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A proposal for the LiB Safety Risk Assessment

through CTIA Battery Certification Program

Nov. 14, 2017

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PCTEST Engineering Laboratory

PCTEST ***Battery Safety & Reliability Lab.***

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Motivation

Why the certified products (Cell, pack, Charger, Host Device System) have so many field incident issues.

Certification has a “Pass or Failure Criteria”, but that is not enough to evaluate the latent safety risk of a cell model; especially for a new model cell, which initiate new technologies.

Each cell design and components of cell have different mechanism of deformation, degradation or failure process; need a safety risk assessment to identify the latent safety risk of a new cell model.

Some of them are system integration issues; need system base safety risk assessment.

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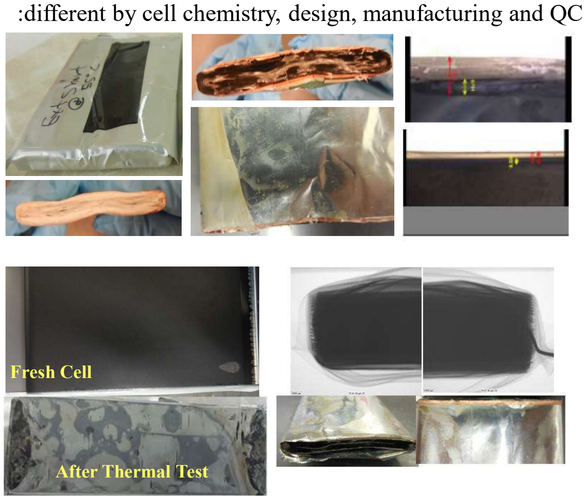
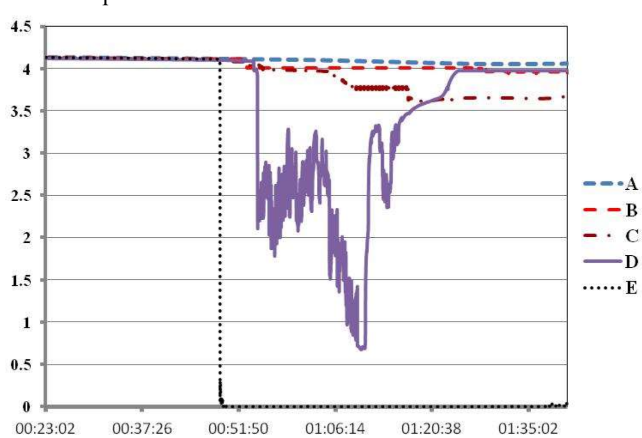
Motivation - 2

Study the mechanism of LiB cell deformation, degradation or failure by the cell abuse/abnormal Testing

Cell deformation, degradation or failure mechanism:
:different by cell chemistry, design, manufacturing and QC



Cell voltage changes during cell thermal test:
: All 5 cell models are pass the criteria of the compliance of the standard and certifications.



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Battery Risk Assessment Method and Process

2. Object

Develop a LiB's safety risk assessment tool for a cell model of the IEEE 1625/1725 battery certification by using the modified Risk Priority Number of the FMEA.

3. Process and Procedure

- Add additional evaluation criteria of the test pass/fail criteria and quantify the test result.
- Calculate the Severity and Occurrence of each test item of a cell.
- Calculate the Criticality (=Severity x Occurrence) of a cell combining all test items.
- Calculate the Protection from the insulation status of the cell.
- Calculate Risk Priority Number.(Criticality of cell x Protection of a cell)
- Analyze the safety & reliability level of a cell from the Risk Priority Number

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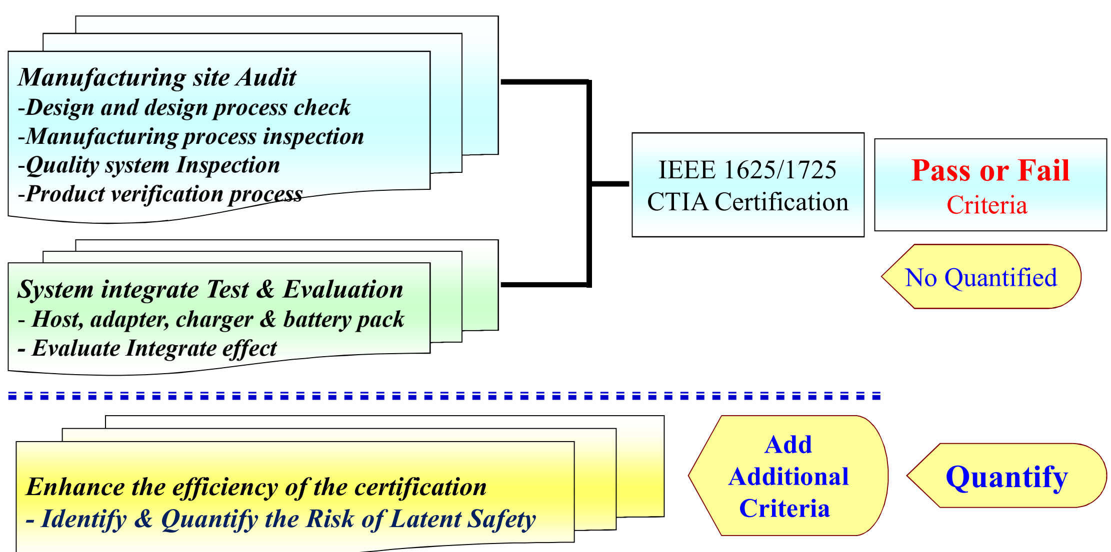
Battery Safety Risk Assessment Process - 1

Minimize or prevent battery field issues by eliminate a latent safety risk battery



Battery Safety Risk Assessment Process- 2

Introduction of FMEA (Failure Mode & Effects Analysis) -1

http://www.qimacros.com/free-lean-six-sigma-tips/fmea.ht

Potential
Failure Mode and Effects Analysis
(Process FMEA)

AIAG Fourth Edition http://www.aiag.org/

Item	Name/number of item	Process Responsibility:	Name
Model Years	model years/programs	Key Date:	07/15/08
Core Team:	Team members		

FMEA Number	Insert FMEA#
Page	1 of 1
Prepared by:	who
FMEA Date:	07/15/08

Process Step / Requirements	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Class	Potential Cause(s) / Mechanism(s) of Failure	Occurrence	Current Process Controls Prevention	Current Process Controls Detection	Detection	R.P.N.	Recommended Action(s)	Responsibility & Target Completion Date	Action Results: Actions Taken & Completion Date	Action Results: Severity	Action Results: Occurrence	Action Results: Detection	Action Results: R.P.N.
Name, Part Number, or Class Function	Manner in which part could fail: cracked, loosened, deformed, leaking, oxidized, etc.	Consequences on other systems, parts, or people: noice, unstable, inoperative, impaired, etc.			List every potential cause and/or failure mechanism: incorrect material, improper maintenance, fatigue, wear, etc.		List prevention activities to assure process adequacy and prevent or reduce occurrence.	List detection activities to assure process adequacy and prevent or reduce occurrence.		0	Design actions to reduce severity, occurrence and detection ratings. Severity of 9 or 10 requires special attention.	Name of organization or individual and target completion date	Actions and actual completion date				0
										0							0
										0							0
										0							0

Potential failure Mode / Potential Effective of Failure : Severity / Class
Potential Cause/Mechanism of Failure : Occurrence
Current process Detection/ Prevention: Detection
RPN (Risk Priority Numbers) = Severity x Occurrence x Detection

Battery Safety Risk Assessment Process- 3

Modified FMEA RPN (Risk priority number) = (C x P) of the quantified test and evaluation result From the certification

		Rating	Meaning
Criticality	Occurrence	1	No known occurrences on similar products or processes
Criticality	Occurrence	2/3	Low (relatively few failures)
Criticality	Occurrence	4/5/6	Moderate (occasional failures)
Criticality	Occurrence	7/8	High (repeated failures)
Criticality	Occurrence	9/10	Very high (failure is almost inevitable)
Criticality	Severity	1	No effect
Criticality	Severity	2	Very minor (only noticed by discriminating customers)
Criticality	Severity	3	Minor (affects very little of the system, noticed by average customer)
Criticality	Severity	4/5/6	Moderate (most customers are annoyed)
Criticality	Severity	7/8	High (causes a loss of primary function; customers are dissatisfied)
Criticality	Severity	9/10	Very high and hazardous (product becomes inoperative; customers angered; the failure may result unsafe operation and possible injury)
Protection		1	Certain - fault will be prevented by Protection
Protection		2	Almost Certain
Protection		3	High
Protection		4/5/6	Moderate
Protection		7/8	Low
Protection		9/10	No protection affect to the defect mechanism

* Protection Ratings are coming from Cell insulation and protection.

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Battery Safety Risk Assessment Process- 4

Test item Classification and Quantification

IEEE 1725 Cell Certification

No.	Test Clause	Test Condition	Criteria and Evaluation
1	Isolation Properties	80% SOC, 150 °C, 10 min.	-Temperature, Voltage, Level & distribution
2	Cell Thermal Test	100% SOC, 130 °C, 60 min.	
3	Short-Circuit /Cycled Cell	55 °C, 80 ± 20 m Ohm	***Quantify***
4	Destructive Physical Analysis-1	Shrinkage Allowance: Room Temp. /Shrinkage Allowance: High Temp./Electrode Geometry	Latent possibility of inducing cell internal short by gap among Separator, Anode and Cathode. / Data consistency in a sample and among 5 samples
5	Destructive Physical Analysis-2	Electrode Tabs /Application of Insulation / Supplementary Insulation/ Internal Short Avoidance /Positioning of Insulating Material	Latent possibility of inducing cell internal short by position & status of insulation mechanism. / Accuracy & uniformity insulation mechanism among 5 samples. ***Quantify***
6	Cell Vent Mechanism	Vent activation pressure	Position and consistency of Vent mechanism

Add quantitative factor to the "Pass or Fail" criteria (rows 1–3)

Add quantitative factor to the "Pass or Fail" criteria (row 5)

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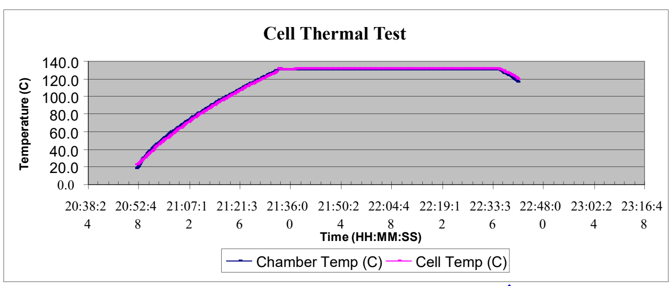
Battery Safety Risk Assessment Process- 5

Additional evaluation criteria and data quantification



Test Condition;

- 130 C, 60 min. at 100% SOC
- Ramping Speed: 5 C/min.

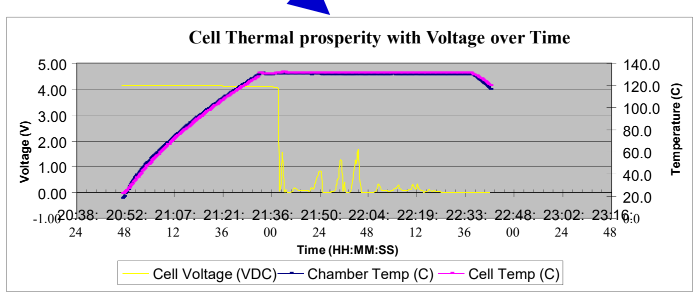
Pass/ Fail Criteria;

: Cell should Not Flame or Explode.

➔ **Data quantification**

Add Voltage profile during Testing

Data quantification



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Battery Safety Risk Assessment Process- 6

Add more inspection items which is strongly related to the Cell safety, but which can not be evaluated by CTIA Certification testing.

Tear Down (DPA) – Check Cell Design/Manufacturing status
- Shrinkage Allowance
- Electrode Geometry and Alignment
- Electrode Tabs and Insulation
- Application of Insulation
- Application of Supplementary Insulation,
- Internal Short Avoidance
- Positioning of Insulating Material
- Anomalies

Activation Pressure of Vent mechanism
- **Cell Vent Mechanism**

Battery Safety Risk Assessment - 1

Cell Safety Risk Assessment should be differentiated between With CID and Without CID.
:Because the cells have different mechanism of deformation, degradation or failure process

Cell Safety Risk Assessment by Cell Type

1) Group - 1
: No CID in a cell

a) Prismatic Cell
b) Pouch type cell
: No cell have PTC in it.

2) Group - 2
: CID in the cell structure

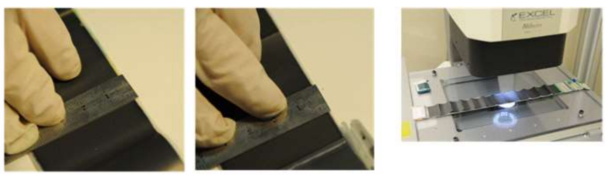
18650 Cylindrical Cell
: some cell have PTC in it.

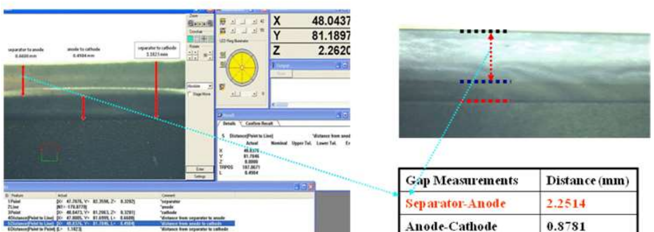
* Focus on this presentation

* Focus on this cells later.

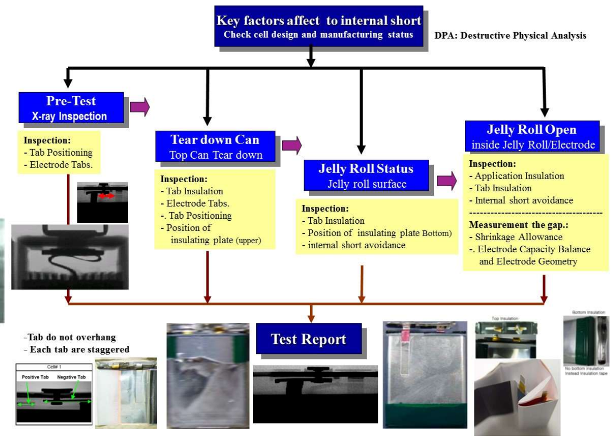
Battery Safety Risk Assessment - 2

Check Cell Design and Manufacturing Status :
- Check Electrode alignment, tab, insulations and anomaly of the electrode assembly.
- Measure the gaps at RT and High Temp.: the gaps between Separator, Anode and Cathode



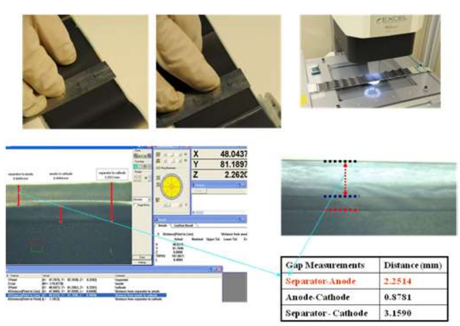


Gap Measurements	Distance (mm)
Separator-Anode	2.2514
Anode-Cathode	0.8781
Separator - Cathode	3.1590

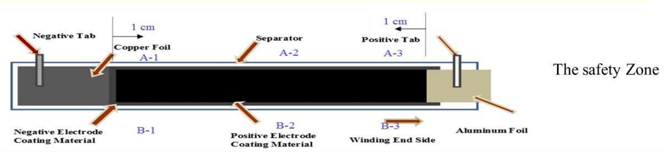


Battery Safety Risk Assessment - 3

Gap measurement/Check Electrode Alignment & Insulation mechanism of the Electrode Assembly

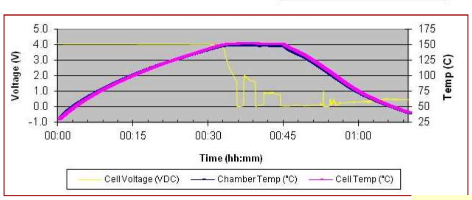


Electrode Gap measurement to evaluate the cell alignment and manufacturing status of insulation mechanism.



Fresh Cell	A-1 Top Left	A-2 Top Middle	A-3 Top Right	B-1 Bottom Left	B-2 Bottom Middle	B-3 Bottom Right
A	**0.331**	0.756	0.970	0.341	0.829	0.395
B	0.793	**0.342**	0.777	0.542	0.801	0.651
C	**0.259**	0.722	0.321	0.602	0.555	0.542
D	0.762	0.441	0.495	**0.367**	0.482	0.389

Cycled Cell	A-1 Top Left	A-2 Top Middle	A-3 Top Right	B-1 Bottom Left	B-2 Bottom Middle	B-3 Bottom Right
A	0.615	**0.335**	0.837	0.547	0.639	0.745
B	0.595	**0.367**	0.467	0.534	0.439	0.698
C	**0.305**	0.522	0.536	0.582	0.453	0.925
D	**0.345**	0.494	0.554	0.479	0.583	0.678



It was the trend of the cell design for the higher energy density cell. This cell has minimum gaps for the cell safety.➔ High Risky cell.

Battery Safety Risk Assessment - 4

The Role of the Separator : - a key component in a lithium-ion cell.

Provides an electronic barrier between the positive and negative electrodes of the battery while **allowing the exchange of lithium ions** from one side to the other through specially engineered pathways.

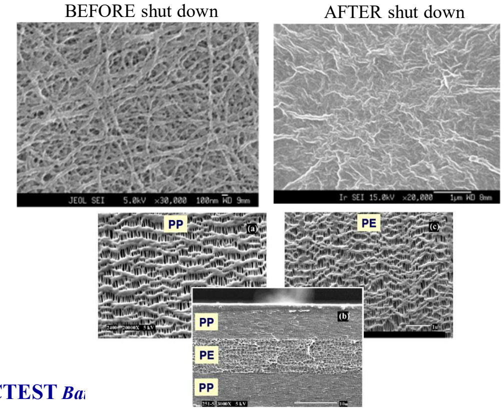
As "Shut-Down Temp." is lower and as "Melt Integrity" is higher are required for enhancing safety of battery.

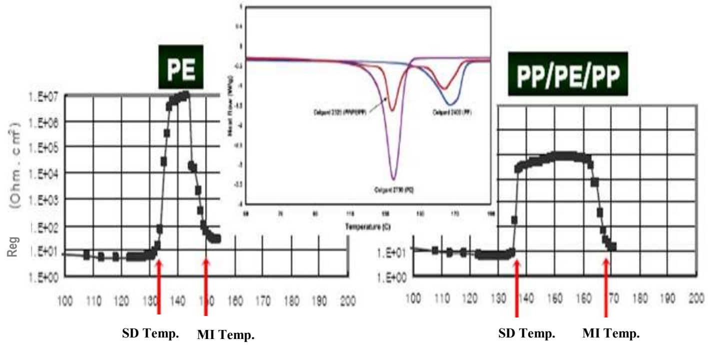
Shut- Down Temp. : Temp. when the pore of a separator is closed and then it lose the function of the ion transfer

Melt Integrity Temp. : Temp. where the separator is melted out that is lose the function of the separation of electrode.

BEFORE shut down

AFTER shut down





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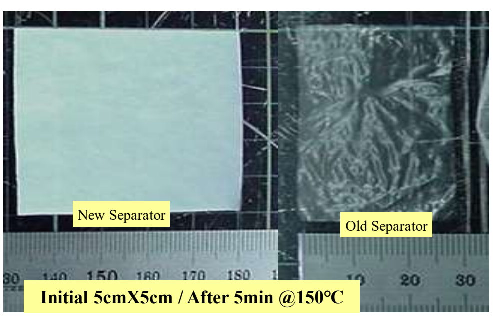
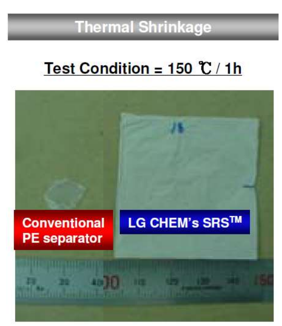
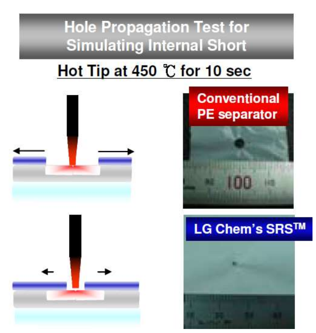
Battery Safety Risk Assessment - 5

The Role of the Separator _Ceramic coating : Thermal Shrinkage Reinforced Separator has the Shut-Down Temp. but doesn't have Melt Integrity, so it is much safer than that of PE, or PP/PE/PP polymer separator.

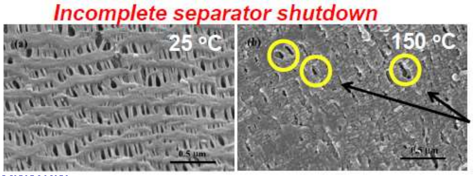




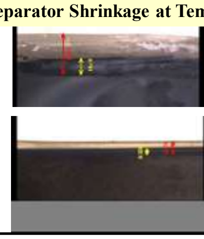


Thermal Shrinkage Reinforced Separator

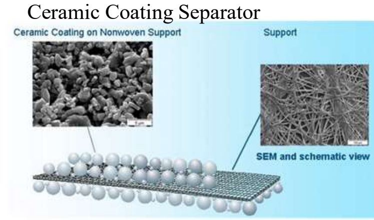
Incomplete separator shutdown



Separator Shrinkage at Temp.



Ceramic Coating Separator



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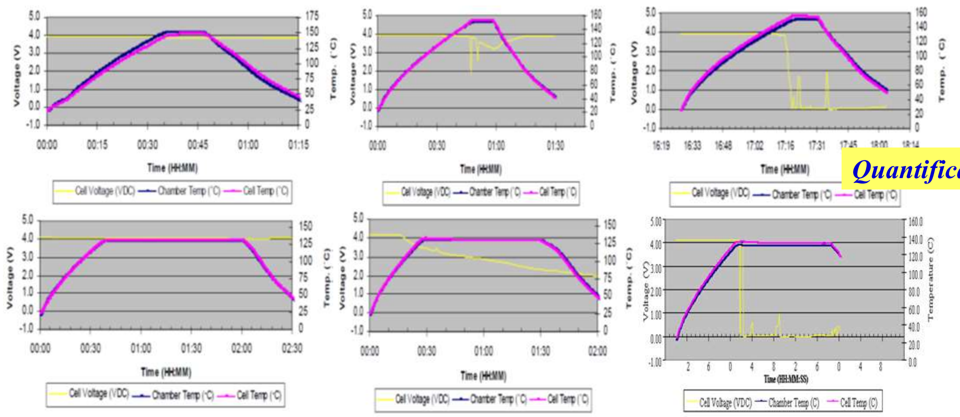
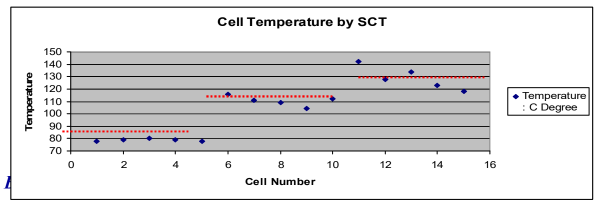
Battery Safety Risk Assessment - 6



Quantification Process



Add additional evaluation Criteria & Quantify

- ➢ Add additional evaluation criteria of the test to the pass/fail criteria.
- ➢ Quantity the test result and grading

Battery Safety Risk Assessment - 7

Result of the Cell Risk Assessment for the Group -1 : Prismatic and Pouch type cells

Cell ID.	Criticality (Severity x Occurrence)				Protection Factor	RPN = C* x P*
	Isolation	Thermal	Short-Circuit	Total		
Cell 1	3	1	1	5	2	10
Cell 2	5	1	1	7	2	14
Cell 3	1	1	3	5	1	5
Cell 4	5	5	5	15	5	75
Cell 5	1	1	1	3	2	6
Cell 6	5	3	3	11	3	33
Cell 7	5	3	3	11	5	55
Cell 8	5	5	1	11	4	44
Cell 9	3	1	1	5	3	15
Cell 10	5	1	1	7	2	14
Cell 11	3	1	1	5	2	10
Cell 12	3	1	3	7	1	7
Cell 13	1	1	1	3	1	3
Cell 14	5	1	1	7	3	21
Cell 15	1	1	1	3	4	12
Cell 16	3	1	3	7	3	21
Cell 17	5	1	1	7	1	7
Cell 18	5	1	1	7	2	14
Cell 19	5	1	3	9	3	27
Cell 20	5	1	3	9	2	18
Cell 21	5	1	1	7	1	7

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Battery Safety Risk Assessment - 8

Reference

1. Paper: Energytech, 2013 IEEE:IEEE *Xplore* Digital Library

Development of a Li ion Battery Safety Risk Assessment Tool

JAESIK CHUNG

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ABSTRACT **— Frequent Li-ion battery (LiB) field safety incidents on the officially approved models have caused big concerns on its safety and certification, however, little attention and study have given to the potential safety risk of the certified battery. We developed a battery safety risk assessment tool by using a modified FMEA method with the RPN concept. To validate this concept we applied the tool to the CTIA LiB safety certification program and evaluated the latent safety risk level of the approved battery models, which enable us to predict the probability of a model's safety incident in the field. To realize this idea we adopted concepts of "system integration effects" and "add additional evaluation factors" to the standard's test items. In conclusion the RPN of the each cell model shows the latent safety risk level of the battery.**

potential safety risk of the certified battery [5].

We are proposing a concept to prevent the battery safety incidents and to provide a tool which can predict safety incidents and can reflect how the incidents occur and from where those initiate.

To realize our proposal, we have introduced idea of: 1) system base testing which includes not only sub-system but also host system and considers system integration effects, 2) add additional measurement factors to the "pass" or "fail" test criteria, which can provide more comparable quantitative data and 3) analyze the test results based on the risk assessment concept to find the latent risk level.

2. Presentation at the IEEE EnergyTech 2013

PCTEST

IEEE-EnergyTech2013
Paper_2013285

Development of a Li ion Battery Safety Risk Assessment Tool through the IEEE Battery Standard Certification

May. 23 , 2013

JAESIK CHUNG PhD. CTO

PCTEST Engineering

3. Presentation at the 30th Internal Battery Seminar & Exhibit

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THE 30TH INTERNATIONAL BATTERY SEMINAR & EXHIBIT

A proposal for Li ion Battery Risk Assessment

Mar. 14 , 2013

JAESIK CHUNG PhD. CTO

PCTEST Engineering

4. Presentation at the NASA Battery Workshop 2012

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Review an effective battery testing and analysis for a risk assessment

Nov. 06, 2012

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Battery Risk Assessment through a Battery Certification

Intel 10W Boost Battery Pulse Test

Introduction to PCTEST Battery Testing

PCTEST Engineering

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Battery Safety Risk Assessment – Group 2 -1

Trends of the 18650 Cylindrical Cell

1. Cell Voltage: 4.2V ➔ 4.4V ➔ 4.5V (?)
   - Anode: Add Silicon to the Anode.
   - Cathode : Higher Voltage and Capacity

2. Size: 18650 ➔ 20700 or 21700

3. Add Bottom Vent Mechanism
   Add Safety Kit inside Cell.

Trend -1: Cell Voltage and Safety Risk

V cell = V cathode – V anode

Combination of cathode/ Anode

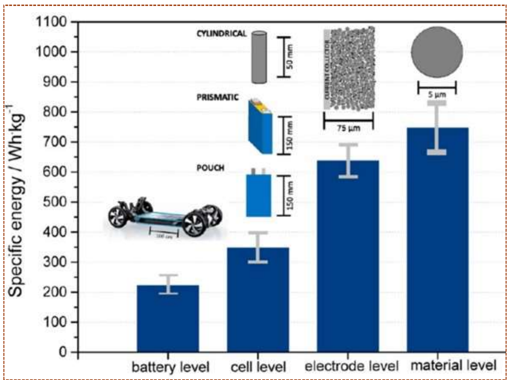
4.2 V ➔ 4.35 V ➔ 4.4V➔4.5V (?)

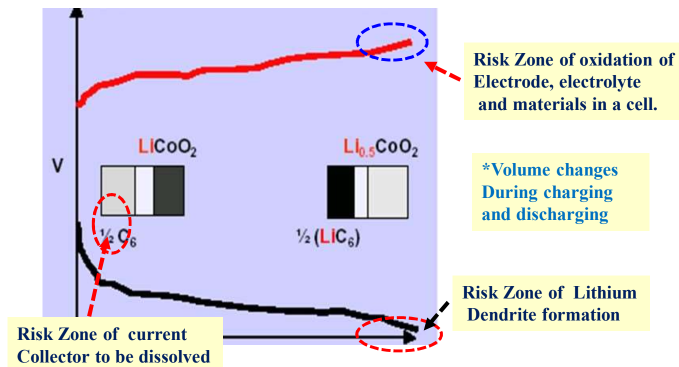
-Increase Cell Energy Density

-How about the Safety?

Cathode: The target value for the year 2025 suggests that Ni-rich NCM and NCA compounds (Ni > 80 mol %) have the potential to reach, or at least approach, energy densities of 300 Wh kg−1 and 700 Wh L−1 at the cell level.

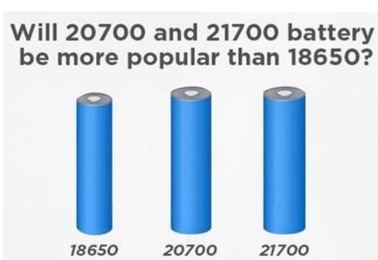
Anode: Si or Si- Alloy Material
1)Pros: High theoretical capacity (3579 mAh/g)
2)Contras: High irreversible capacity loss at first cycle, Slow Li diffusion
Big Volume expansion during cycling





Trend -2: Cell Size :to Increase Energy Density

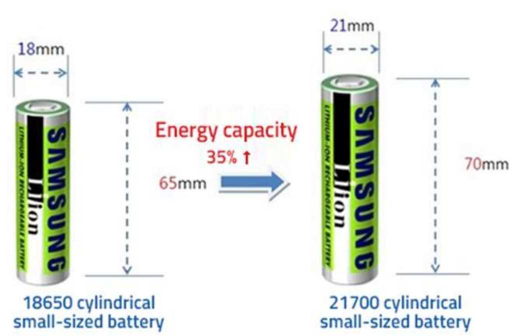
1) 20700 VS 21700 LiB, who will be the winner?



Cell Model	Volume	Volume Ratio
18650	661.62 ㎤	1
20650	816.81 ㎤	1.23
20700	879.65 ㎤	1.33
21650	900.54 ㎤	1.34
21700	969.81 ㎤	1.466

2) Why Tesla choose 21-70 for the cars?

3) Will 21700 replace 18650 in the future?



http://www.xtar.cc/news_detail/newsId=135.html#sthash.nNap6sdn.dpuf

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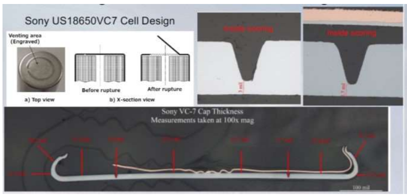
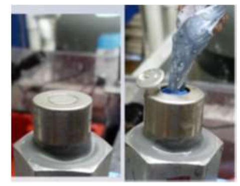
Trend -3: Additional safety: Bottom Vent Mechanism

To reduce the risk of side wall rupture during Thermal runaway



***Side wall rupture during Cell Thermal runaway**



*Reference: 2016 NASA Aerospace Battery WS. P:resented by Dr. Eric Darcy.
18650 Cell Bottom Vent Preliminary Evaluation into its Merits for Preventing Side Wall Rupture.

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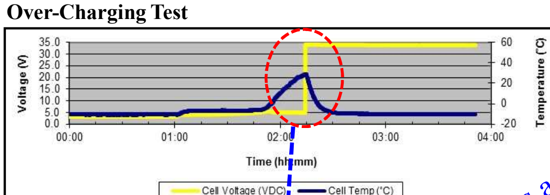
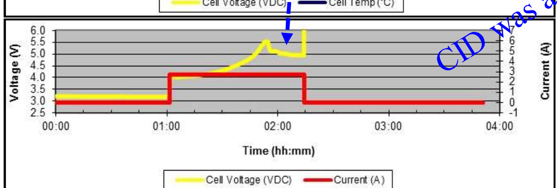
Battery Safety Risk Assessment – Group 2 - 2

CID & Vent Mechanism Design Criteria

Operation Pressure : Vent Mechanism > CID
Maximum Operation Pressure: - Over-charging, External, Thermal test :
CID should be activated lower conditions than that of the cell Over-charging, External, Thermal test
Minimum Operation Pressure: Thermal cycle test :
CID should be activated higher condition than that of the Thermal Cycle Test

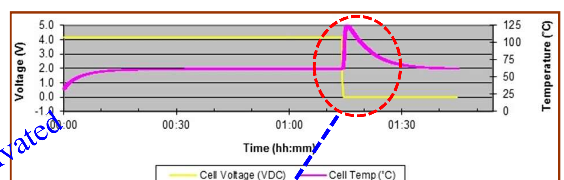
Over-Charging Test

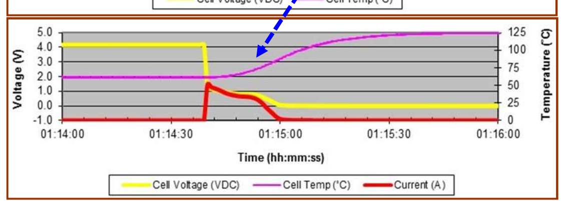




CID was activated

External Short-Circuit Test





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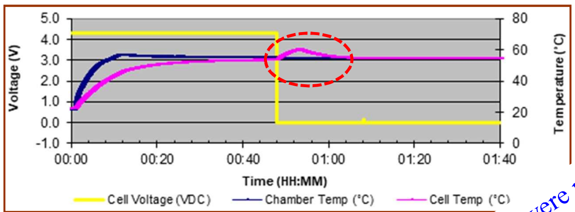
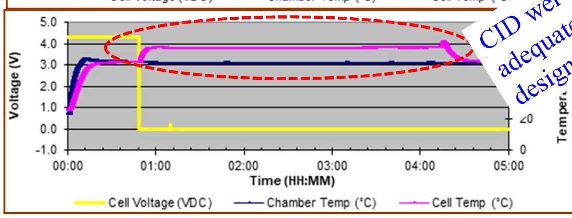
Battery Safety Risk Assessment – Group 2 - 3

CID and Vent mechanism Activation issue: CID was not activated adequately as it was designed.

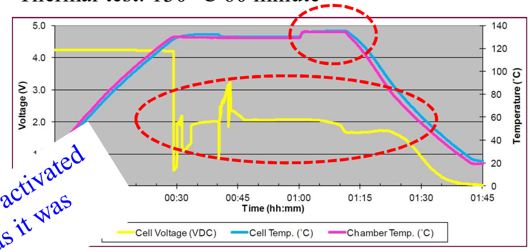
External Short-circuit test Result

5 cell test: 2 cells and 3 cells are different



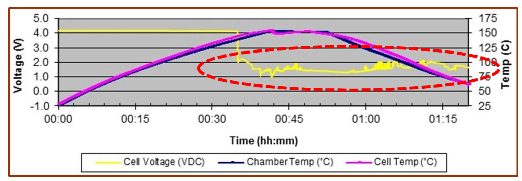


Thermal test: 130 °C 60 minute



CID were not activated adequately as it was designed.

Thermal test: 150 °C 10 minute



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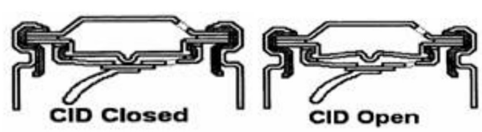
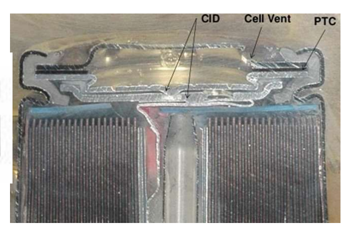
Battery Safety Risk Assessment – Group 2 - 4

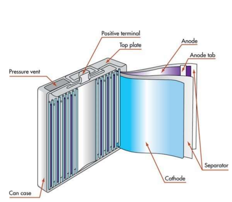
Battery Safety Vent Mechanism

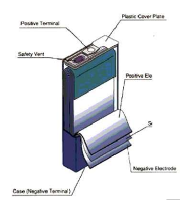
1. 18650 Cylindrical Cell:
   1) Top Cap: CID + Safety Vent + PTC
   2) Bottom Vent





2. Prismatic Cell : Portable Application Cell
   :Top or Side Vent Mechanism

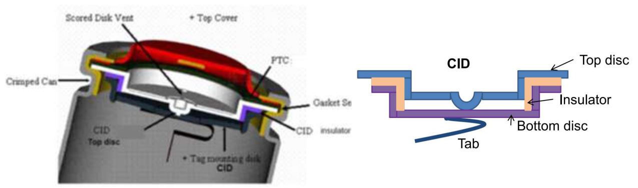


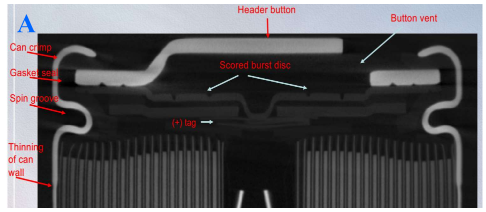


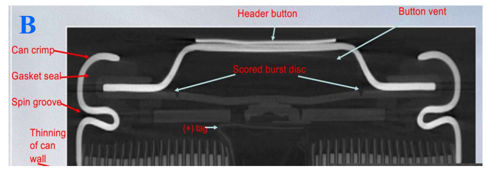
3. Pouch Cell:
   :Regards "thermal sealing point" as a Vent Mechanism

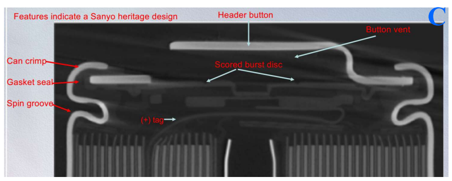
Battery Safety Risk Assessment – Group 2 - 5

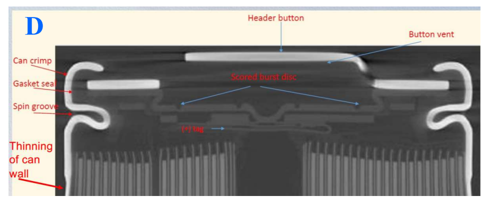
Role of safety vent and CID to a Cylindrical LiB cell safety











*Ref.:2016 NASA Aerospace Battery WS. Presented by Dr. Eric Darcy.
18650 Cell Bottom Vent Preliminary Evaluation into its Merits
for Preventing Side Wall Rupture.

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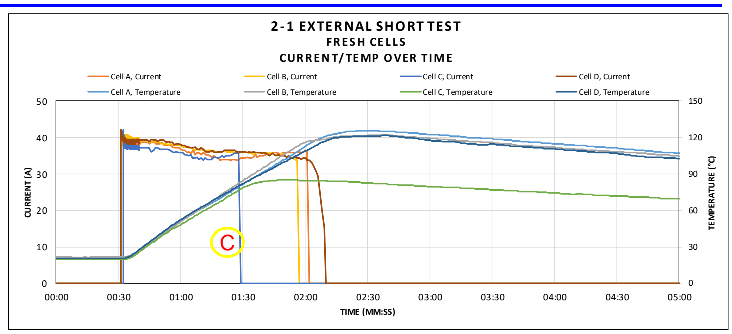
Battery Safety Risk Assessment – Group 2 - 6

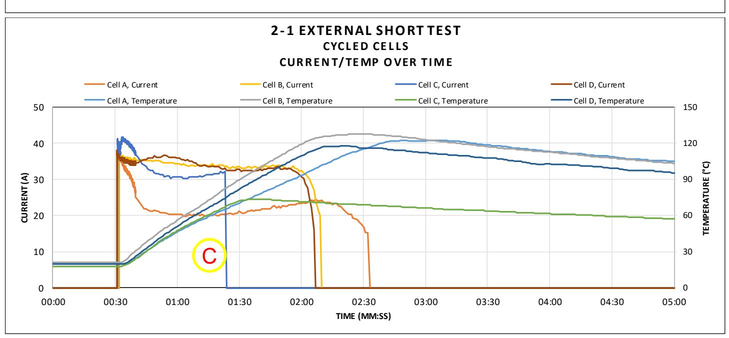
External Short Test :

comparison between fresh & cycled cell

Test Condition

- Externally short circuit fully charged cells independently with a load of < 80 +/- 20 m ohm.
-Maintained it until a discharged state of less than 0.1V has been reached.
-Test is performed for 0.5 – 1.0 hours after current is no longer drawn (CID open) or the case temperature is within 10°C +/- 5 of the ambient temperature.
-Test to be terminated immediately if fire or explosion occurs.





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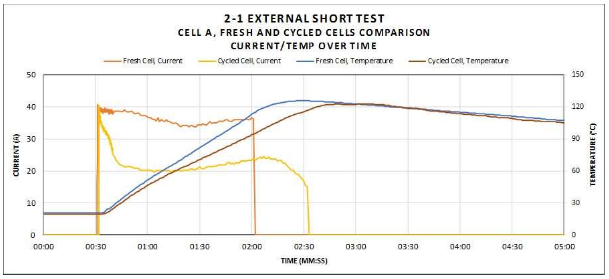
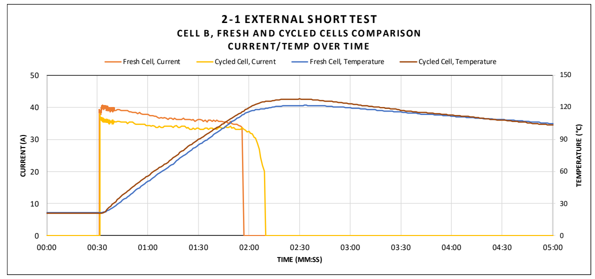
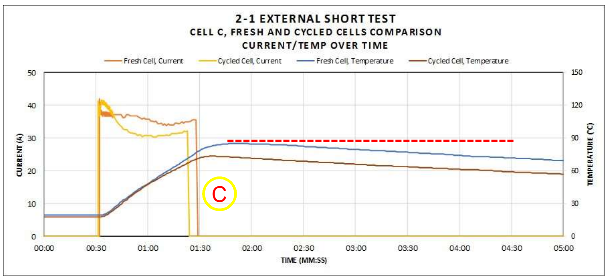
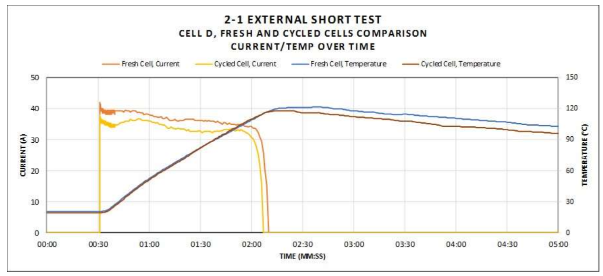
Battery Safety Risk Assessment – Group 2 - 7

External Short Test : comparison between 4 cell models









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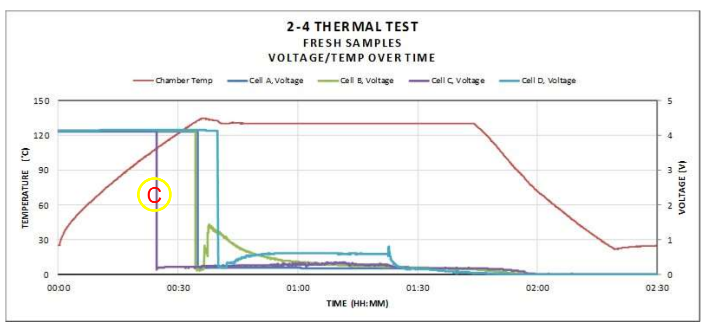
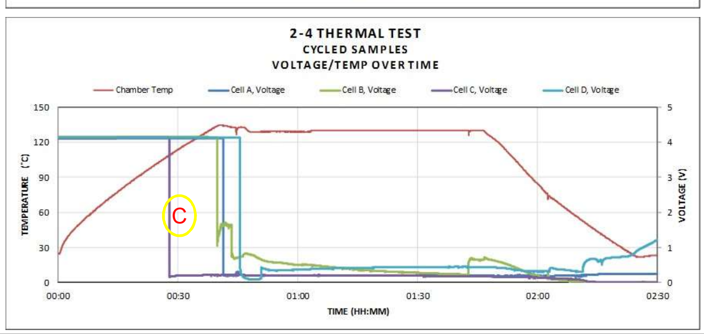
Battery Safety Risk Assessment – Group 2 - 8

Thermal Test :
comparison between fresh & cycled cell





Test Condition

-Maintain fully charged cell in 130 ± 2°C chamber for 1.0 hour after the cell temperature reach to 130 ±2°C and then cooldown the temp to RT.
Temperature Ramping speed: 5 ±2°C per minute.

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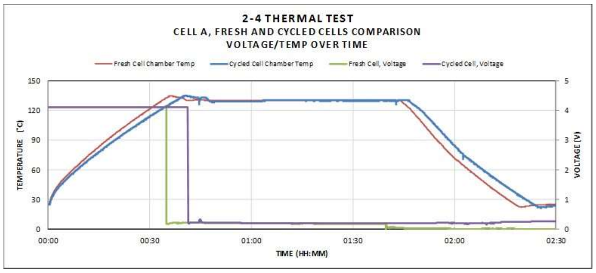
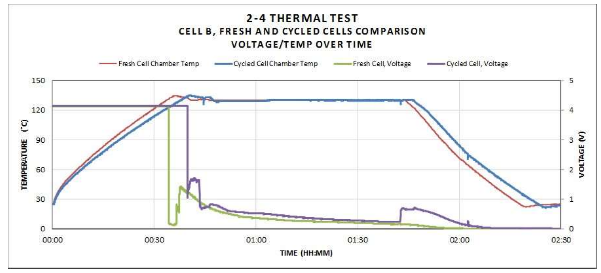
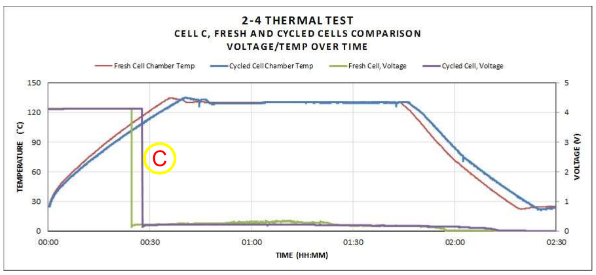
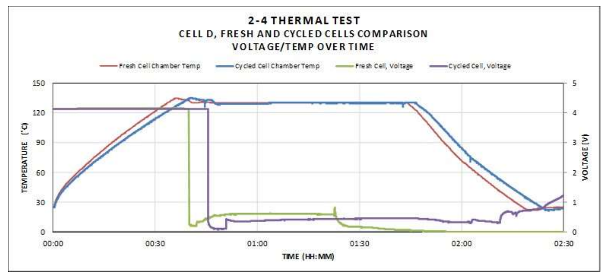
Battery Safety Risk Assessment – Group 2 - 9

Thermal Test : comparison between 4 cell models









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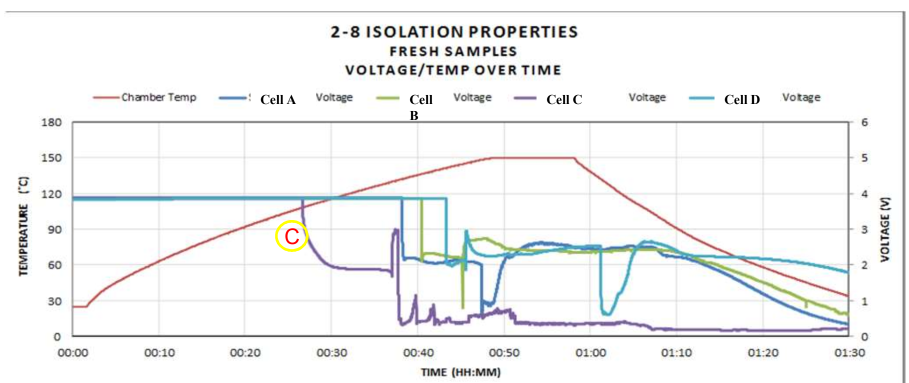
Battery Safety Risk Assessment – Group 2 - 10

Thermal Test-2 : comparison between 4 cell models

Test Condition
-Maintain Cells, charged 80% of the SOC, in 150 ± 2°C chamber for 10 Min. after the cell temperature reach to 150 ±2°C and then cooldown the temp to RT.
Temperature Ramping speed: 5 ±2°C per minute.



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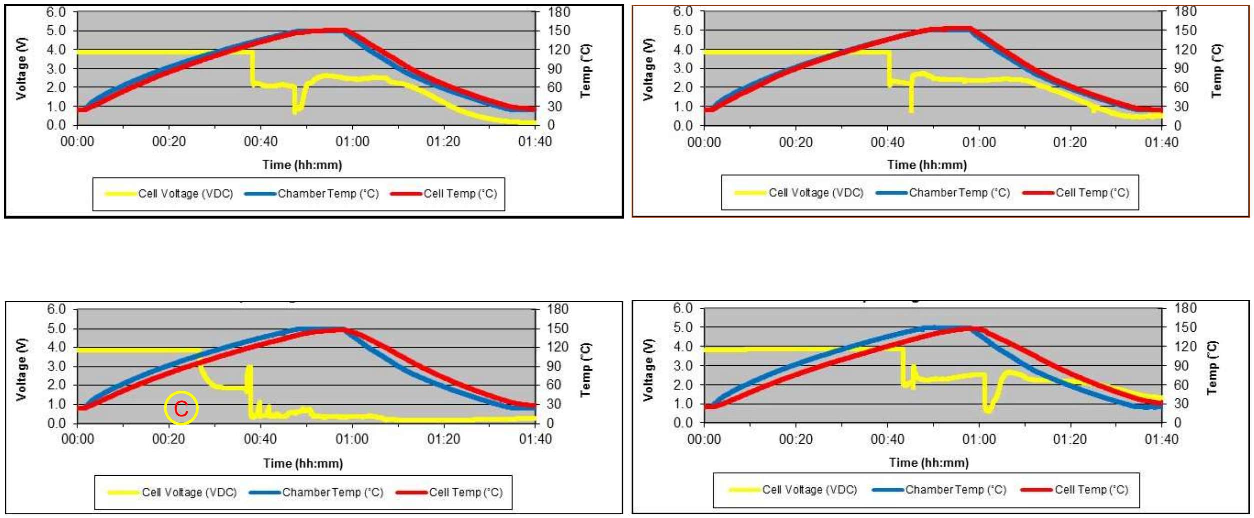
Battery Safety Risk Assessment – Group 2 - 11

Thermal Test-2 : comparison between 4 cell models



Battery Safety Risk Assessment – Group 2 - 11

Test Result & Safety Mechanism

On external short circuit Test and Thermal Test;

- Company C cell samples (Fresh & cycled) always activated the safety mechanism in advance compare to the others 3 cell models
- Company C cell samples shown more consistency between fresh cell and cycled cell.

➔ Company C cell has more Accurate Safety mechanism.
CID and Vent Mechanism.

Verification Test on Progress

- Activation of the CID and Vent Mechanism
- PTC Activation effects.
- Cell Alignment and Electrode Safety Gap Measurement

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Conclusion and Future plan

Proposed Cell Safety Risk Assessment tool can quantify the latent safety risk a cell model.

This tool classify the level of the latent safety risk of a cell model.

The efficiency of Certification can be enhanced by combining it with pack and host system.

Additional research need for the cylindrical cells :
- PTC Effects
- With CID (Cylindrical) vs Without CID (Prismatic &Pouch)
- With CID or Safety Kit
- High power application vs High Energy cell

Quantification of Latent Safety Risk of a model
Cell + Pack + Charger + Host System

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Thank you for your Attention!!!

It is not easy to predict, prevent and completely eliminate the field incident at the point of manufacture, But it is definitely not an impossible thing.

The greatest factor is the way in which every difficulty is foreseen, victory awaits him who has everything in order luck, People said it.; Amundsen

Contact information: jaesik.chung@pctest.com