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Qualification of GS Yuasa Large Format Li-ion Cells for Space

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- Brief Introduction of GS Yuasa Lithium Power (GYLP)
- Li-ion Cell Qualification Approach
- Qualification Testing of the LSE190
- Upcoming Qualification Programs



GS Yuasa Organization Overview



Powering the Next Generation



Japan Storage Battery Co., Ltd



GS Yuasa Corporation



Yuasa Battery Manufacturing

GS Yuasa Organization Milestones in Lithium Ion:

- Li-ion battery development began in 1985
- Production of commercial Prismatic lithium-ion batteries begins in 1993
- LSE Space cell Development timeline:
 - 1st Generation cell design locked in 1998
 - 2nd Generation cell design locked in 1999
 - 3rd Generation cell design locked in 2009

GS Yuasa 2009 Sales: USD 2.6 billion



Thermal Batteries



Ni-MH



Large-sized Li-ion



Traction Batteries



Stationary Batteries



Automotive Batteries

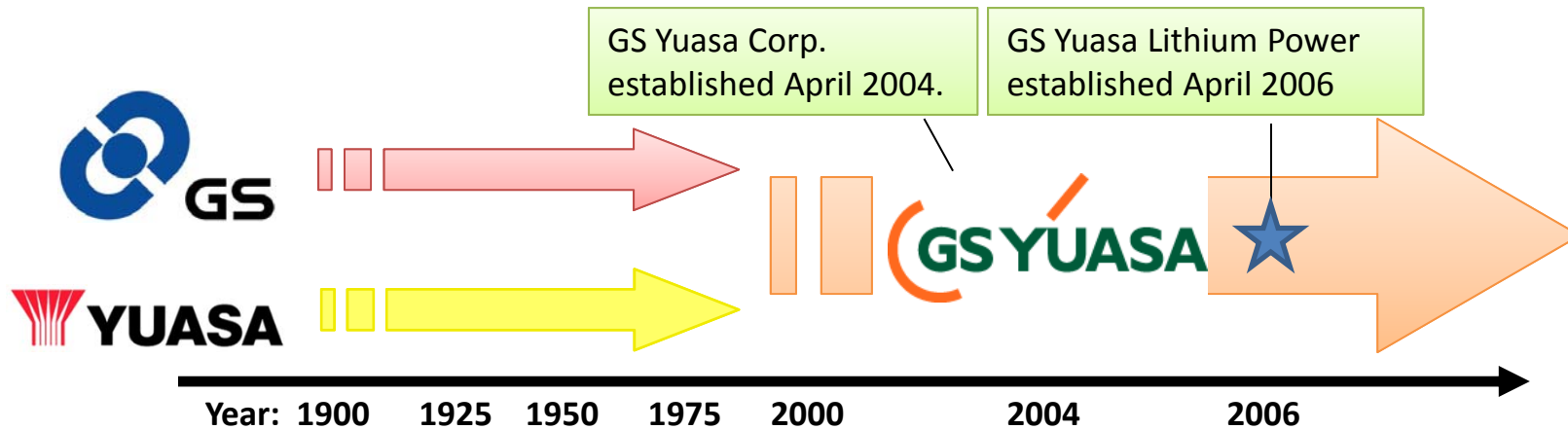


Motorcycle battery

GS Yuasa Lithium Power, Est. 2006



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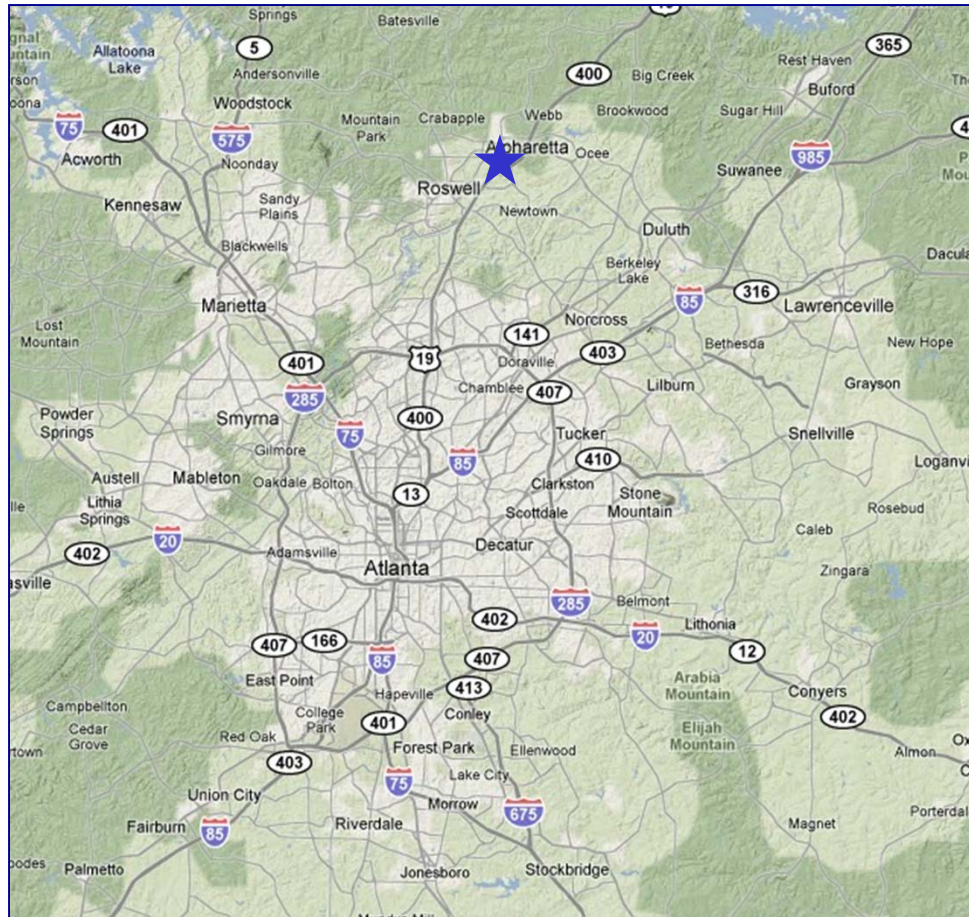
GS Yuasa Lithium Power's (GYLP) Mission:

- Provide sales and support of GS Yuasa's lithium-ion offerings to North American Customers.
- Provide cell and battery level engineering solutions
- Program Management
- Logistics & Export Compliance
- Cell and Battery Testing
- Quality System ISO9001:2008 & AS9100:2009
- Battery Assembly

GS Yuasa Lithium Power, Roswell, GA Facility



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Engineering and manufacturing facility is located in the city of Roswell, Georgia.

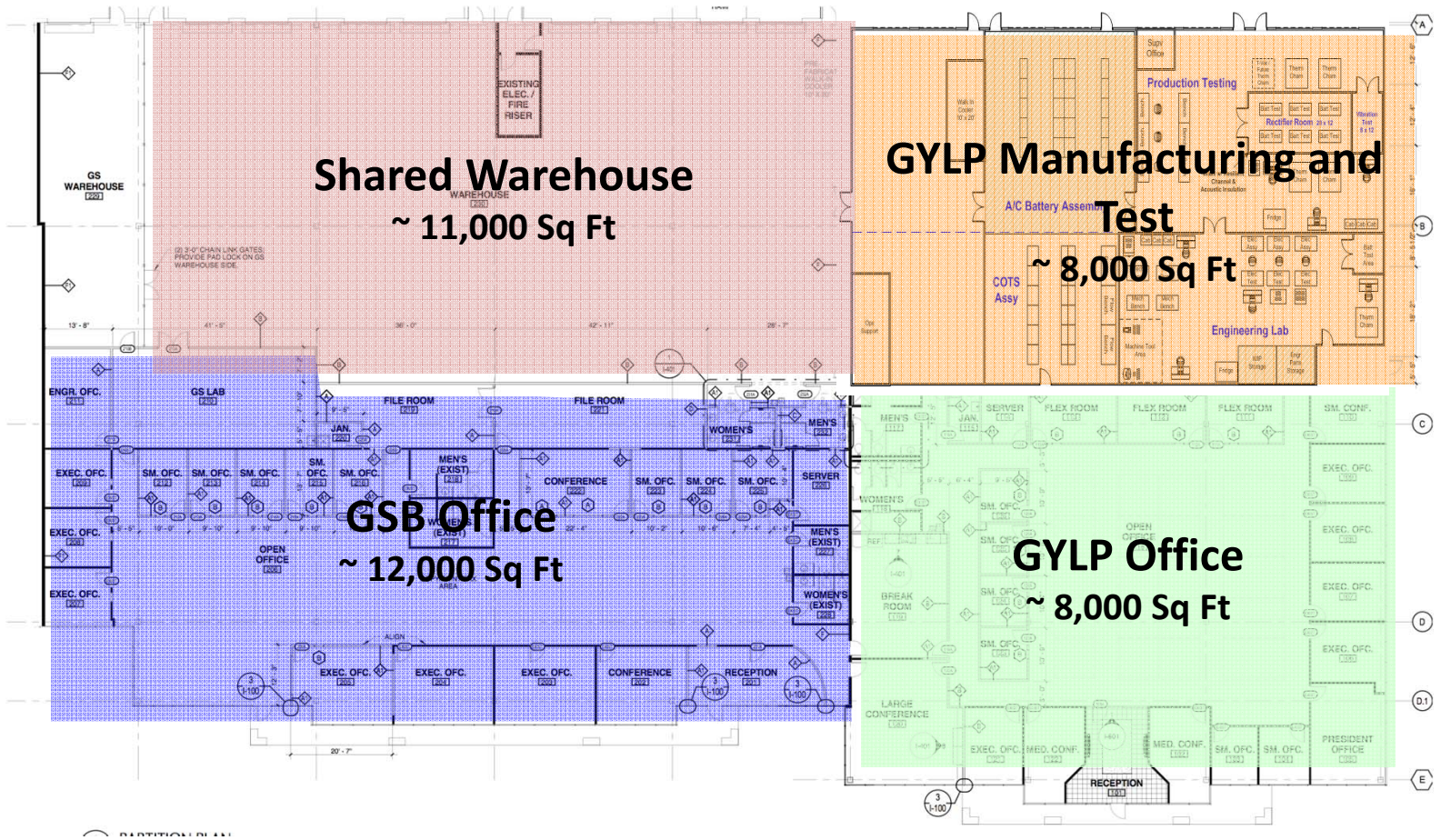


GS Yuasa Lithium Power, Roswell, GA Facility



Powering the Next Generation

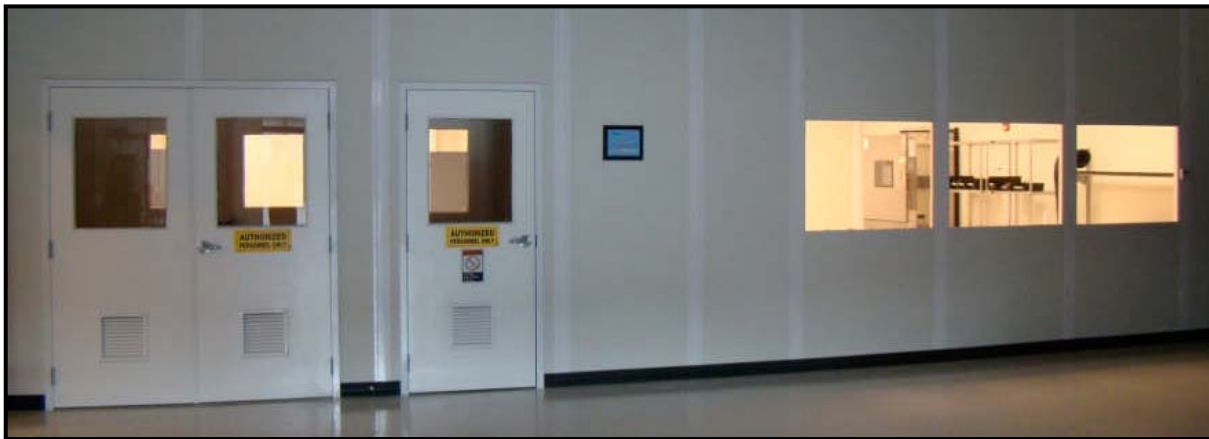
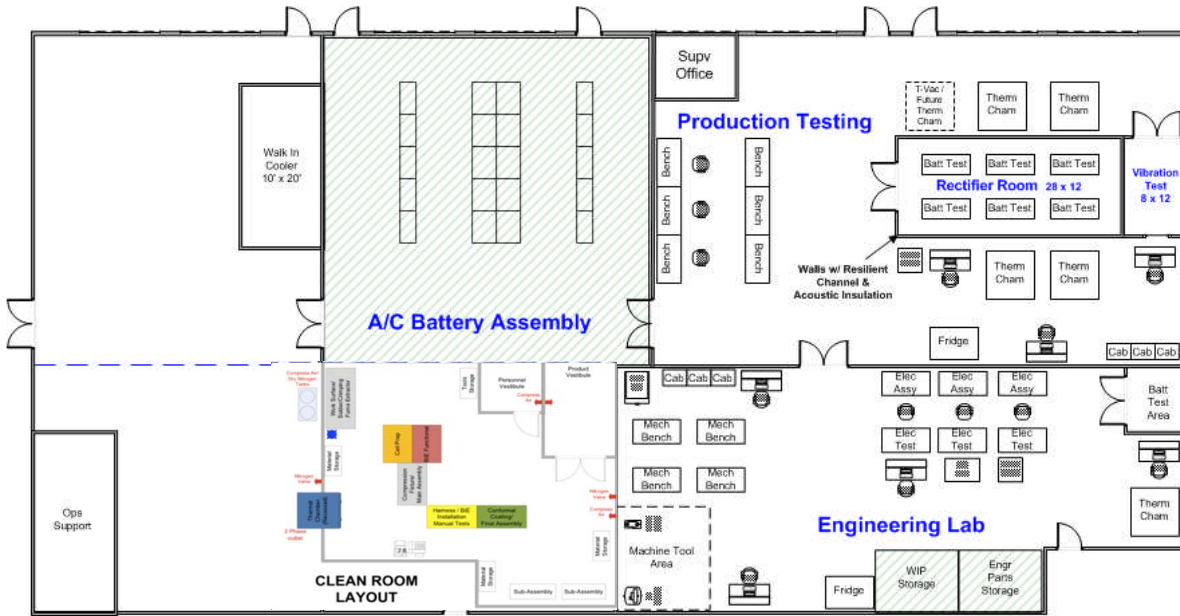
Total building area: 40,465 sq. ft.
GS Yuasa Lithium Power office is co-located next to GS Battery USA, our sister company.
Warehouse is also available for future expansion



GS Yuasa Lithium Power, Roswell, GA Facility



Powering the Next Generation



GS Yuasa Lithium Power, Roswell, GA Facility



Powering the Next Generation



- Bitrode 50V-250A
- Bitrode 5V-100A
- Thermal Chamber [32 ft³]
- Thermal Chamber Small
- Vibration Test [8800 lbf, 17600 lbf]
- Vacuum Chamber
- Class 100K clean room
- Walk-in Refrigerator



History and Approach of GS Yuasa Qualification Programs

GS Yuasa has Managed and Executed Several Unique Qualification Programs

Space Cell Type	Number of Qualification Programs
50Ah	4
100Ah	5
145Ah	1
175Ah	2
190Ah	2
Specialty Size	1
Total Qualification Programs	15

- All qualification programs performed at Kyoto Facility
- Includes LEO and GEO Programs
- US and Foreign Customers

Successful qualification has enabled numerous successful missions

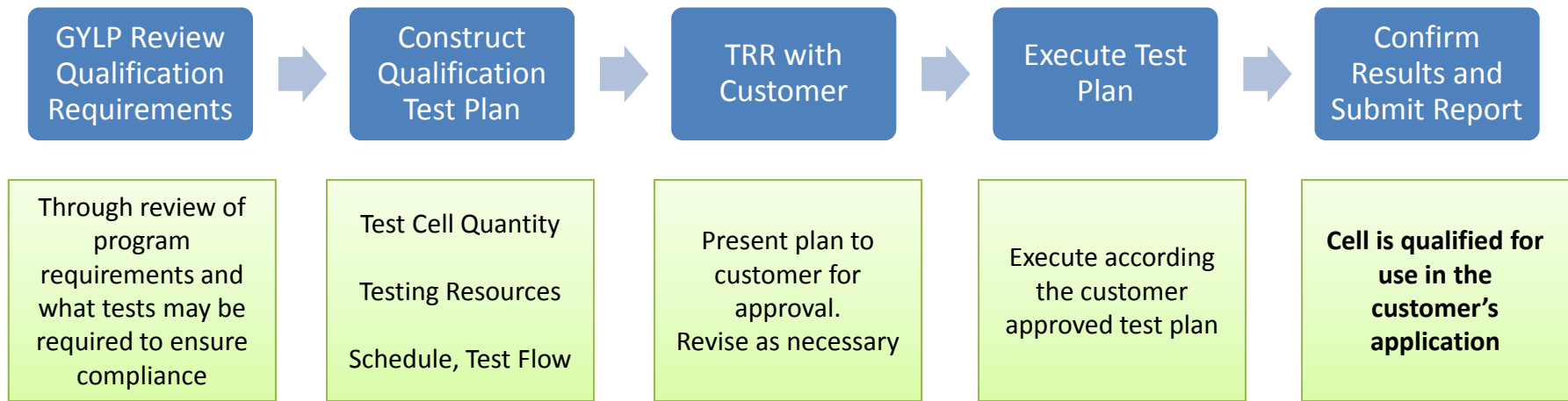
Satellites		Cells On-Orbit		Wh On-Orbit	
Flown (2003-Oct-2011)	To Be Flown in 2011	Flown	To Be Flown in 2011	Flown	To Be Flown in 2011
51	11	2,377	364	1,030,391	136,708
By End of Calendar Year 2011					
62		2,741		1,167,099	



Cell Qualification Approach for USA Customer



Powering the Next Generation



LSE190 Cell Qualification Testing

Specification of LSE190 Cell



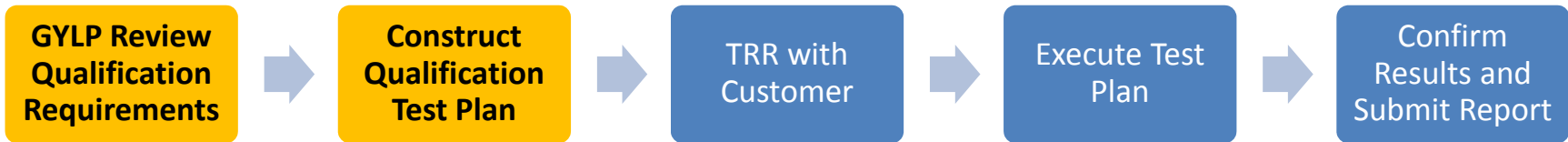
Powering the Next Generation

Item		Next generation cell, standard type	(Ref.) Heritage cell (Gen. 2)
		190Ah cell	175Ah cell
Dimension / mm	Height *	263	263
	Width	165	165
	Thickness	50	50
Mass* / kg		4.62	4.65
Capacity / Ah	Nominal	205	183
	Rated	190	175
Specific energy / Wh/ kg	Nominal	164	146
	Rated	152	139
Note		Same size as 175Ah cell	—

Review Requirements and Create Test Plan

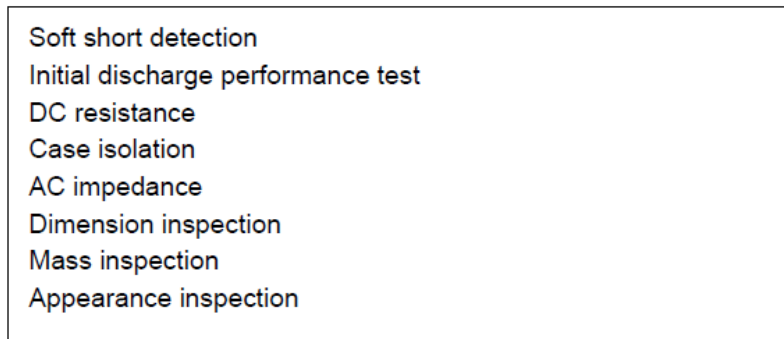


Powering the Next Generation

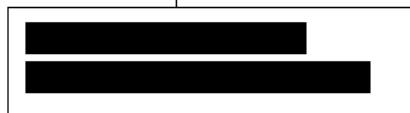


1 Test flow for LSE190's QM cells

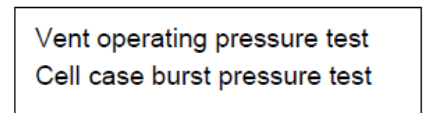
Initial inspection test



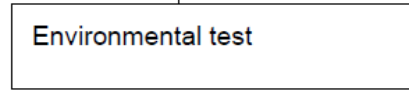
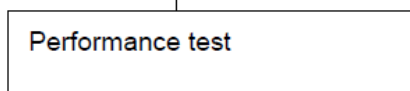
Acceptance test



Lot Acceptance test

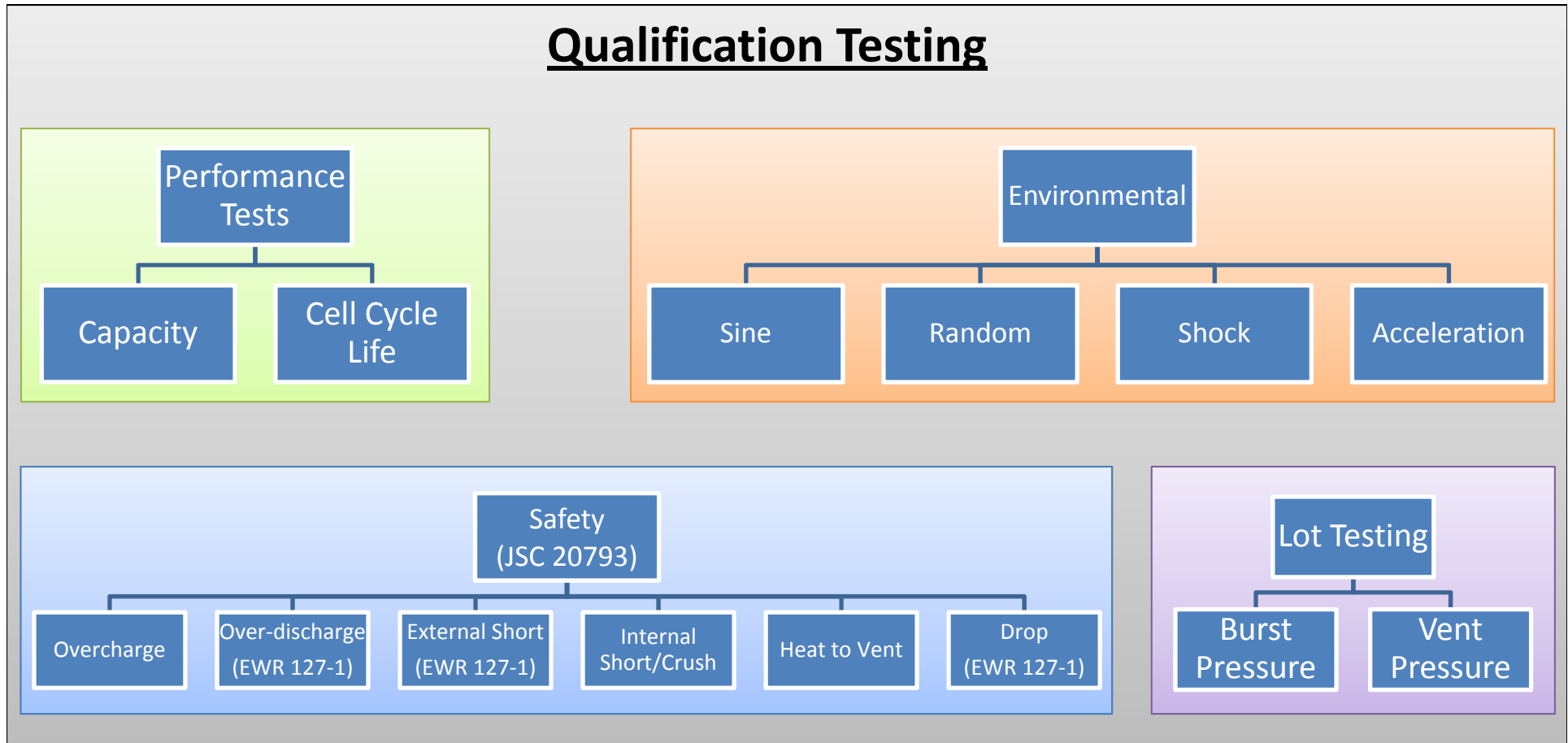


Qualification test



Qualification testing is organized into four main test areas

Qualification Testing



Create Test Schedule



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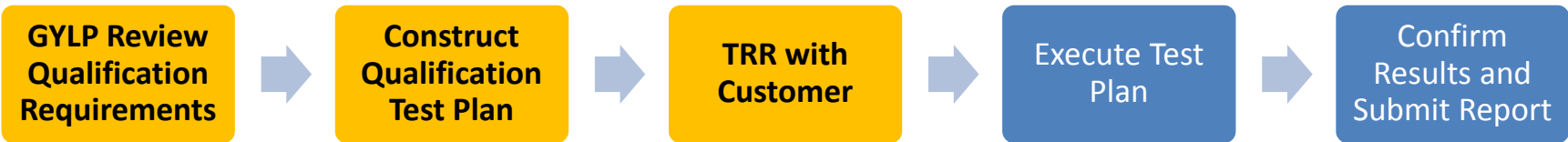
Test item		1 st week	2 nd week	3 rd week	4 th week	5 th week	6 th week	7 th week	8 th week	9 th week	10 th week	11 th week	
Initial performance test	Soft short detection (At 3.20V)	█											
	Initial discharge performance test		█										
	DC resistance		-										
	Case isolation		-										
	AC impedance		-										
	Dimension inspection		-										
	Mass inspection		-										
	Appearance inspection		-										
Acceptance test	█		█	█	█								
Lot Acceptance test	Vent operating pressure test					█							
	Cell case burst pressure test					█							
Qualification test	Performance test			█	█	█							
	Cycle life test						█	█	█	█	█	█	
	Environmental test	Sine vibration					█						
		Random vibration						█					
		Shock							█				
		Acceleration								█			
	Safety test	Overcharge								█			
		Overdischarge									█		
		External short										█	
		Internal short / Crush											█
		Heat to vent											█
Drop													█

Test schedule is subject to change by test department's situation.

Review Qualification Procedure with Customer



Powering the Next Generation

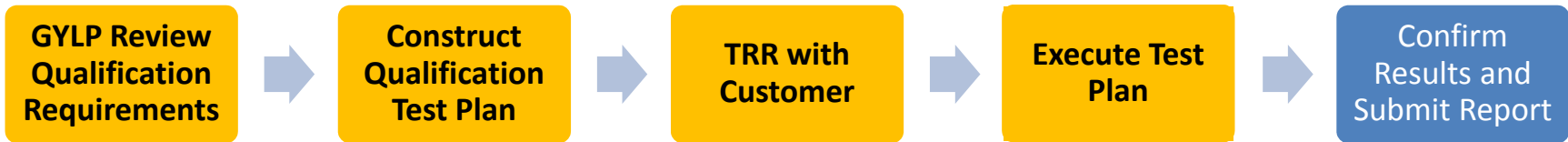


Test schedule, flow, procedures are presented to the customer for approval...

Review Qualification Procedure with Customer



Powering the Next Generation



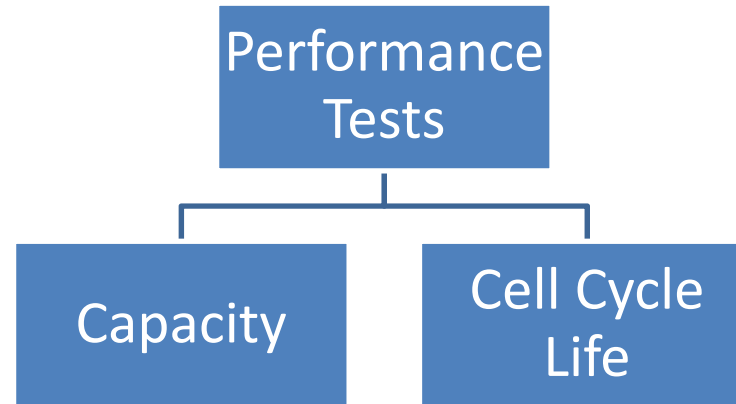
Test schedule, flow, procedures are presented to the customer for approval...

***Authority to Proceed
Granted***



Execute Test Plan

Performance testing designed to baseline the cell characteristics at various conditions.



LSE190, Discharge Performance



Powering the Next Generation

Requirement: Demonstrate discharge capacity at various temperatures.

Test Procedure

Step	Operation	Type	Current / A	Voltage / V	Time	Temp.
1	Charge	CC/CV	38	4.10	8 hours	At -10deg. C, 0deg. C, 20deg. C and 30deg. C (One cycle at each temp)
2	Rest	–	–	–	10 min or more	
3	Discharge	CC	38	2.75	–	
4	Rest	–	–	–	10 min or more	

Test cell	Condition / method
A-4, A-5, A-8 and A-10	(Effect of temperature) 1st cycle Charge: 0.2CA(38A), 4.1V, CC/CV, 8hr, -10 deg. C Discharge: 0.2CA(38A) to 2.75V, -10 deg. C 2nd cycle Charge: 0.2CA(38A), 4.1V, CC/CV, 8hr, 0 deg. C Discharge: 0.2CA(38A) to 2.75V, 0 deg. C 3rd cycle Charge: 0.2CA(38A), 4.1V, CC/CV, 8hr, 20 deg. C Discharge: 0.2CA(38A) to 2.75V, 20 deg. C 4th cycle Charge: 0.2CA(38A), 4.1V, CC/CV, 8hr, 30 deg. C Discharge: 0.2CA(38A) to 2.75V, 30 deg. C

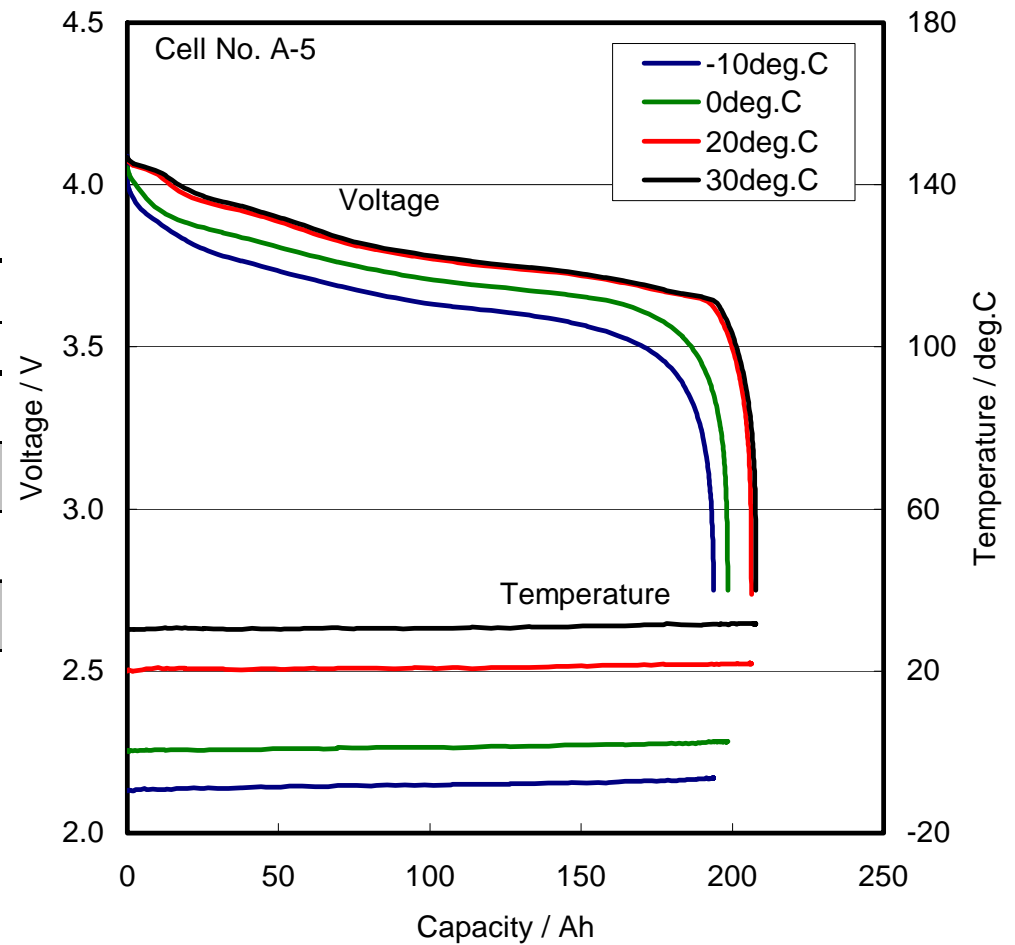
LSE190, Discharge Performance



Powering the Next Generation

Cell No.	Discharge capacity at different temperatures / Ah ⁻¹			
	-10deg.C	0deg.C	20deg.C	30deg.C
A-4	193.8	198.4	206.2	208.1
A-5	193.9	198.5	206.3	207.8
A-8	193.0	197.8	205.6	207.3
A-10	194.0	198.7	206.2	207.7

Capacity vs. voltage curve typical of LSE cells at test temperatures



Requirement: Demonstrate that the capacity retention of the LSE190 is comparable to similar GS Yuasa cell designs

Test Procedure

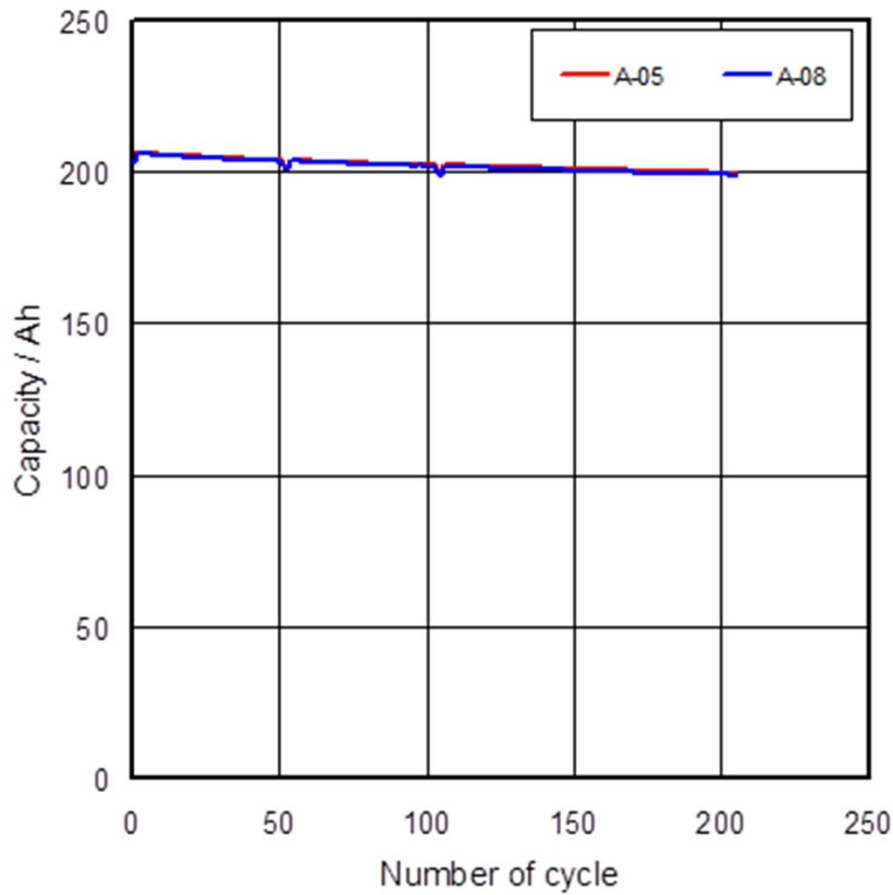
Test cell	Condition / method
S/N A-5 and A-8	(Cycle condition) Charge: 0.5CA(95A), 4.1V, CC/CV, 4hr, 25 deg. C Discharge: 0.5CA(95A) to 2.75V, 25 deg. C Number of cycle: 200 (Capacity check condition) Charge: 0.2CA(38A), 4.1V, CC/CV, 8hr, 15 deg. C Discharge: 0.2CA(38A) to 2.75V, 15 deg. C

LSE190 cell performance will be compared to the LSE110. This is also a next generation cell with the same electrode design in a smaller form factor.

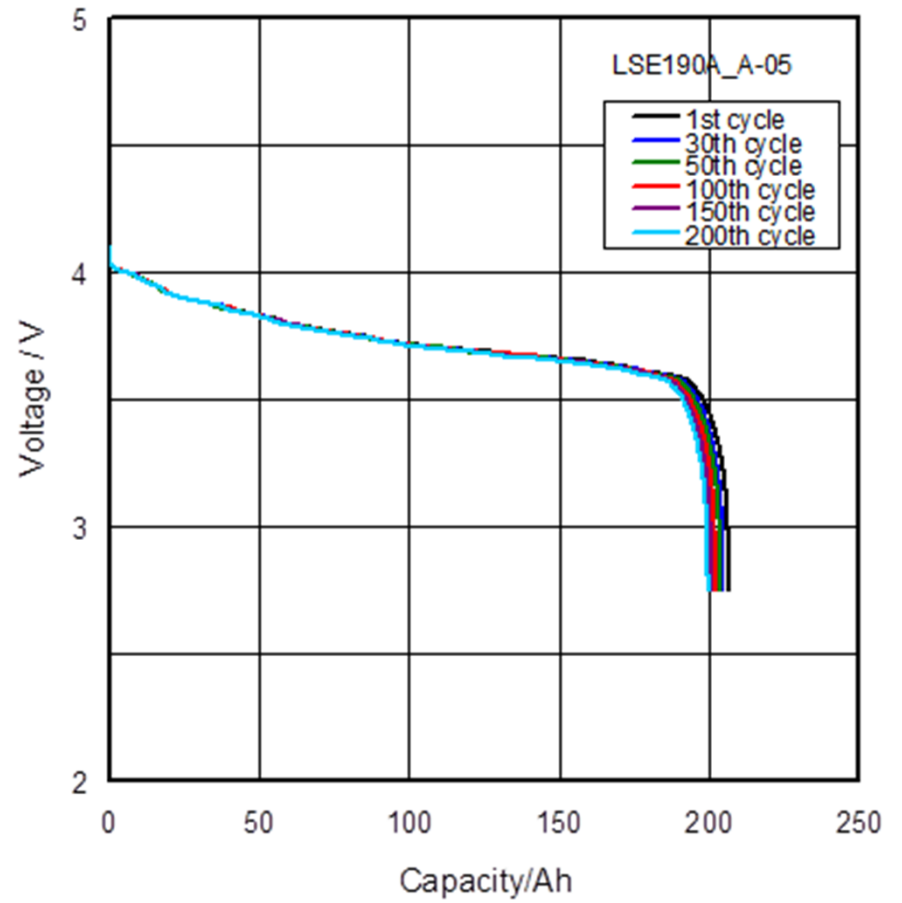
LSE190, Cycle Life Performance



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LSE190 Cell Capacity vs. Cycle



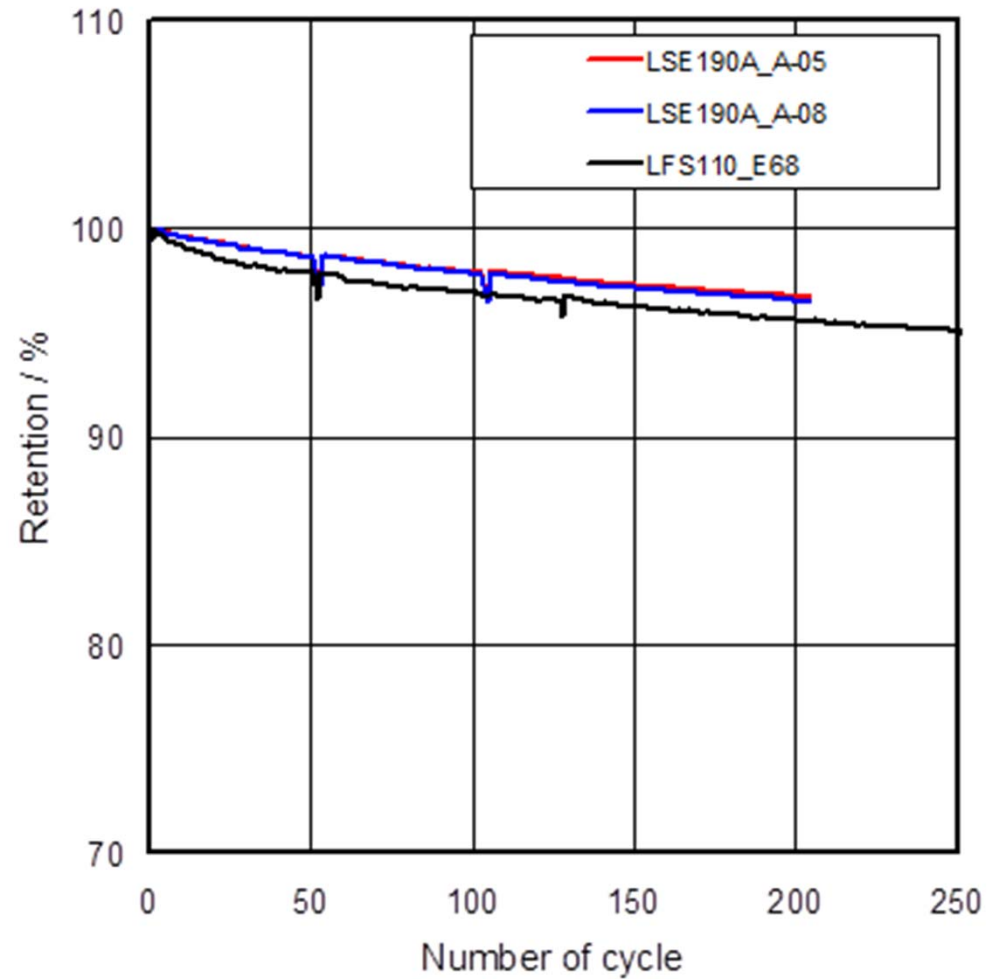
LSE190 Voltage Profile vs. Cycle

LSE190, Cycle Life Performance



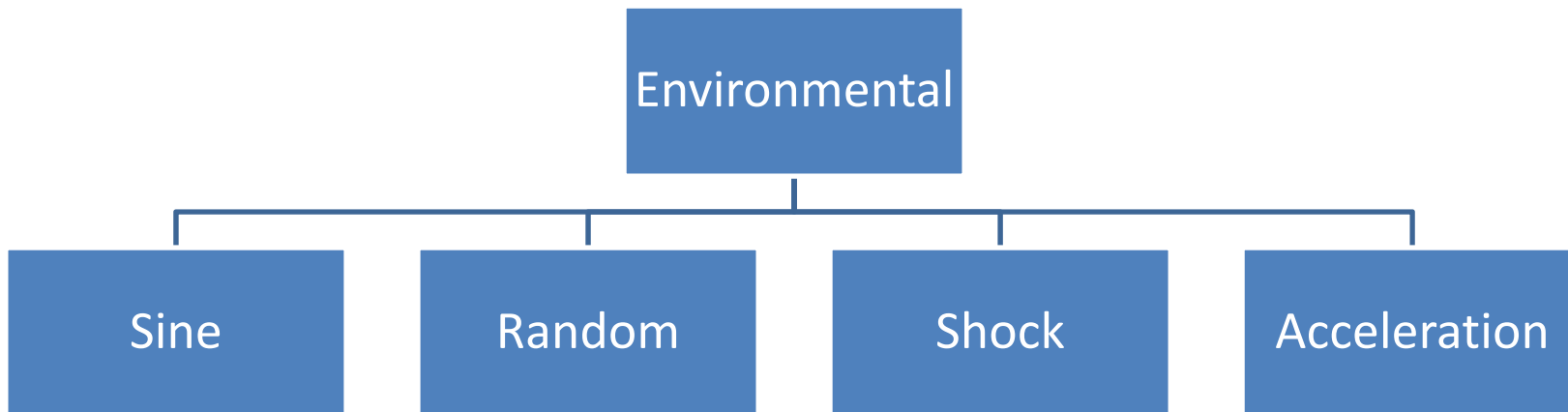
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LSE190 shows better capacity retention compared to the LSE110 next generation cell.



Retention Comparison to LSE110

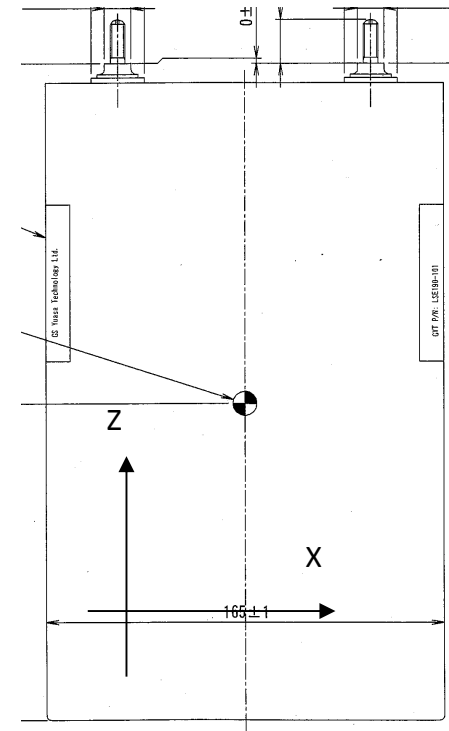
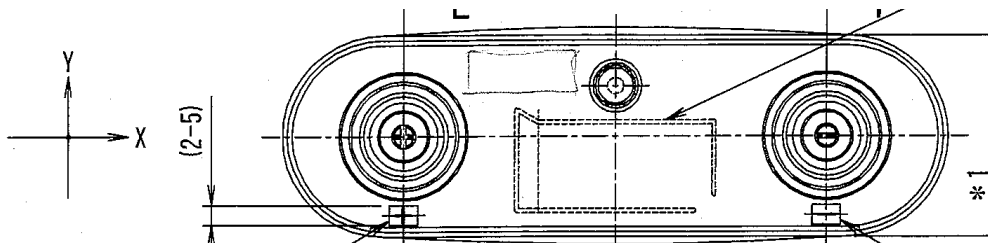
Environmental testing performed to confirm the ability of the cell to survive and perform in the application



GS Yuasa can perform the full suite of environmental tests for ensuring mission compliance

Test Sequence

Step	Operation
1	Capacity Check & SOC adjustment
2	Sine Vibration Test
3	SOC adjustment
4	Random Vibration Test
5	Capacity check & SOC adjustment
6	Shock Test
7	Capacity & SOC adjustment
8	Acceleration Test
9	Final Capacity Check



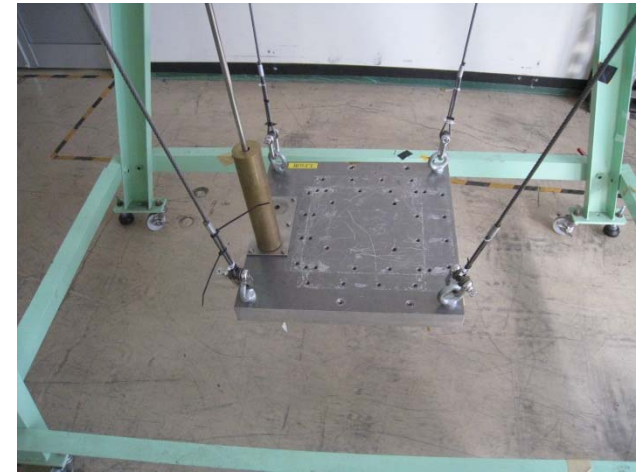
GYT Environmental Test Equipment



Powering the Next Generation



- Vibration Test:
Sine: 0.1-20kHz
Random: Max 20kHz
- Shock Test:
Accel: 29-166713m/s²
Time: 0.1-60ms
- Acceleration:
Accel: 2.4-240G
Max Weight: 30kg



Standard Environmental Testing Levels



Powering the Next Generation

Sine Vibration

Direction	Frequency (Hz)	Levels
Axial Direction (Z axis)	5~20	11mm
	20~30	18g
	30~70	20g
	70~100	15g
Radial Direction (X and Y axis)	5~16	11mm
	16~30	12g
	30~100	15g
Sweep Rate: 3 octave/minute		

Shock (Impact)

Frequency Range / Hz	Shock Response Spectra (Q=10)
100	20g
1300	1400g
10000	1400g
Tolerance: -6dB, Q=10	
Duration = 3 times per axis (positive and negative component, Total of 18 shocks)	

Random Vibration

Direction	Frequency / Hz	Levels	GRMS / g	Duration / min
X and Z axis	20~58	+6dB/octave	23.6	3
	58~700	0.5g ² /Hz		
	700~2000	-6dB/octave		
Y axis*	20~58	+6dB/octave	21.0	3
	58~700	0.395g ² /Hz		
	700~2000	-6dB/octave		

Acceleration

Direction	Level
±X, ±Y, ±Z	25G for 5 Min

Launch Vehicles Used

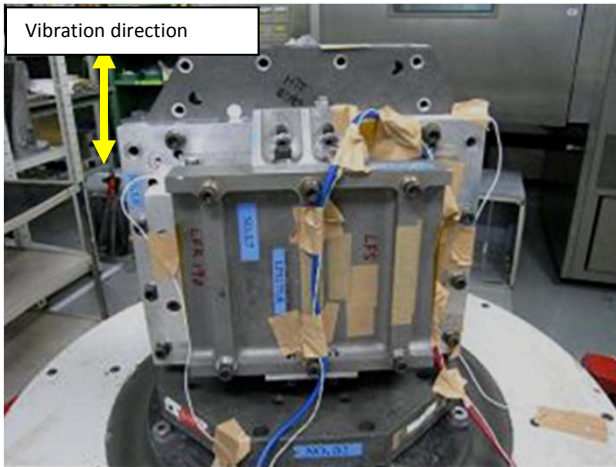
1	Ariane-5ECA
2	Ariane-5GS
3	Atlas-5
4	GSLV Mk 1(2)
5	H-2A-202
6	H-2B-304
7	Proton-M Briz-M
8	Rokot-KM
9	Soyuz-2-1 Fregat
10	Zenit-3SL

Sine Vibration

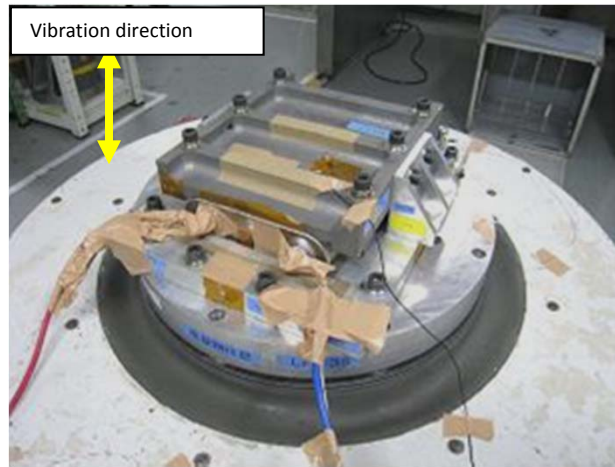
The cell is exposed to sine vibration along each major axis.

Cell is discharged at C/5 rate throughout the vibration event and voltage is monitored for anomalies.

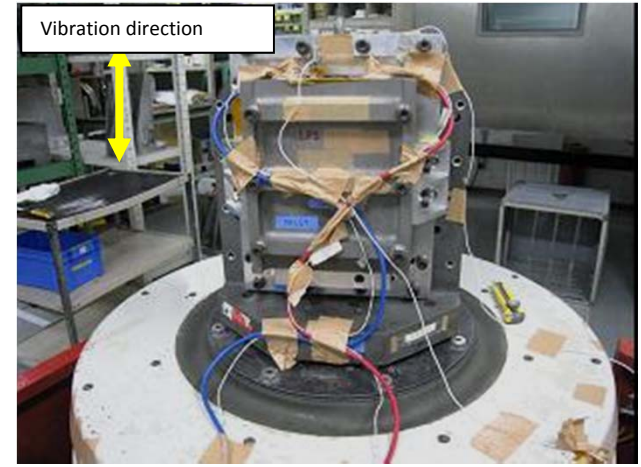
Direction	Frequency (Hz)	Levels
Axial Direction (Z axis)	5~20	11mm
	20~30	18g
	30~70	20g
	70~100	15g
Radial Direction (X and Y axis)	5~16	11mm
	16~30	12g
	30~100	15g
Sweep Rate: 3 octave/minute		



X-axis sine vibration

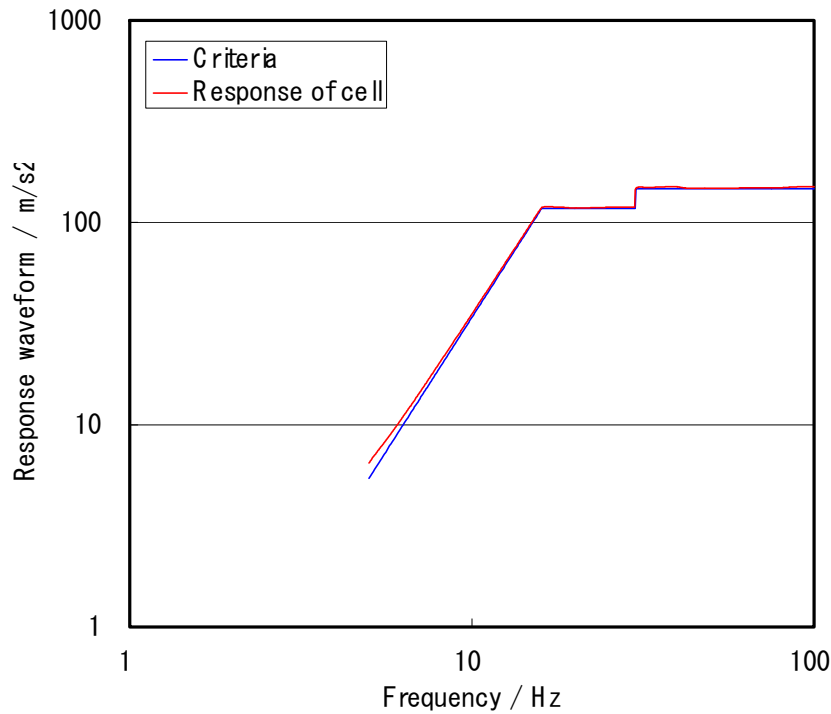


Y-axis sine vibration

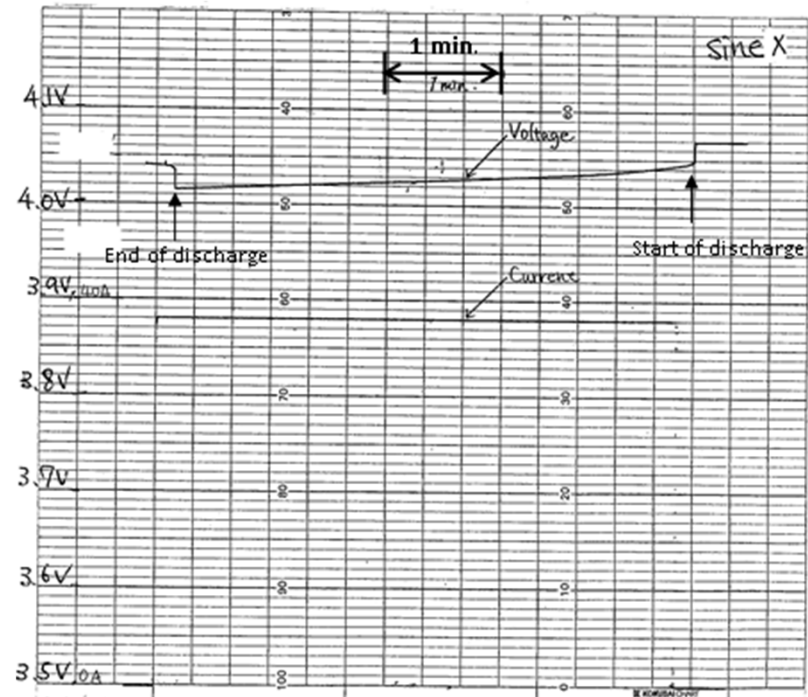


Z-axis sine vibration

Sine Vibration



Response of cell x-axis sine vibration



Voltage profile during x-axis sine vibration

Voltage profile shows no abnormal activity while exposed to the Sine Vibration environment.

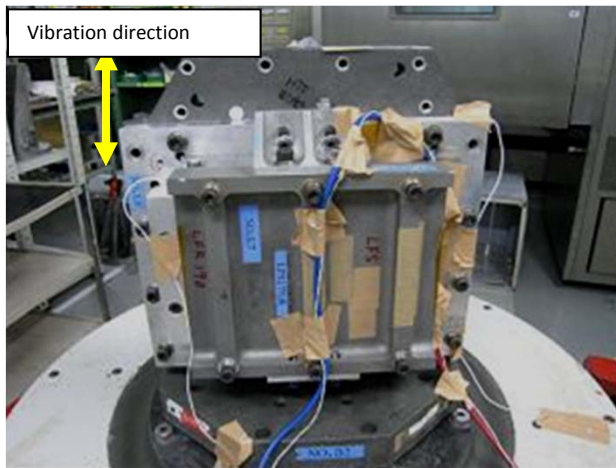
Random Vibration

The cell is exposed to random vibration along each major axis.

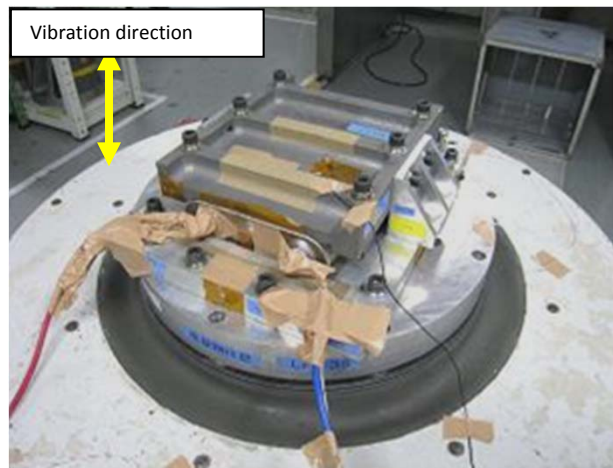
Cell is discharged at C/5 rate throughout the vibration event and voltage is monitored for anomalies.

Direction	Frequency / Hz	Levels	GRMS / g	Duration / min
X and Z axis	20~58	+6dB/octave	23.6	3
	58~700	0.5g ² /Hz		
	700~2000	-6dB/octave		
Y axis*	20~58	+6dB/octave	21.0	3
58~700	0.395g ² /Hz			
700~2000	-6dB/octave			

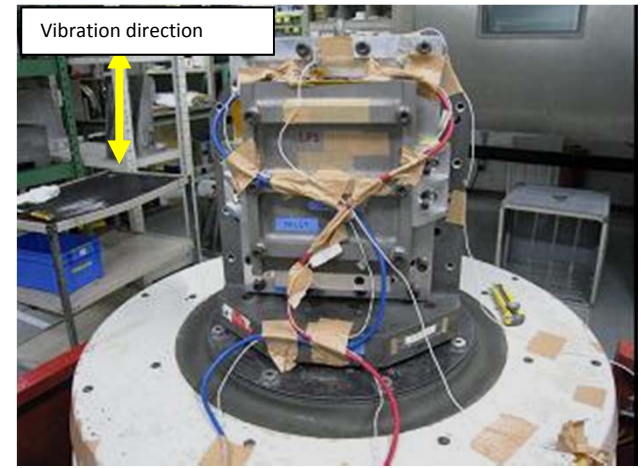
*Y-axis is reduced slightly due to machine limitations



X-axis random vibration

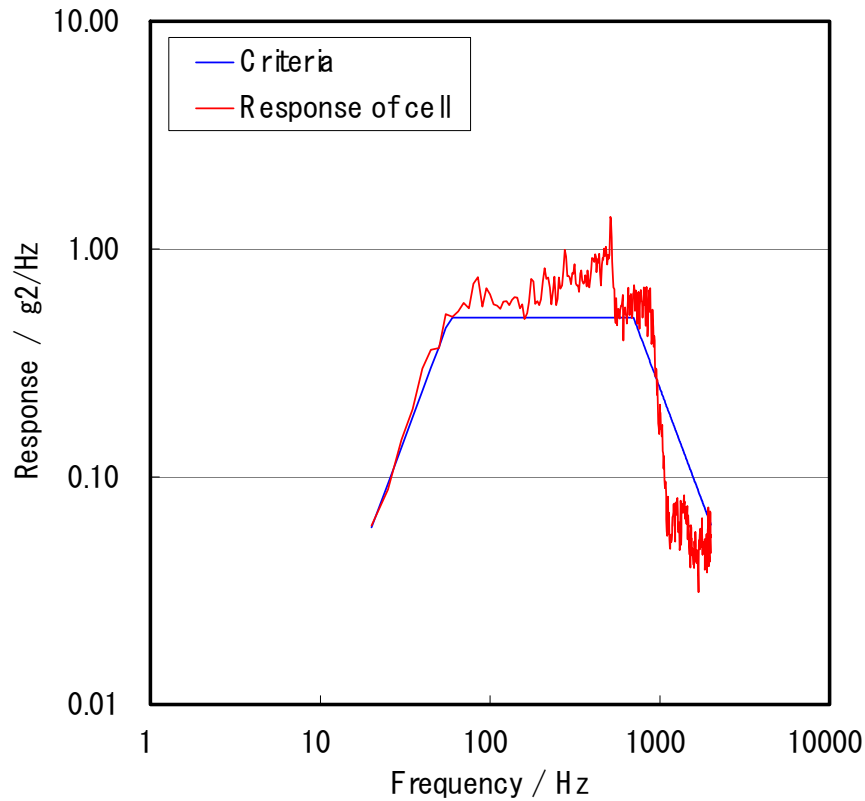


Y-axis random vibration

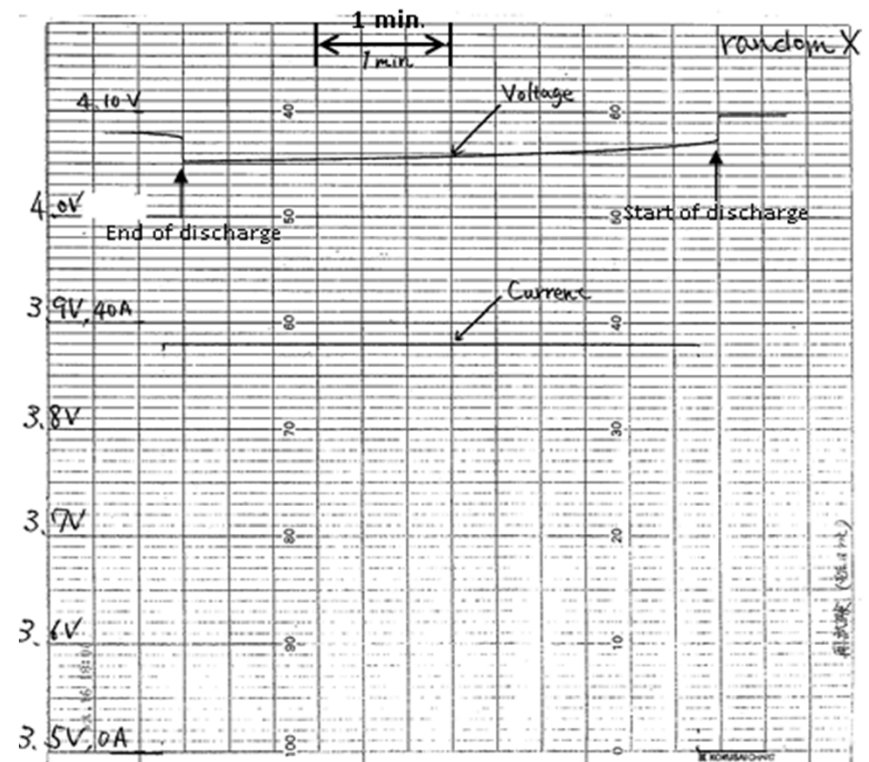


Z-axis random vibration

Random Vibration



Response profile during x-axis random vibration



Voltage profile during x-axis random vibration

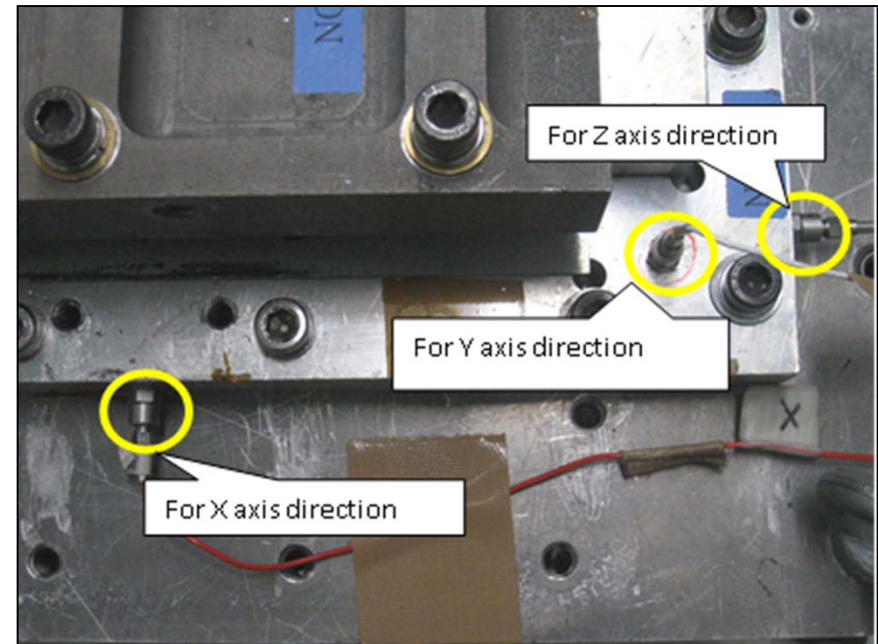
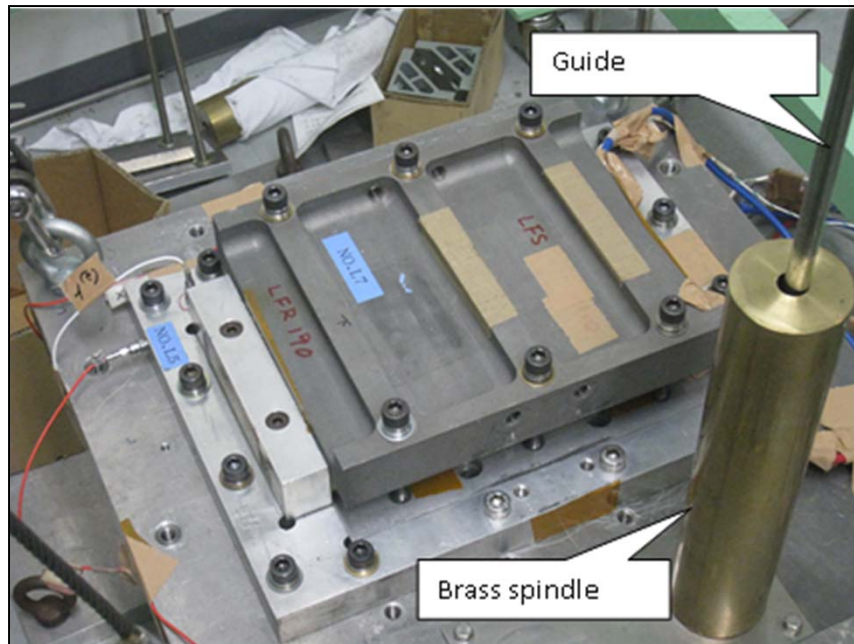
Voltage profiles show no abnormal activity while exposed to the random vibration environment.

Shock (Impact)

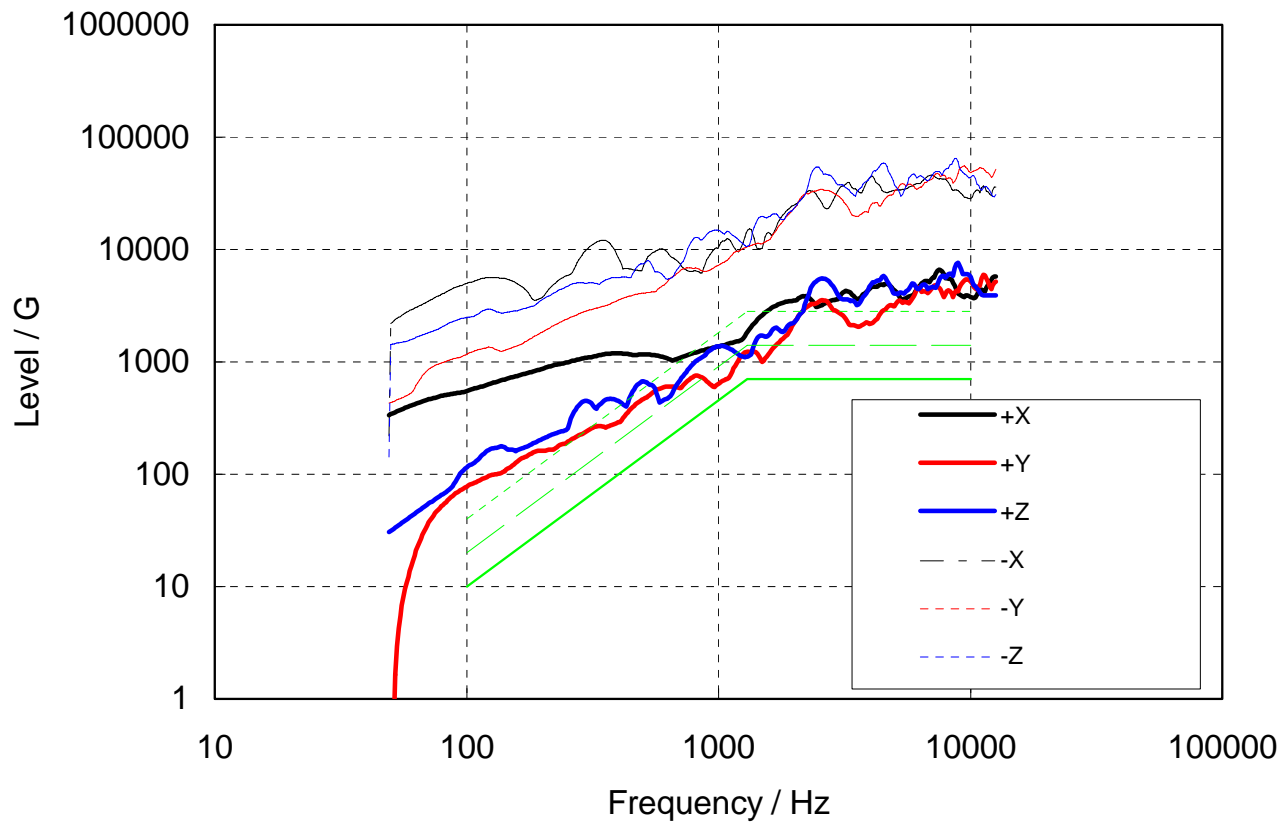
The cell is exposed to an impact shock profile.

Cell is discharged at C/5 rate throughout the shock event and voltage is monitored for anomalies.

Frequency Range / Hz	Shock Response Spectra (Q=10)
100	20g
1300	1400g
10000	1400g
Tolerance: -6dB, Q=10	
Duration = 3 times per axis (positive and negative component, Total of 18 shocks)	

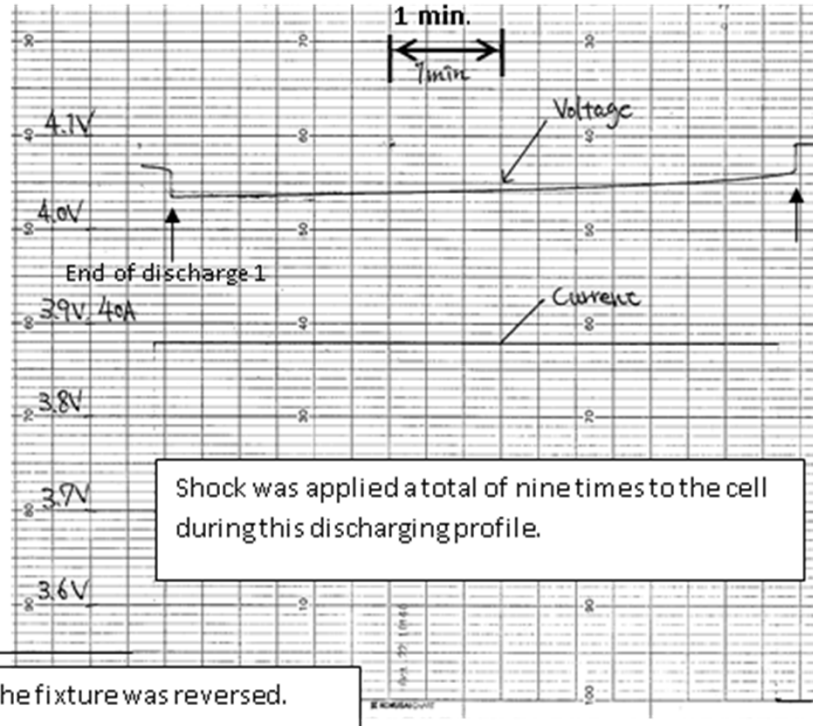
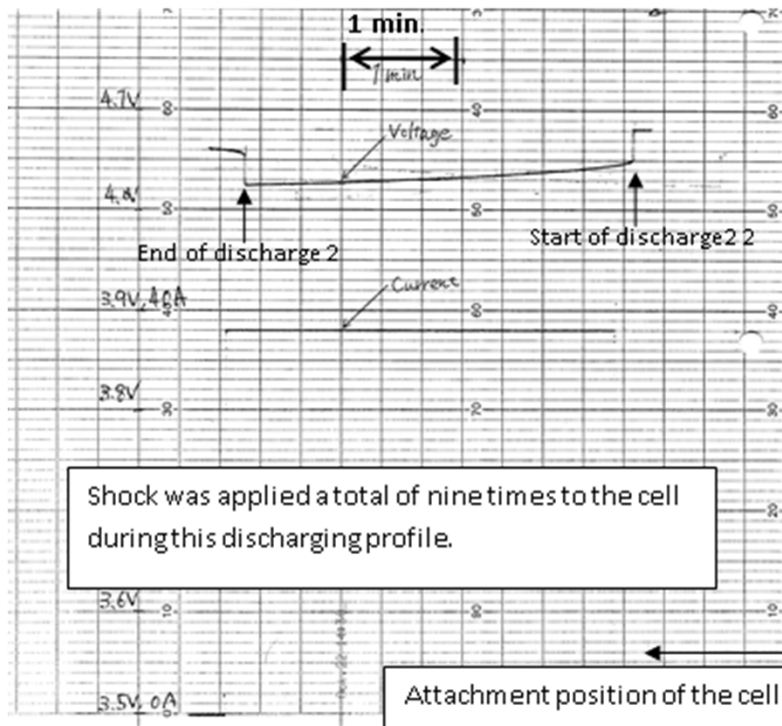


Shock (Impact)



Cell Response to Shock Profile

Shock (Impact)



Attachment position of the cell in the fixture was reversed.

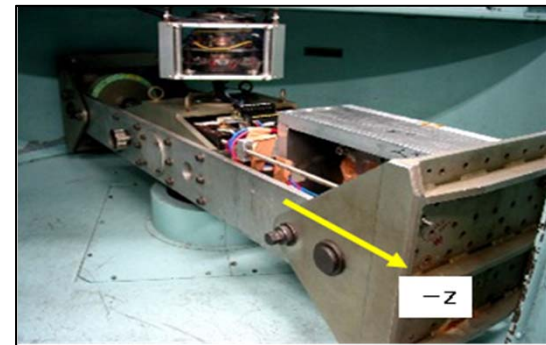
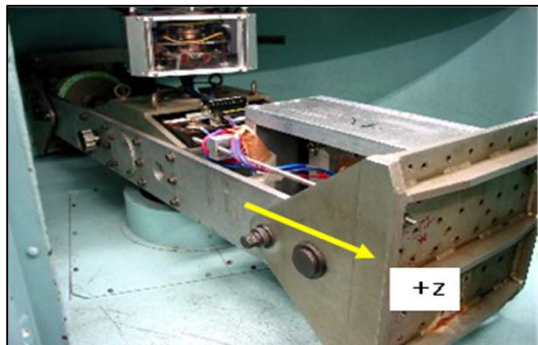
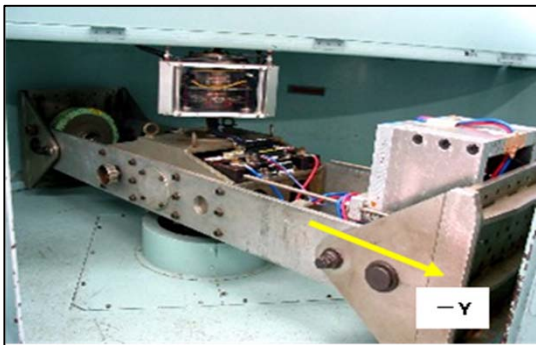
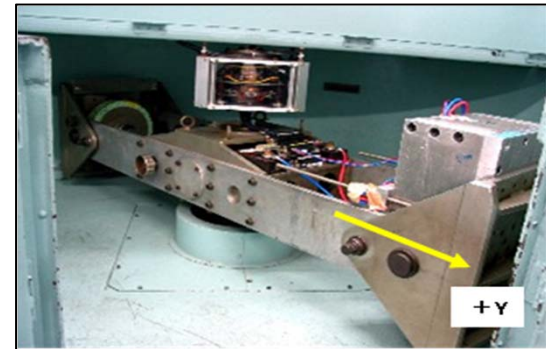
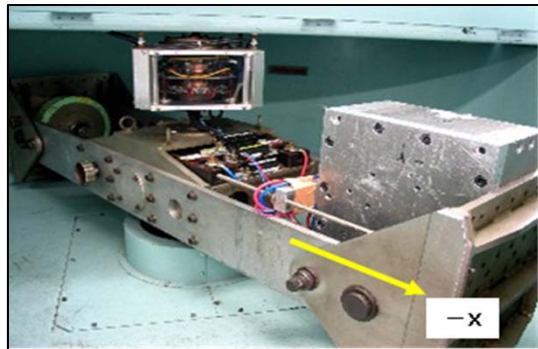
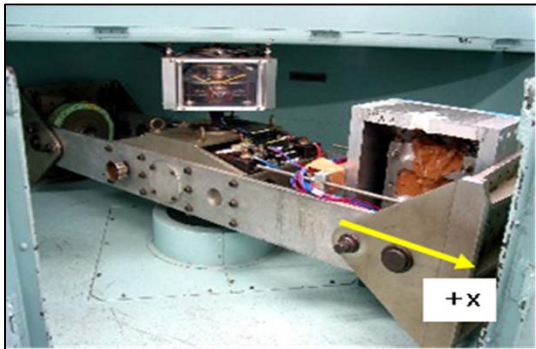
Voltage profiles show no abnormal activity while exposed to the Shock environment.

Acceleration

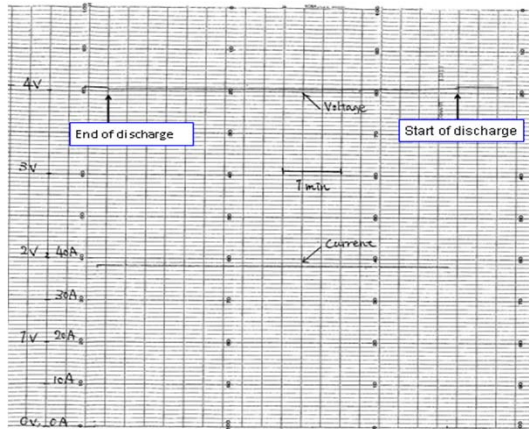
The cell is exposed to an acceleration profile.

Cell is discharged at C/5 rate throughout the shock event and voltage is monitored for anomalies.

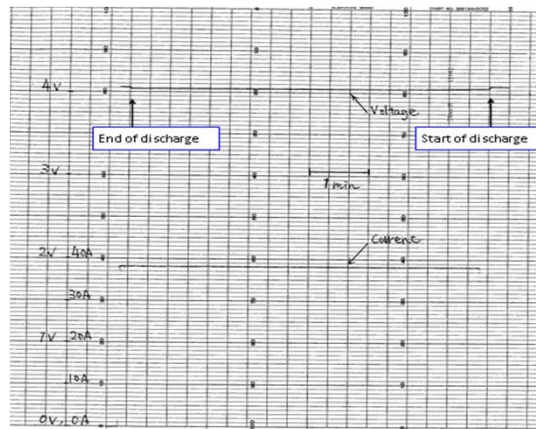
Acceleration Test	Level
$\pm X, \pm Y, \pm Z$	25G for 5 Min



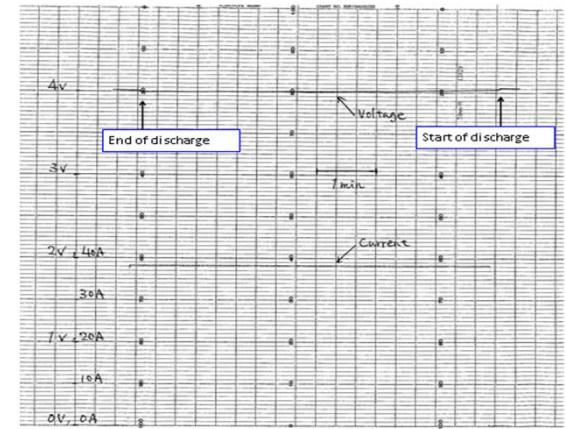
Acceleration



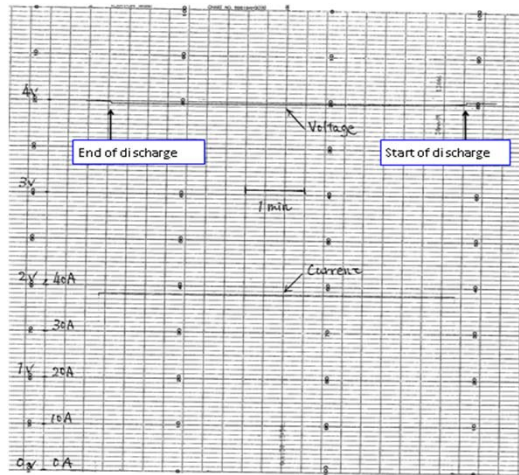
+X



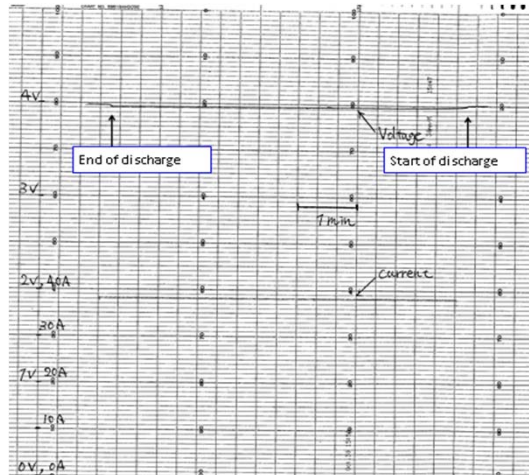
-X



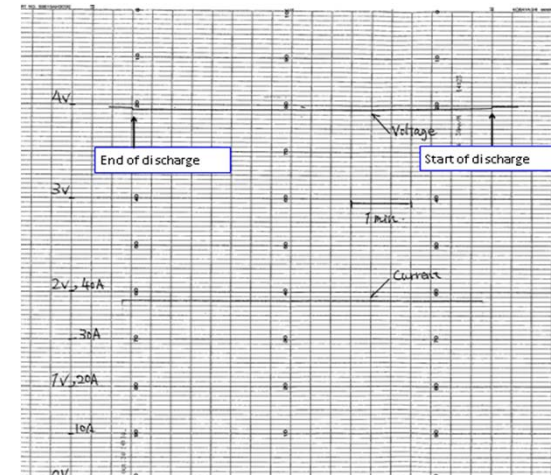
+Y



-Y



+Z



-Z

Voltage profiles show no abnormal activity while exposed to the acceleration environment.

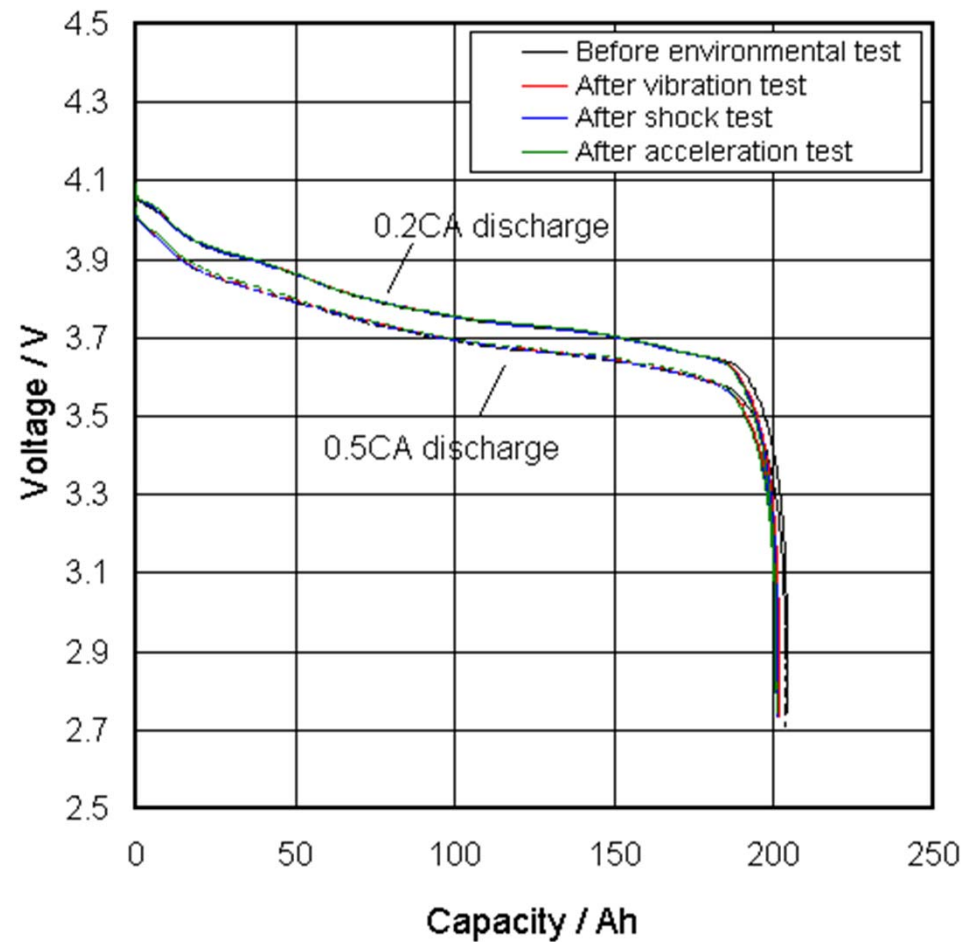
Environmental Capacity Results



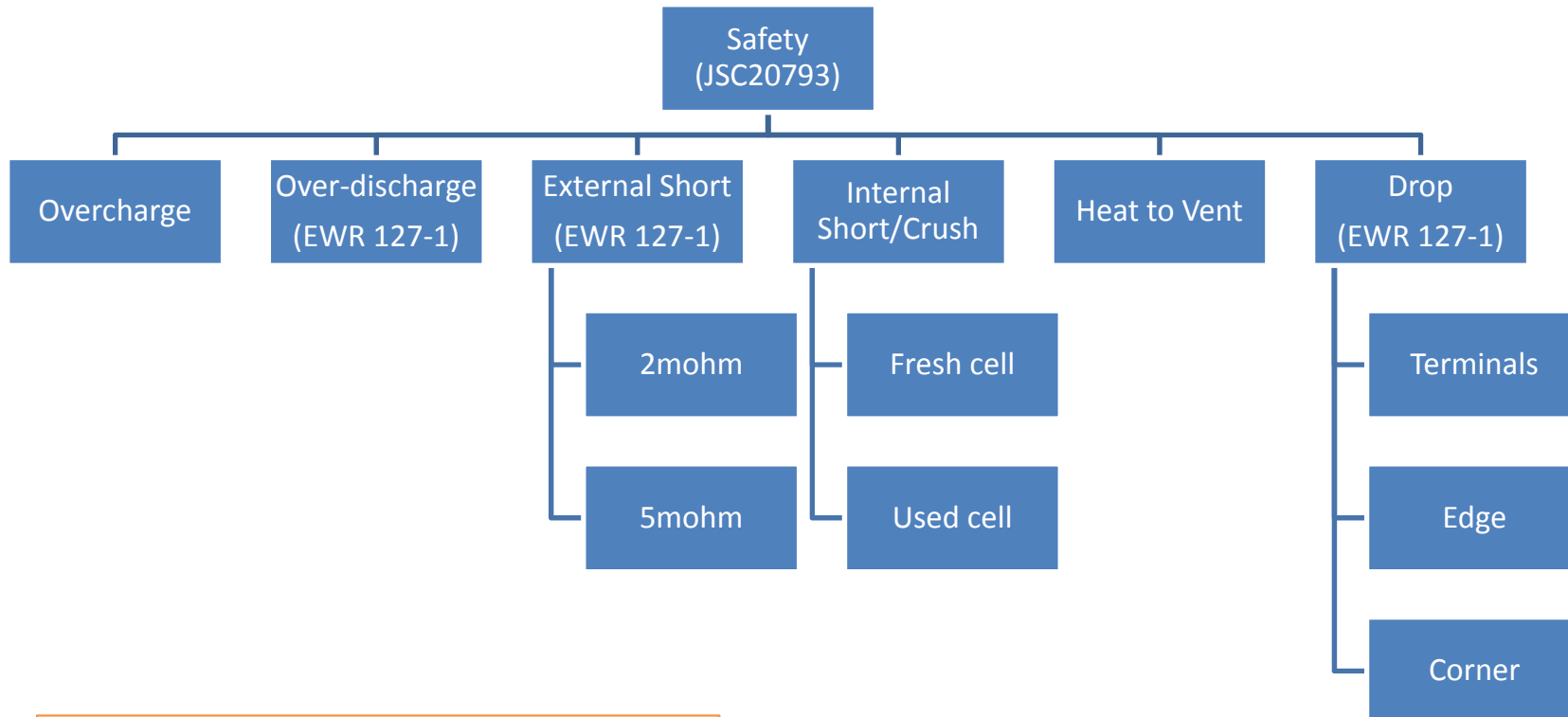
Powering the Next Generation

Discharge performance before, between, and after the environmental tests is compared.

Chart shows that cell performance is unaffected by the vibration suite.



LSE190 is tested according to the recommendations found in JSC 20793



Each test consumes (1) LSE190 cell

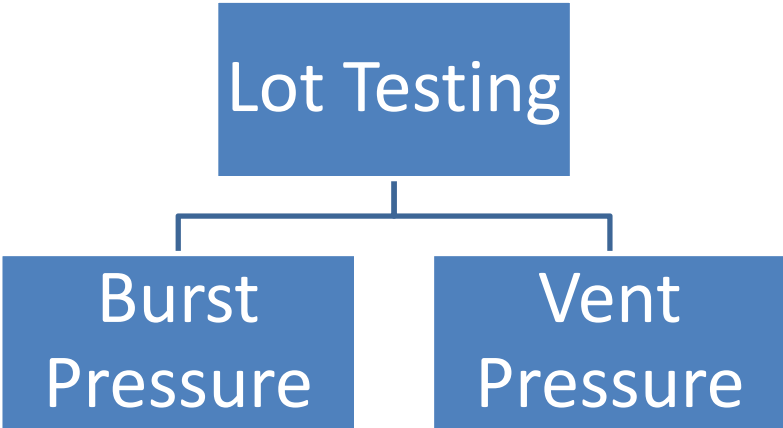
Safety Testing Results Summary



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Cell Safety Qualification Tests (JSC 20793)	Overcharge		Cell did not vent. Cell voltage reached 4.7 volts after electricity equal to 154 Ah was charged above 100% SOC. No significant temperature increase was observed during overcharge.
	Over-discharge (Forced Discharge)		Cell did not vent. Cell acts as a resistor due to short circuit caused by copper dissolution.
	External short	2 milliohm	Cell did not vent. Fuse function engaged about 6 seconds after the short circuit. A current of about 1400A was monitored until fuse function engaged.
		5 milliohm	Cell did not vent. A current of about 650 A was monitored throughout the test. Cell was discharged to 0 V, Condition did not cause fuse function to operate.
	Internal short / Crush	Fresh cell	Cell did not vent. Deformation of the cell observed where the weight hit.
		Used cell	Cell did not vent. Deformation of the cell observed where the weight hit
	Heat to vent		Cell vented when cell temperature reached to approximately 145 degrees C. A small amount of gas was emitted from the cell. Approximately 10 minutes after the venting, fire emission was monitored.
	Drop	Terminal	Cell did not vent. Deformation was observed around terminals.
		Edge	Cell did not vent. Tiny scratches were formed around the edge of the cell.
		Corner	Cell did not vent. Scratches were formed along the corner of the cell.
	Vent Pressure		Vents used for LSE190-101 Flight lot comply with operational range
Burst Pressure		Cell Case demonstrated to burst at 3.25MPa	

Lot testing consists of confirmation of the vent operational pressure and case burst pressure absent a vent.



Lot Testing, Vent Pressure

LSE190 has two vent features:

- Cover-plate
- Case

- 100% of the vents from a lot are measured for thickness of the machined channel.
- The vents with the maximum and minimum remaining material thickness are selected for testing to bracket the vent lot operational pressure.

Cell Case Lot Number	Results (MPa)	Cover Plate Lot Number	Results (MPa)
2009030024-1	1.47	2009030049-3	1.28
2009030024-1	1.71	2009030049-3	1.60
2009040014-3	1.39	2009050029-1	1.30
2009040014-3	1.68	2009050029-1	1.50
2009040014-3	1.38	2009050029-2	1.30
2009040014-3	1.68	2009050029-2	1.50
2009030024-2	1.46	2009030049-3	1.28
2009030024-2	1.71	2009030049-3	1.60
2008090032-4	1.36	2009060054-1	1.44
2008030032-4	1.75	2009060054-1	1.53
2008090032-5	1.36		
2008090032-5	1.75		
2009040014-4	1.38		
2009040014-4	1.68		

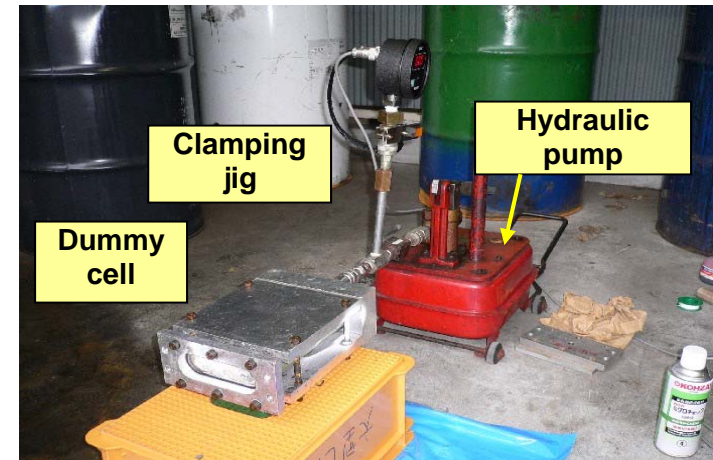
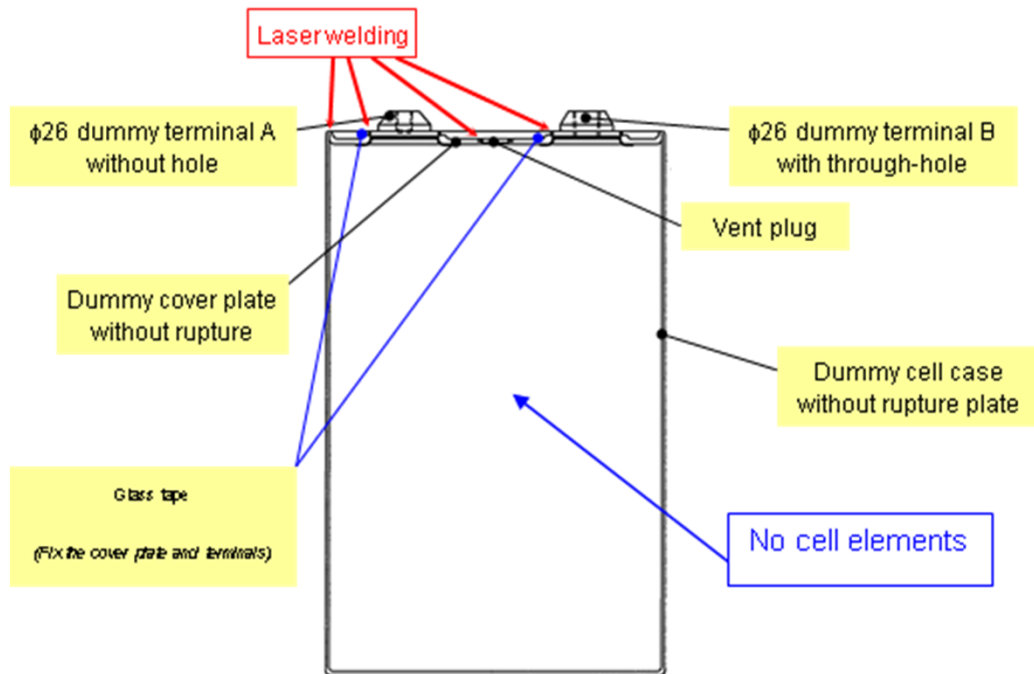
Acceptance Criteria	
Upper Limit (MPa)	2.0
Lower Limit (MPa)	1.0



LSE Cover plate vent relief feature

Lot Testing, Burst Pressure Test

Cell case and cover plate without machined vents is used for burst pressure test.
All appropriate cell features are laser welded according to the approved GYT procedures.



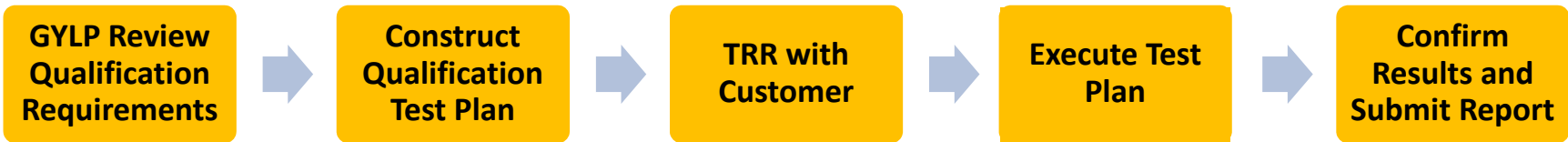
Impact lot No.	Burst test result / MPa
20 03 19	3.25

Acceptance Criteria	
Minimum Pressure (MPa)	3.0

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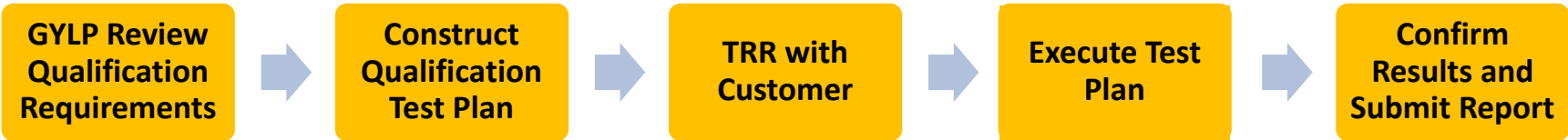


Summarize the data and provide to customer

Submit Report



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Summarize the data and provide to customer



**LSE190 Next Generation GEO Cell
Approved for Service**

LSE145 – Next Generation GEO Type
LSE134 – Next Generation LEO Type



- GS Yuasa is proficient in the Planning, Management, and Implementation of a Li-ion Cell Qualification program.
- Through the use of a standard suite of severe internally developed qualification tests it is possible to envelope most mission requirements.
 - This enables quick turnaround on the planning and execution of qualification programs.
 - Limits the need for special export licenses
- GS Yuasa has the test resources available to perform the full complement of Qualification tests and does not need to contract.

Thank You
Questions?