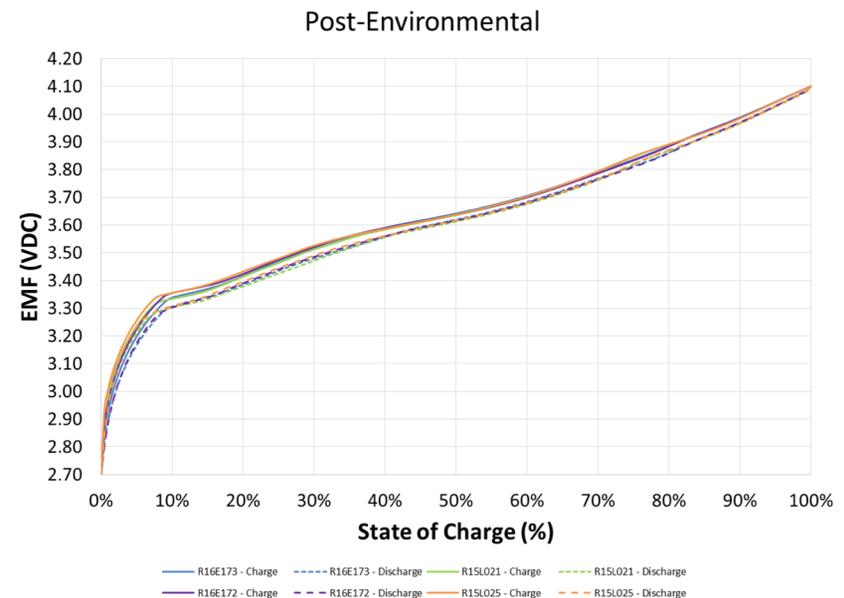
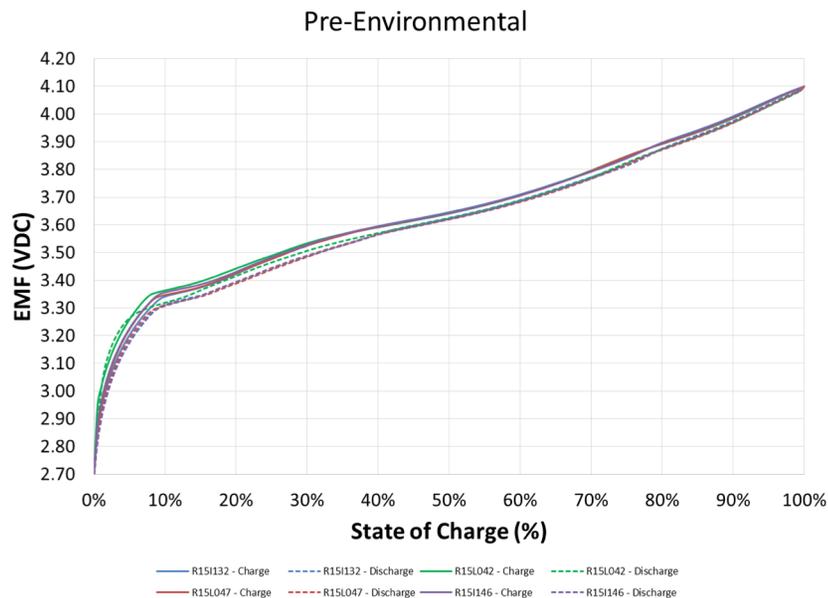
- Results show comparison between temperatures as wells as material source.

	20C	40C	Diff.	Foreign	Domestic	Diff.
Average ACIR	1.620	1.555	0.066	1.614	1.561	0.054
Average OCV	3.641	3.641	0.000	3.640	3.642	0.002

Electrical Characterization: EMF

- Initially discharged to 0% SoC at C/100
- 1 complete cycle (charge and discharge) conducted at C/100
- Foreign and Domestic cells tested at 20°C and 40°C

Cells Tested
8



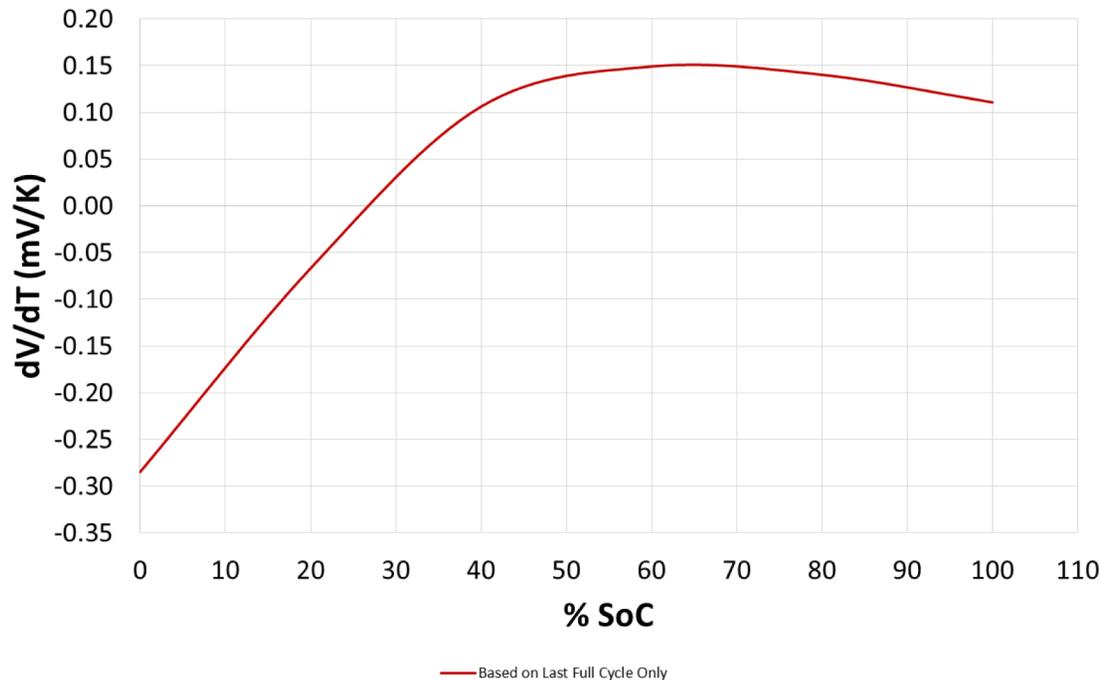
Electrical Characterization: Thermo-Neutral Potential

- Cells thermally cycled at varying states of charge while monitoring voltage

- SoC's: 0% - 100%

- 6 cycles between -20°C and 50°C, 10°C/hr, 1hr dwell times

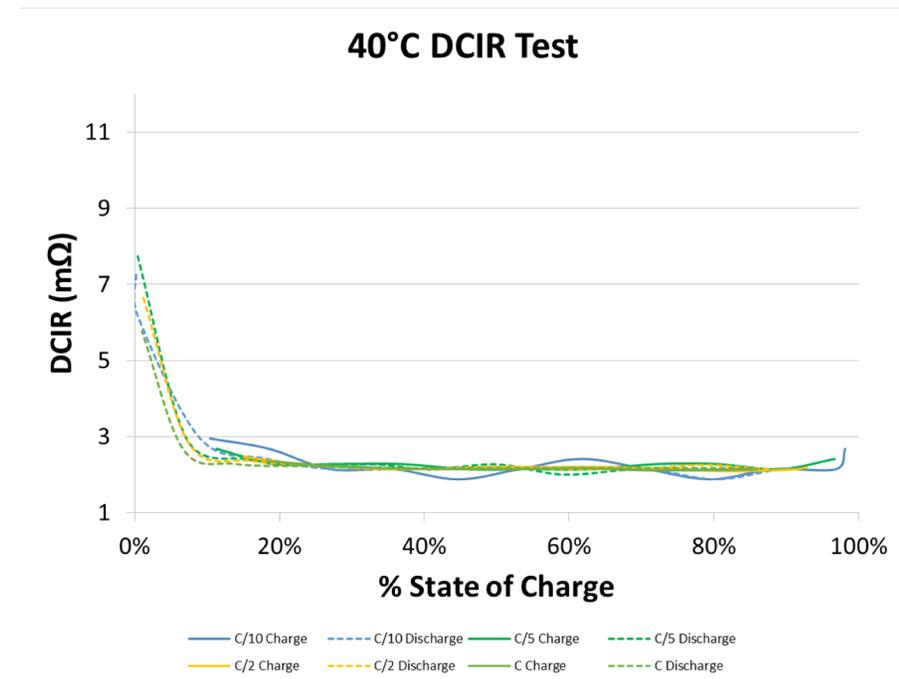
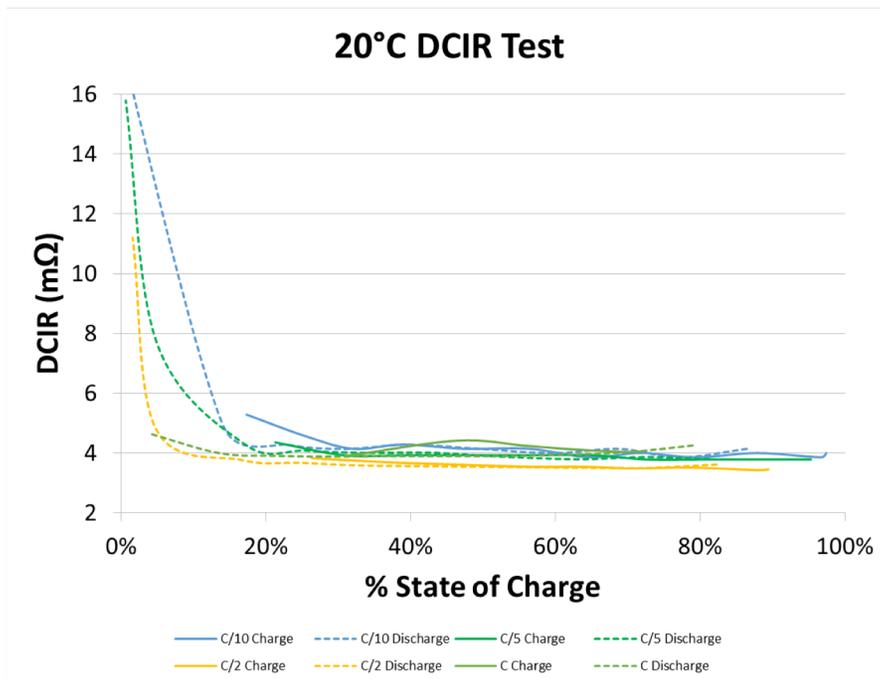
Cells Tested
4



Electrical Characterization: DCIR

Cells Tested
8

- Cells tested under the following conditions
 - 20°C or 40°C
 - C, C/2, C/5, C/10
- Results:
 - All values above 20% SoC are less than 5mΩ.



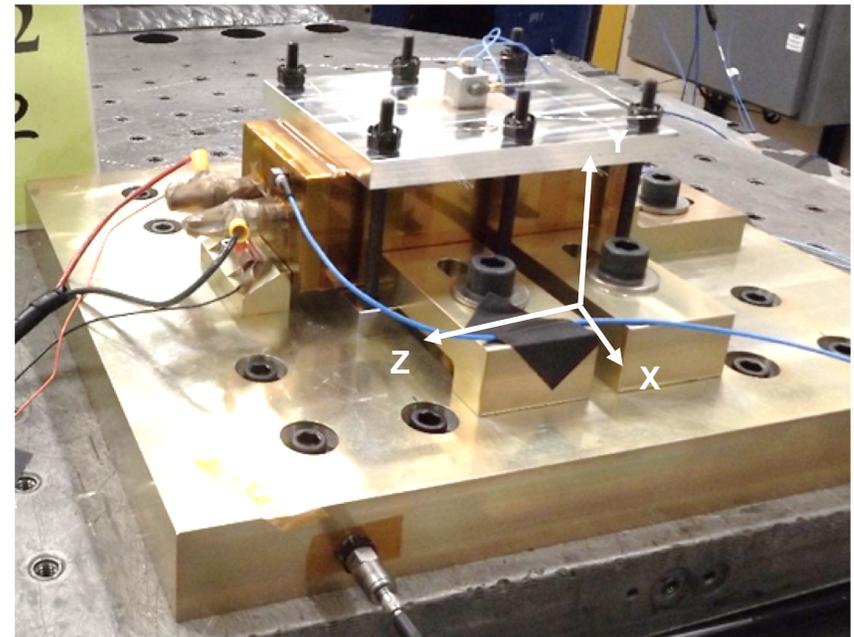
Environmental Testing: Vibration

Cells Tested

46

• Test Setup

- Capacity measurements taken before and after vibration testing
 - Average Domestic and Foreign capacity measurements dropped <0.5Ah
- Profile test order:
 - Low Level Sine
 - » 0.5g from 10 to 2000Hz, 2oct/min
 - High Level Sine
 - » 20g from 5 to 100Hz, 2oct/min
 - Random vibration profile
 - » Max input of 27Grms, 4min each axis
 - Low Level Sine (repeat for pre/post comparison)
 - » 0.5g from 10 to 2000Hz, 2oct/min

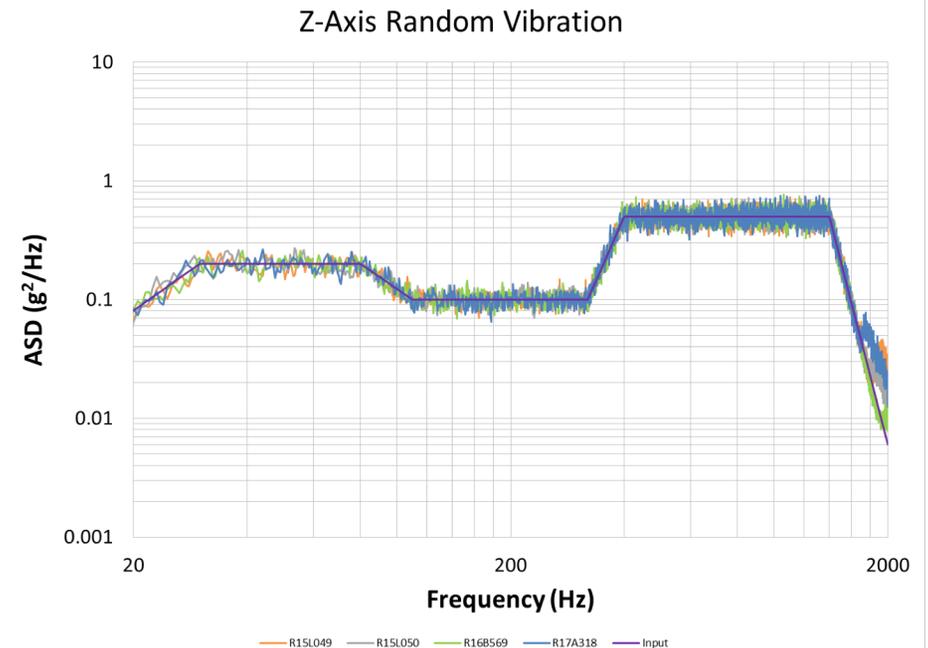
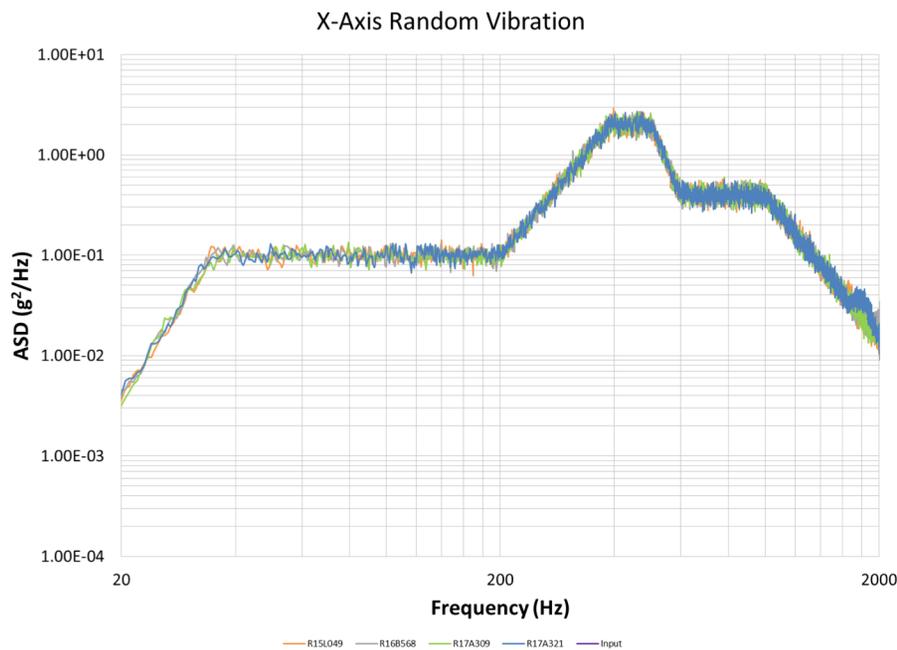


Environmental Testing: Vibration Results

• Vibration Test Results

Cells Tested
46

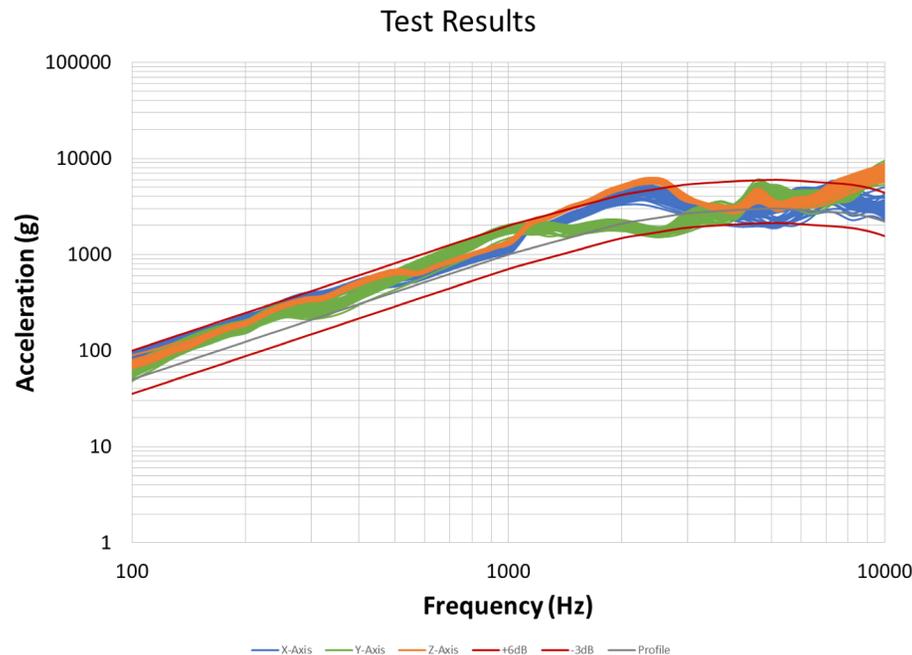
- Random vibs levels:
 - » X-Axis: 27.03Grms
 - » Y-Axis: 19.79Grms
 - » Z-Axis: 25.04Grms
- LLS: Average frequency shift: 14Hz



Environmental Testing: Shock

Cells Tested
42

- Cells subjected to 3 pulses minimum in each axis
 - Test setup results in Y-Axis receiving 6 pulses
- ACIR measured after each pulse
 - Average standard deviation: 0.008mΩ

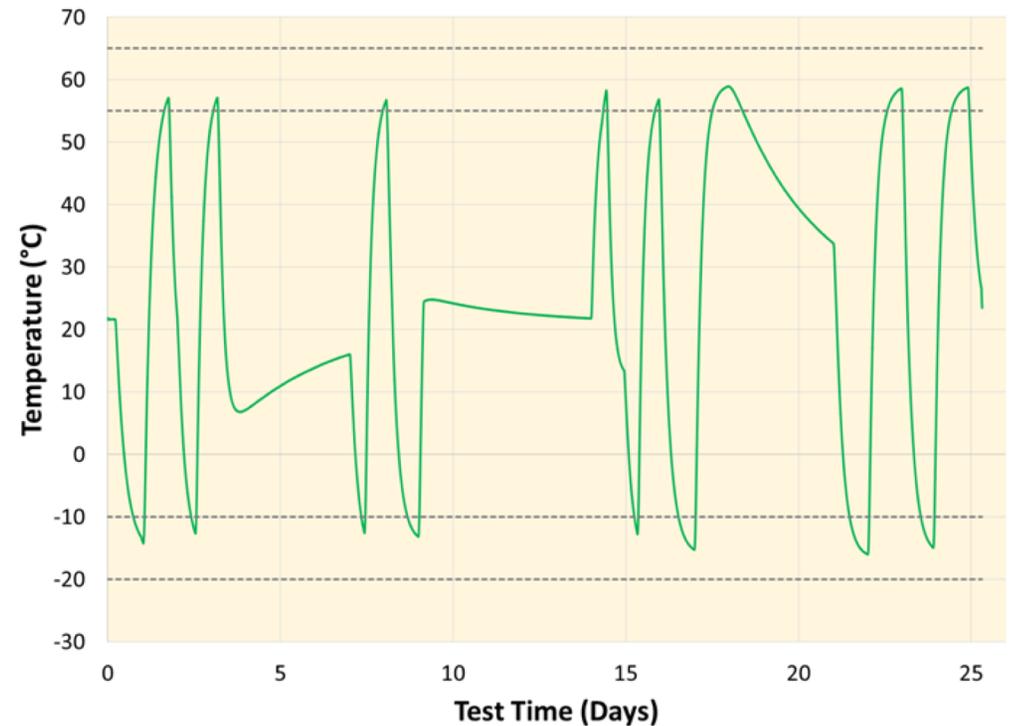


Frequency (Hz)	Level (g)
100	50
1000	1000
2000	2100
3000	2700
4000	2900
5000	3000
5500	3000
6000	2900
7000	2800
8000	2700
9000	2500
10000	2200

Environmental Testing: TVAC

Cells Tested
32

- Cells selected from vibration and shock testing
- Performed at 5×10^{-5} Torr and 100% SoC
- RGA screening every 30min to detect foreign material (electrolyte)
- Cell's mass measured pre and post TVAC
 - Average difference 0.001kg
- 8 hot/cold cycles between -15°C and 60°C
- 2hr dwell at each temperature



Environmental Testing: Radiation

– Testing completed in the following groups:

Cells Tested
6

Domestic			Foreign		
Cell ID	Dose Rate	Exposure	Cell ID	Dose Rate	Exposure
Cell 1	3kRad/min	0.5MRad	Cell 4	3kRad/min	0.5MRad
Cell 2	3kRad/min	1MRad	Cell 5	3kRad/min	1MRad
Cell 3	3kRad/min	2MRad	Cell 6	3kRad/min	2MRad

– Post radiation capacity measurement and charge retention tests completed

○ Average retained capacity was 99.86%

Cell ID	Pre-Radiation EoD Capacity (Ah)	Post-Radiation EoD Capacity (Ah)	Difference (Ah)
Cell 1	72.833	72.943	0.109
Cell 2	72.756	72.805	0.050
Cell 3	72.686	72.567	-0.119
Cell 4	69.859	70.399	0.540
Cell 5	69.864	70.404	0.540
Cell 6	69.570	69.879	0.309

Safety Testing - Overcurrent

Cells Tested
8

– Purpose:

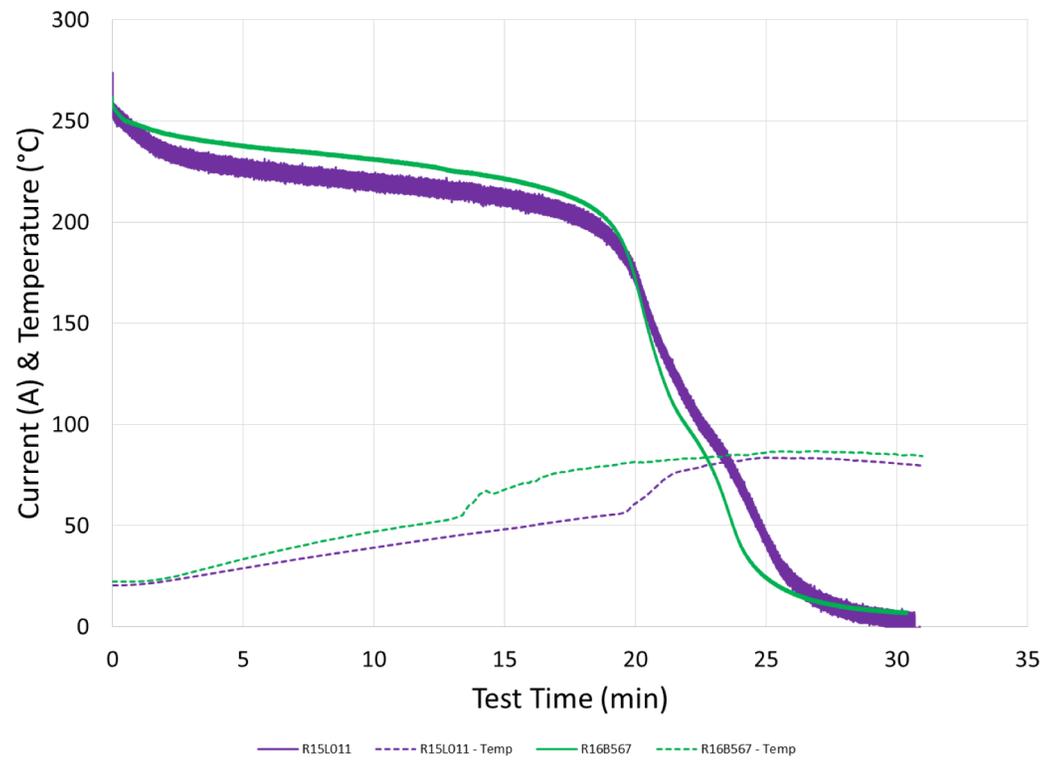
- Exploratory, 72Ah Cell does not have a PTC, and is not internally protected from a shorting event.

– 8 cells subjected to a 10mΩ short via custom resistor rig

– Cell Current

- Average: 277A
- Min: 272A
- Max: 287A

– All cells vented



Safety Testing: Vent/Burst Testing

Cells Tested

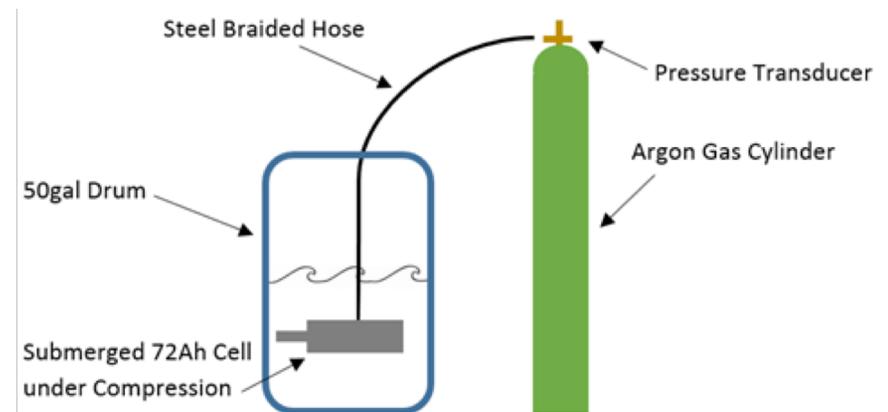
4

– Test Method

- Cells flat discharged prior to puncturing side wall
- Compressed via custom plates with NPT threaded hole
- Pressurized using Argon gas under water to mitigate projectile debris
- Pressure monitored via transducer

– Burst-to-vent ratio

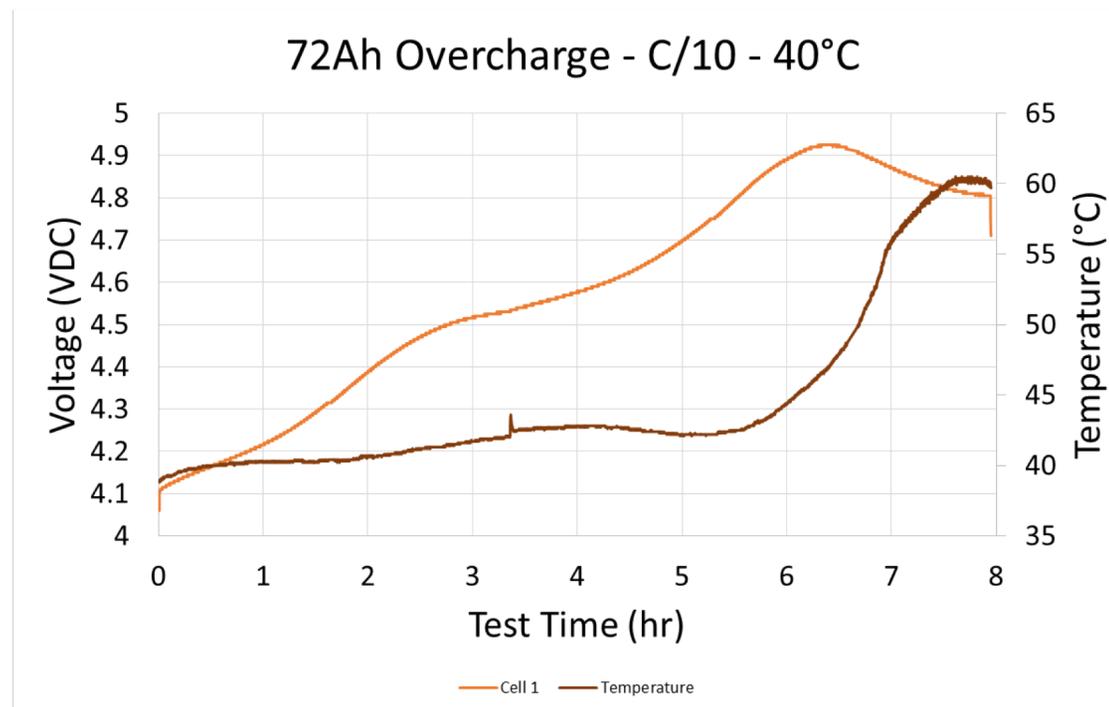
- Average Burst Pressure: 920 psi
- Average Vent Pressure: 181 psi
- Ratio is 5:1



Safety Testing: Overcharge

- Cells allocated from initial screening and environmental testing
- Cells tested at 20°C and 40°C
- C/10 charge rate
- Cells vented at approximately 3.5 – 4hrs into charge

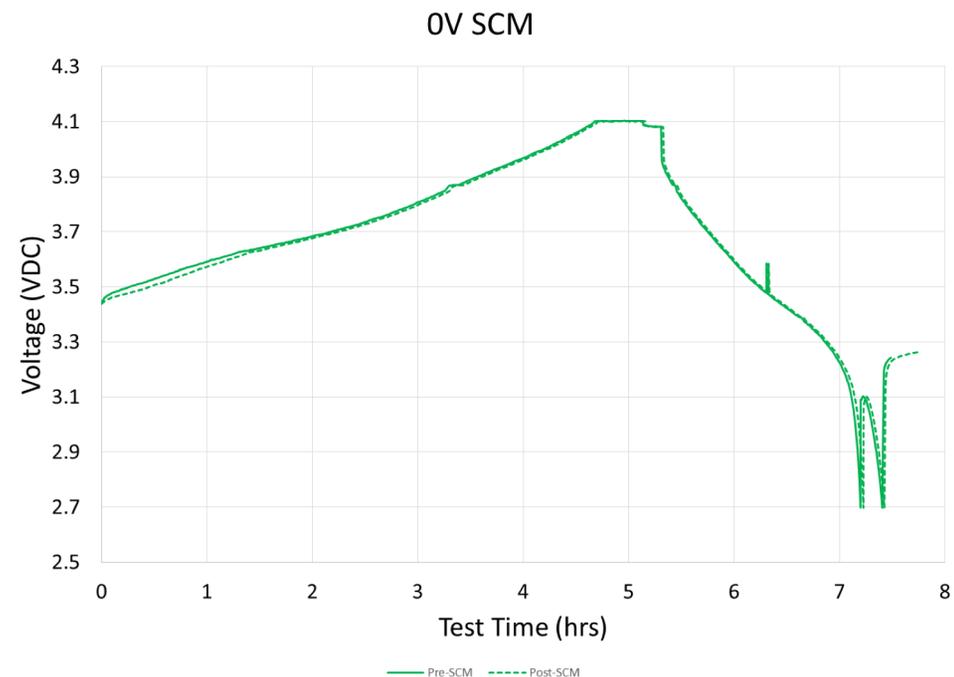
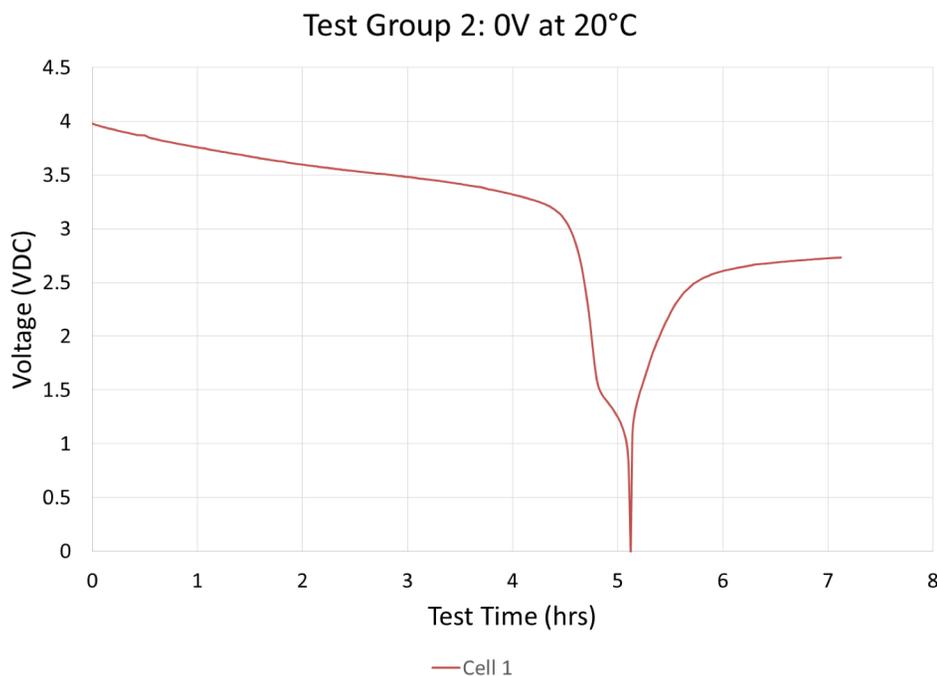
Cells Tested
5



Safety Testing: Over-Discharge 0V & 1.5V

- 4 Cells Over-discharged to 1.5V
- 4 Cells Over-discharged to 0V
- Pre and Post test capacity measurements conducted
 - 100% retained capacity
- Cells to continue with Life Testing

Cells Tested
8

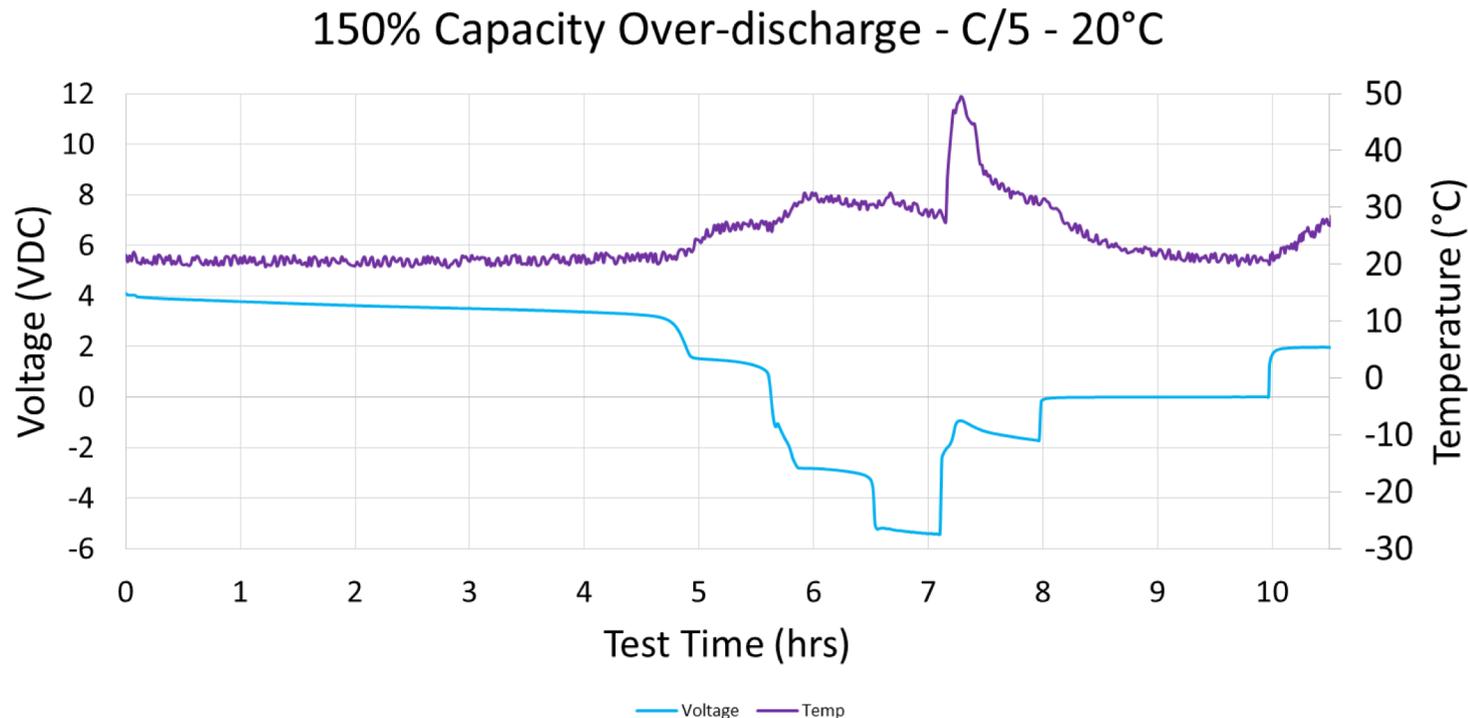


Safety Testing: 150% Capacity Over-Discharge

- Cells allocated from initial screening and environmental testing
- All cells resulted in vent activation

Cells Tested

4



Qualification Status

- Qualification report to be released Q1 2019
- Completed Tests:
 - Electrical Characterization
 - Environmental Testing
- Upcoming/Ongoing Tests:
 - Life Tests ongoing:
 - » Abused Cells Life testing
 - » Environmental Life Testing
 - Destructive Parts Analysis (DPA)
- Testing in progress:
 - 20°C Overcharge testing 25% complete, ECD end of year