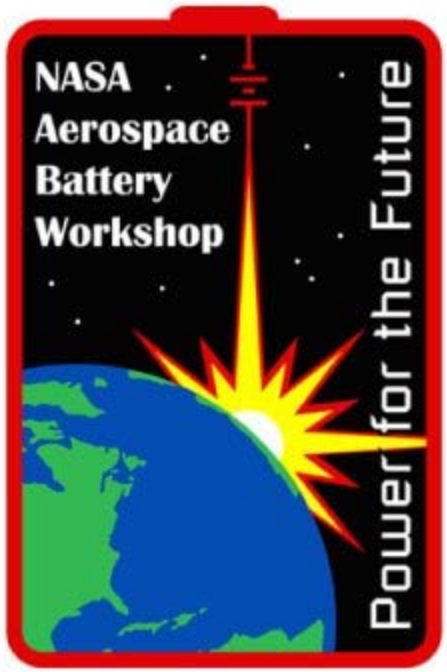
Review an effective battery testing and analysis for a risk assessment



Nov. 06, 2012

JAESIK CHUNG, JAMES PARK, KWANG JUNG, RANDY ORTNIZE

PCTEST Engineering

PCTEST ENGINEERING LABORATORY, INC.
A PERSONAL COMMUNICATIONS TESTING COMPANY

Research Motivation and Work scope

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Introduction

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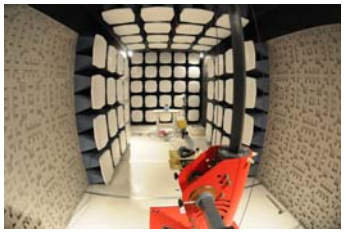
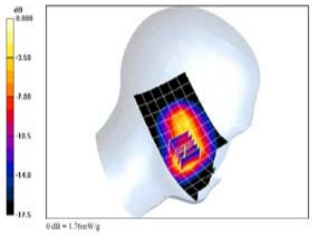
Introduction of PCTEST





- Founded in 1989 (~24 yrs) at MD USA by former FCC engineer
- Verizon/ at&t /Sprint Authorized Test Lab: for wireless Device.
- Test capabilities for **LTE, EMC/EMI, SAR, CTIA, OTA and HAC**
  - A2LA ISO/IEC 17025 accreditation since 2000.
  - US NIST / NVLAP ISO/IEC 17025 accredited since 1995.
  - ANSI ISO/IEC Guide 65 TCB, FCB, CAB.
- CATL ISO/IEC 17025 accreditation for CDG/OTA/HAC/Battery
- CDMA Certification Forum (CCF) Authorized Testing Facility.
- R & D for Battery and System Safety and Reliability.
- CTIA Authorized Test Lab: **Battery Safety Certification**
- Battery safety and Reliability Project.

• EMC/EMI: Electromagnetic compatibility/Interference, SAR: Specific Absorption Rate
• OTA: Antenna Performance: Over-the-Air, HAC: Hearing Aid Compatibility
• ANSI: American National Standard Institute
• CTIA: Cellular Telecommunications and Internet Association

A2LA ACCREDITED CERTIFICATE #2041.01
ANSI
NVLAP Lab Code #100431-0
CTIA Authorized Test Lab LAB CODE 20020221-00
CDMA Certification FORUM

Business Scope of Battery Safety &Reliability

1. **CTIA Battery Certification program: Cell phone/ Notebook PC/GPS**
   - Cell, Battery Pack, Adaptor and Host - Manufacturing site Audit
2. UN DOT Lithium Transportation Test
3. Battery Performance, Safety & Reliability Test and R&D Project
4. Cell, Pack Design Review & assessment / System base Analysis
5. Develop New Test Method & Acceleration Test Method for Reliability
6. Benchmarking Analysis/ Failure & Field Issue Analysis/ Recall support
7. Consulting Battery Selection Guideline and Technology.

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Why the battery field issues have happened?

- *Battery field issues*

- *Battery Standard and Certifications*

Battery Accident and Standard for Transportation

1. Battery accident: Transportation

The fatal crash of a UPS (Boeing 747-400F jumbo cargo flight) jet carrying a large shipment of rechargeable lithium batteries suggests that safety issues still remain for transporting these flammable devices.
Departed Dubai International Airport toward Germany crashed and killed both pilots.

2. Battery Transportation Stand : Global

1) United Nations (UN) :Primary and Secondary Cells and Batteries

- Recommendations on the Transport of Dangerous Goods, Manual of Tests and Criteria, Part III, Section 38.3

2) International Electro technical Commission (IEC)

- IEC 62281:Safety of **Primary and Secondary Lithium Cells and Batteries** During Transportation

Battery field Issues have occurred during in use

1. Battery accident: During In Use

*** The cells were certified: UN DOT(IEC 62281), IEC 62133, UL 1642/ 2054, National Standard**

2. National or Regional

1) UL: Underwriters Laboratories

• UL 1642: Lithium Batteries. • UL2054: Household and commercial Batteries.

2) International Electrotechnical Commission

• IEC 62133: Secondary Cells and Batteries Containing Alkaline or Other Non-acid Electrolytes-Safety Requirements for Portable Sealed Secondary Cells, and for Batteries Made from Them, for Use in Portable Applications

3) Japanese Standards Association

• JIS C8714: Safety Tests for Portable Lithium Ion Secondary Cells and Batteries For Use In Portable Electronic Applications

4) National base Standard: Destination country

• Korea, •China

UN DOT Certification

Primary and secondary batteries

	Test Name	Sample Number	
		Cell	**Battery**
T1	Altitude Simulation	**20 Cells** **- 1 cycle Full charge cell: 10** **- 1 cycle Full discharge cell: 10**	**16 Packs** **- 1 cycle Full charge cell: 4** **- 1 cycle Full discharge cell: 4** **- After 50 cycles Full charge cell: 4** **- After 50 cycles Full discharge cell: 4**
T2	Thermal Test		
T3	Vibration		
T4	Shock		
T5	External Short Circuit		
T6	Impact	**20 Cells** **- 1cycle SOC 50% : 5 cells** **- 50 cycles full discharge 5 cells** **- Battery Cell 1cycle SOC 50% : 5 cells** **- Battery Cell 50 cycles full discharge: 5 cells**	**No Test**
T7	Overcharge	**No Test**	**8 Packs** **- 1 cycle Full charge cell: 4** **- After 50 cycles Full charge cell: 4**
T8	Forced Discharge	**20 Cells** **- 1 Cycle Full Charge Cell: 10** **- 1 Cycle Full Discharge Cell: 10**	**No Test**
	Total Sample Number	**60 Cells – 7 test item.**	**24 Packs – 6 test item.**

*** IEC 62281**

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UL 1642 for Secondary batteries.

*** Revised November 25, 2009**

Test	Fully charged	Batteries conditioned by charge-discharge cycling
Electrical Tests		
Short-Circuit[a]		
at room temp.	5	5
at 55°C (131°F)	5	5
Abnormal Charge	5	5
Forced Discharge[b]	5	5
Mechanical Tests		
Crush[a]	5	5
Impact	5	5
Shock	5	5
Vibration	5	5
Environmental Tests		
Heating	5	5
Temperature Cycling	5	5
Low Pressure (Altitude Simulation)	5	5
Fire Exposure Test		
Projectile	5 (10)	–

[a]For multicell use, see 10.3.

[b]For series use only, see 12.2 for details on samples.

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Test Item Comparison between IEC 62133 and UL 1642

	Test Items IEC 62133	Test Items- UL 1642		
1	Continuous Low Rate Charging	Electrical Test	1	Short circuit at Room Temp.
2	Vibration		2	Short circuit at 55 C (131 F)
3	Molded Case Stress at High Ambient Temperature		3	Abnormal Charge
4	Temperature Cycling		4	Forced Discharge
5	Incorrect Installation of a Cell (Nickel Systems Only)	Mechanical Tests	5	Crush
6	External Short Circuit		6	Impact
7	Free Fall		7	Shock
8	Mechanical Shock		8	Vibration
9	Thermal Abuse	Environ-mental Tests	9	Heating
10	Crushing of Cells		10	Temperature Cycling
11	Low Pressure		11	Low Pressure (Altitude Simulation)
12	Overcharge for Nickel Systems	Fire Exposure	12	Projectile
13	Overcharge for Lithium Systems			
14	Forced Discharge			
15	Cell Protection against High Charging Rate (Lithium Systems Only)			

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Expert Opinion and my opinion

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What the expert said about the battery Safety?

At Battery Show 2011, Battery Safety 2011, 2012 International Battery Seminar & Exhibit

Field battery Safety incidents almost always originate due to an internal short (that was not detectible or predictable at the point of manufacture).

Thermal runaway from internal short can not be prevented by typical production component because the shorts can be driven and sustained "internal" to the cell.

Safety incidents take place on the order of one in 10 million cells for the most experienced Manufacturers (well beyond six Sigma).

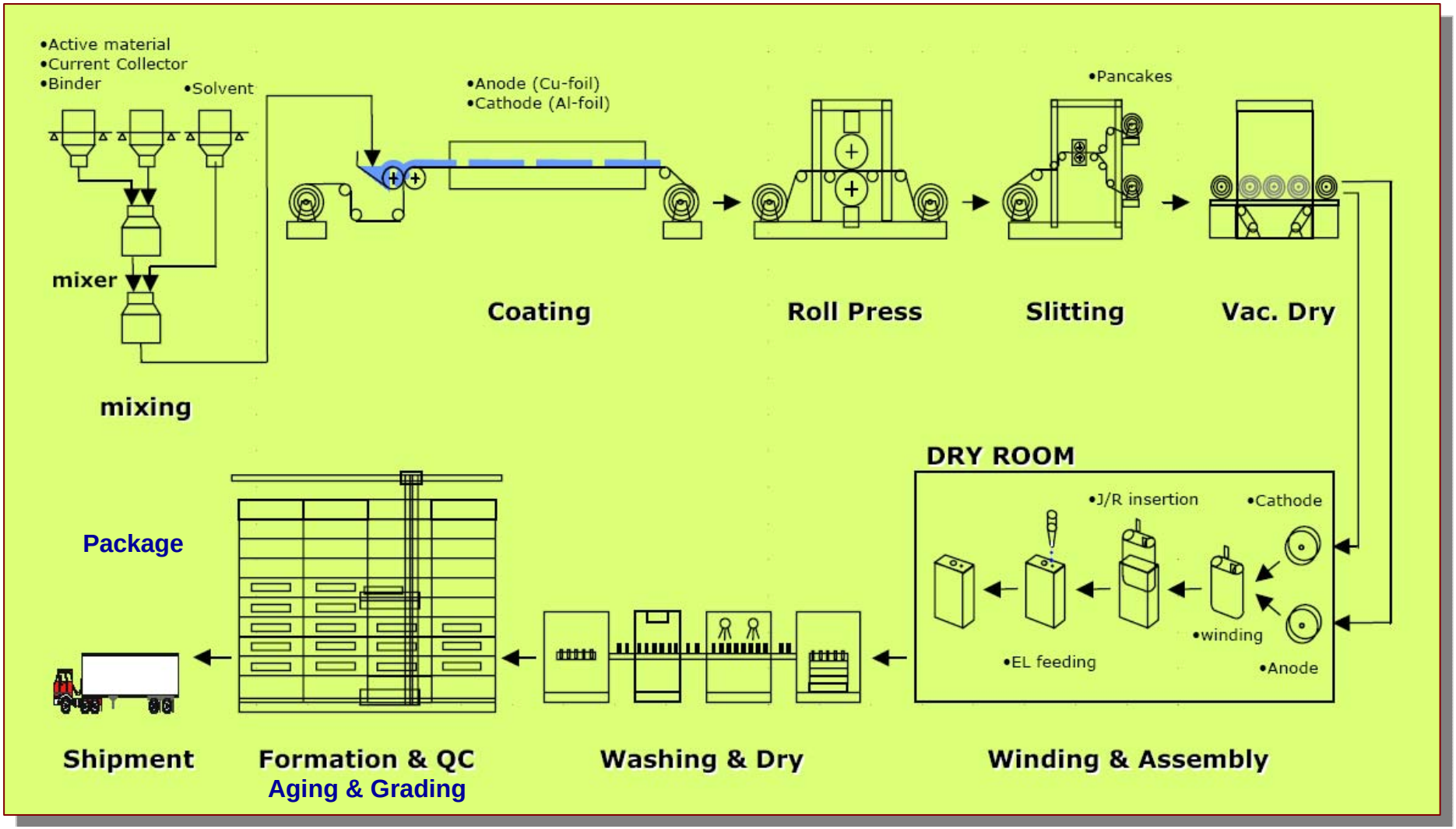
Battery industry does not have safety tests that "predict" safety in the field, Nor reflect/ anticipate the reality of how safety incidents occur in the field.

Thermal runaways in safety incidents occur during "normal" operation in the field (no warning), after some time in the filed, and are not detectable at the point of manufacture.

Internal shorts will never be completely eliminated.

Lithium ion Battery Manufacturing Process

- Battery Manufacturing has long process and many kinds of materials which may have impurities.
- Each machine and process has manufacturing tolerance which affect battery quality and safety.



Degradation mechanism and Battery Safety

System Affect to the battery safety

Host System affect to Battery : Electrical/Thermal Consideration
User Environment
Abuse/Abnormal Condition

Homogeneous Thermal Distribution:
Battery Pack Design and System Design has to consider battery

Hg: Heat generation

Hd: Heat dissipation

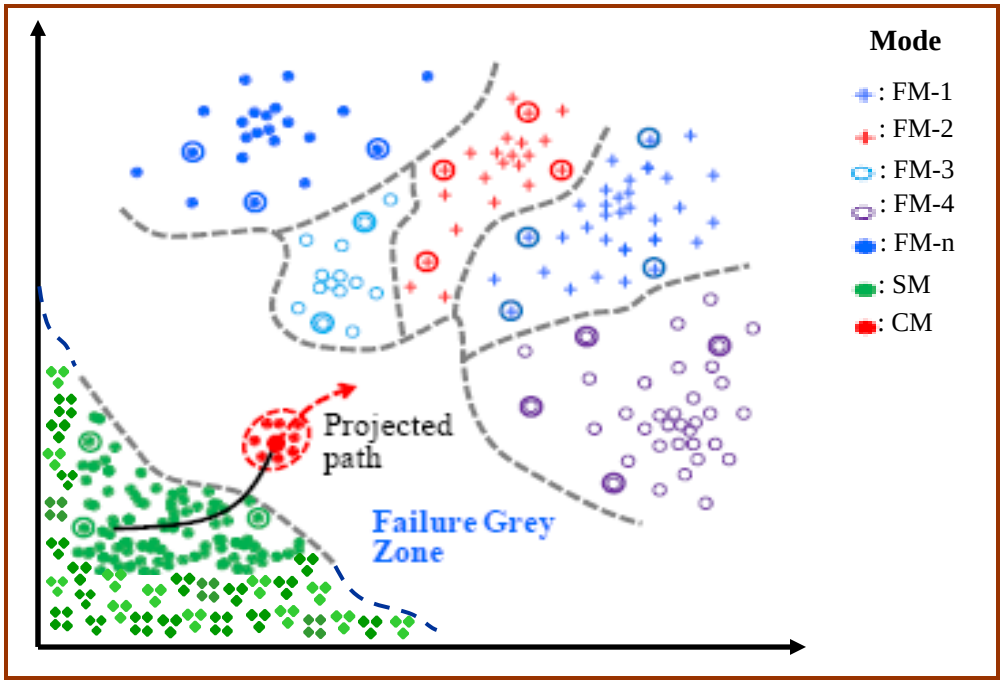
Some times the Battery safety is the System issue

The Role of the Certification

Filtering out the potential risk (bad design & manufacturing) to the product in advance.

Product → **Certification** → **Market**

-Testing / - Audit

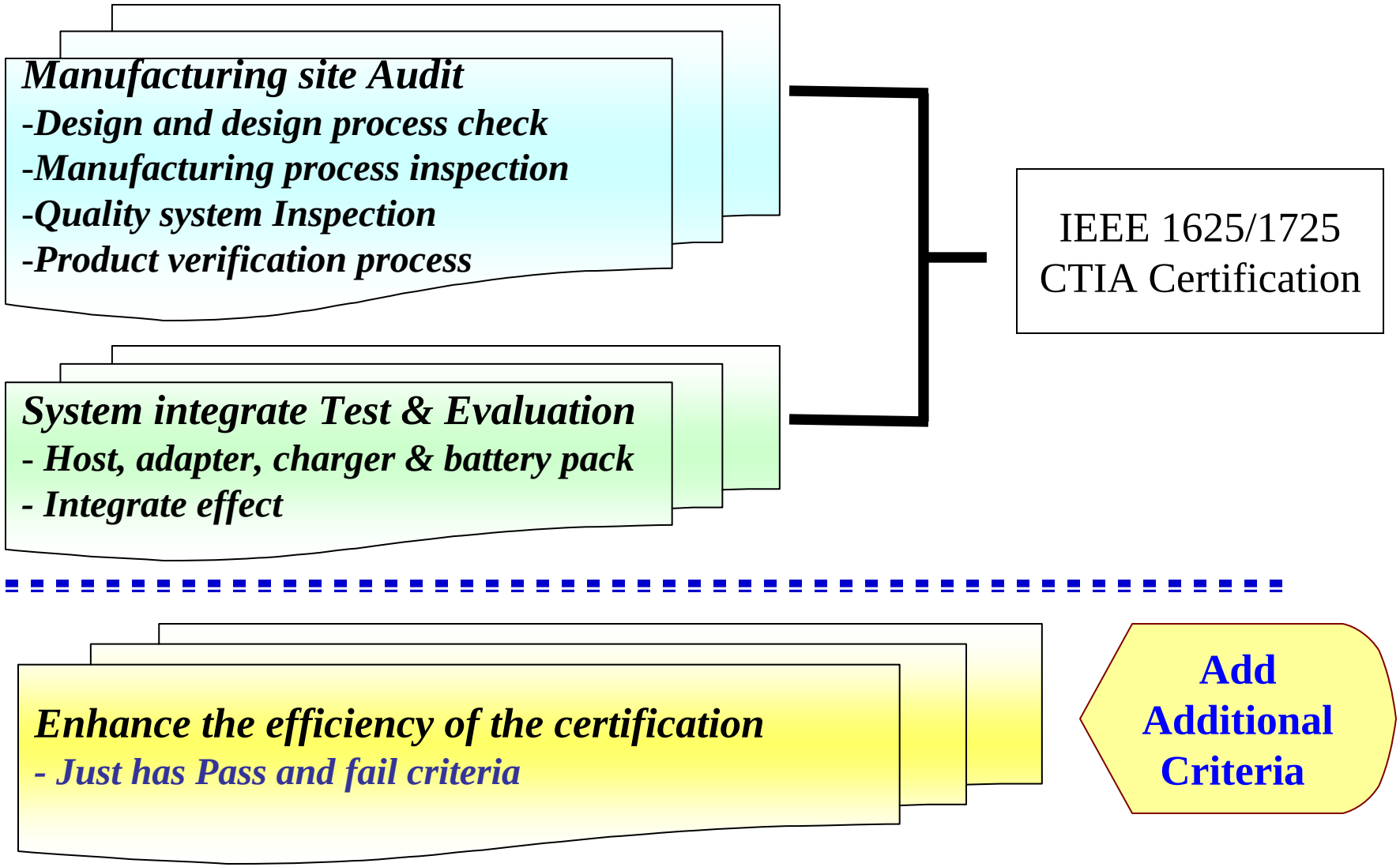


Test : find the trigger

- **Electrical Impact**
- **Mechanical Impact**
- **Thermal Impact**
- **Application use condition**

- **Design Defect**
- **Manufacturing Defect**
- **Abuse or Abnormal condition**

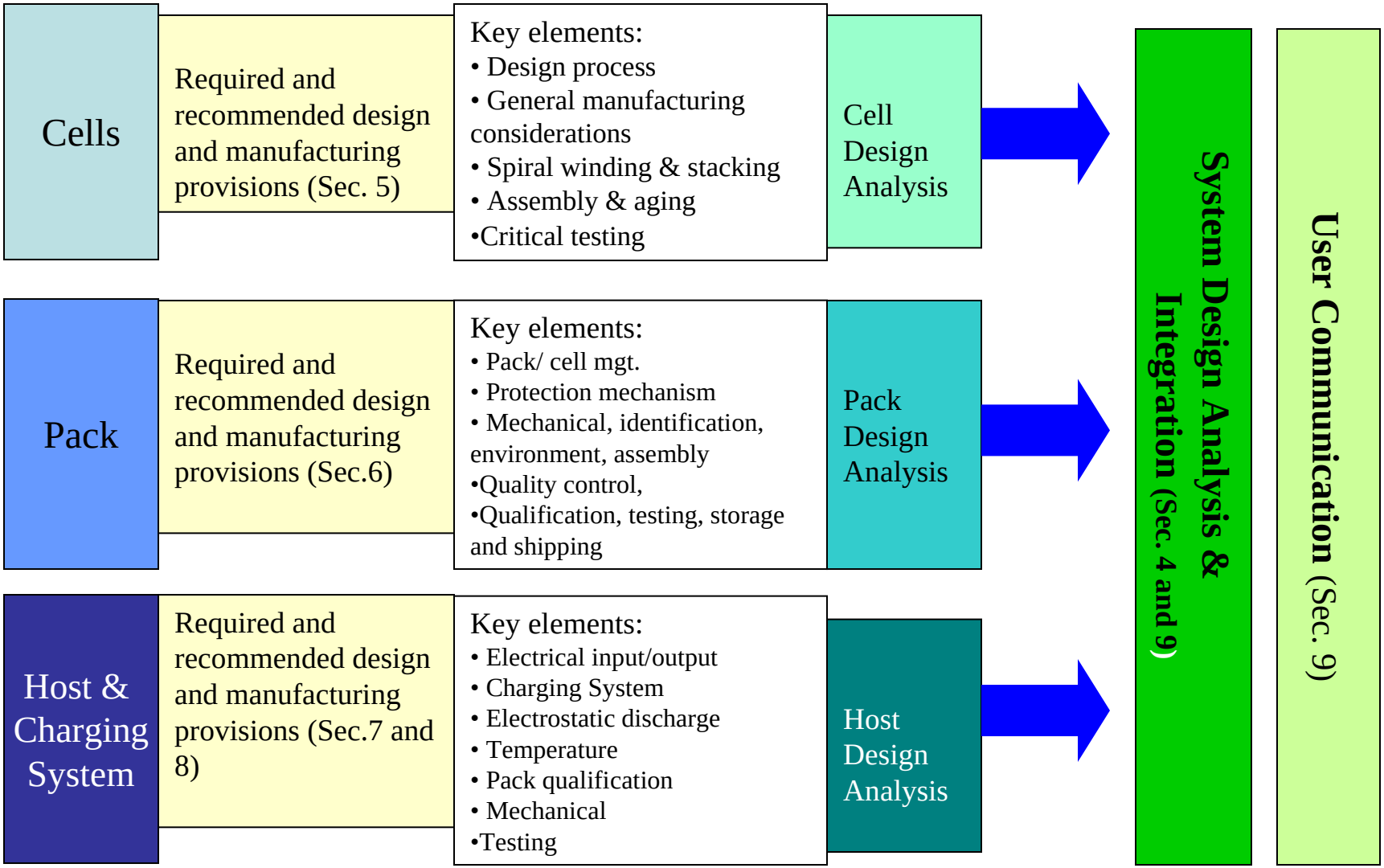
How the field issues can be reduced or prevented?



IEEE 1625 / IEEE 1725 Concept

Required and Recommended Design and Manufacturing Provisions

Manufacturing site Audit, Product Test/Review, Manufacture Declaration



*** Pre-requirement: UN DOT certificate, IEC62133/UL1642 test report, ISO-9000 Certificate.**

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An effective battery testing and analysis for a risk assessment

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I. Motivation

II. Objective

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

III. Process

- **Add additional evaluation criteria of the test to the pass/fail criteria.**

  Add more inspection items which is strongly relate to the safety but which can not be evaluated by sample testing.

- **Calculate the Severity and Occurrence of each test item of a cell.**
- **Calculate Criticality (=Severity x Occurrence) of a cell combining all test items.**
- **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**

1. Process-1:Add additional evaluation criteria

1. Combine: Characterization Tests + Pass/Fail Test

1) Characterization Tests provide valuable data and information.

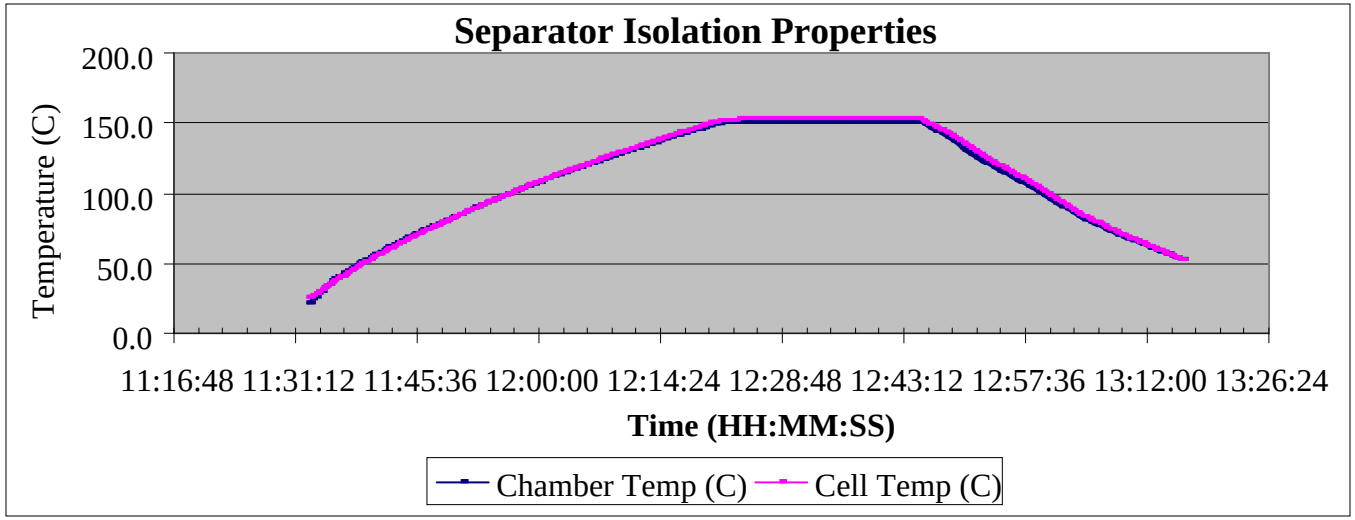
2) Pass/Fail Test

➔ Add more evaluation Criteria to the Pass/Fail Criteria

2. Add more evaluation items which is strongly related to the Cell safety, but which can not be evaluated by sample testing.

: as a protection factor

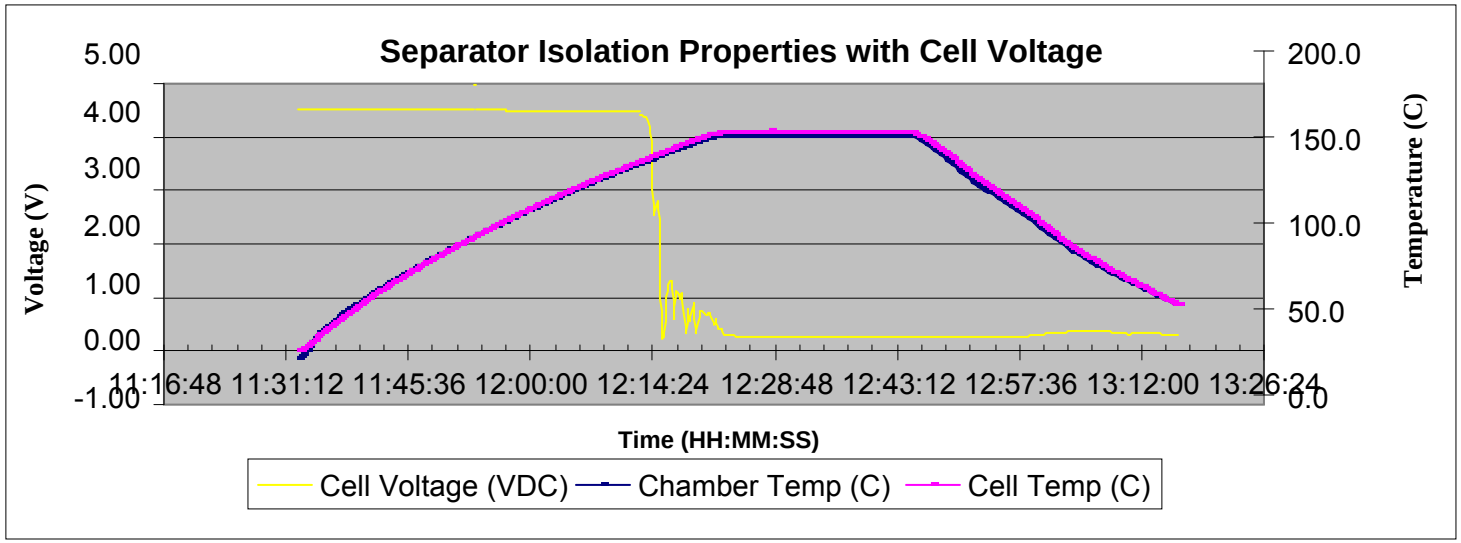
1. Process-1:Add additional evaluation criteria-1



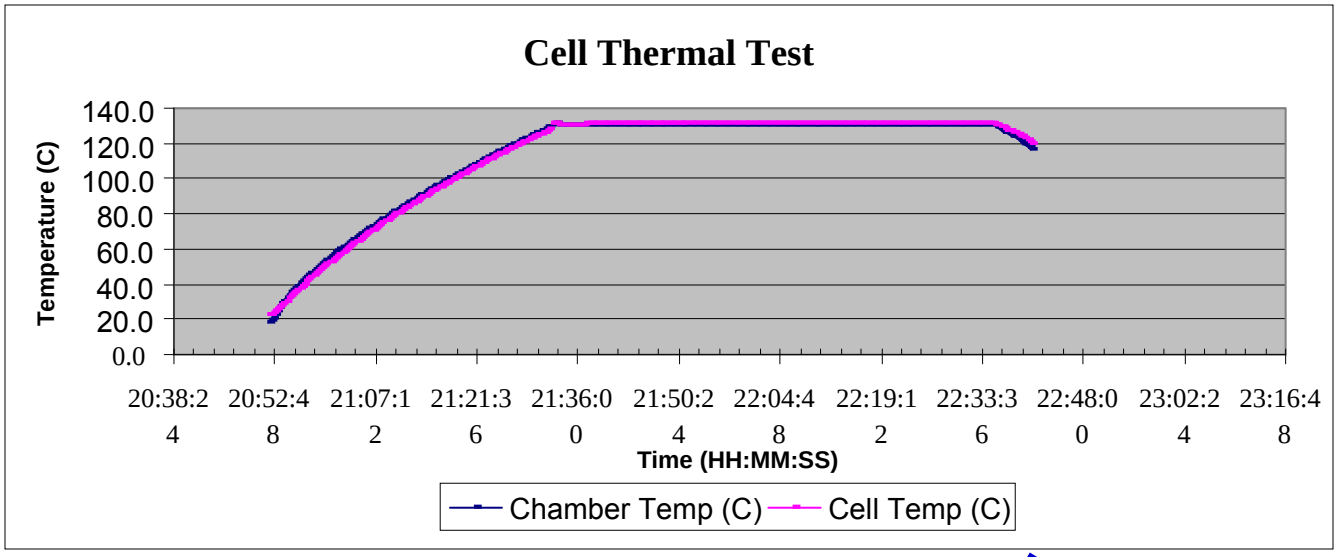
Pass/ Fail Criteria;

- No Fire, Smoke, Explosion/breaching

Add Voltage profile during Testing



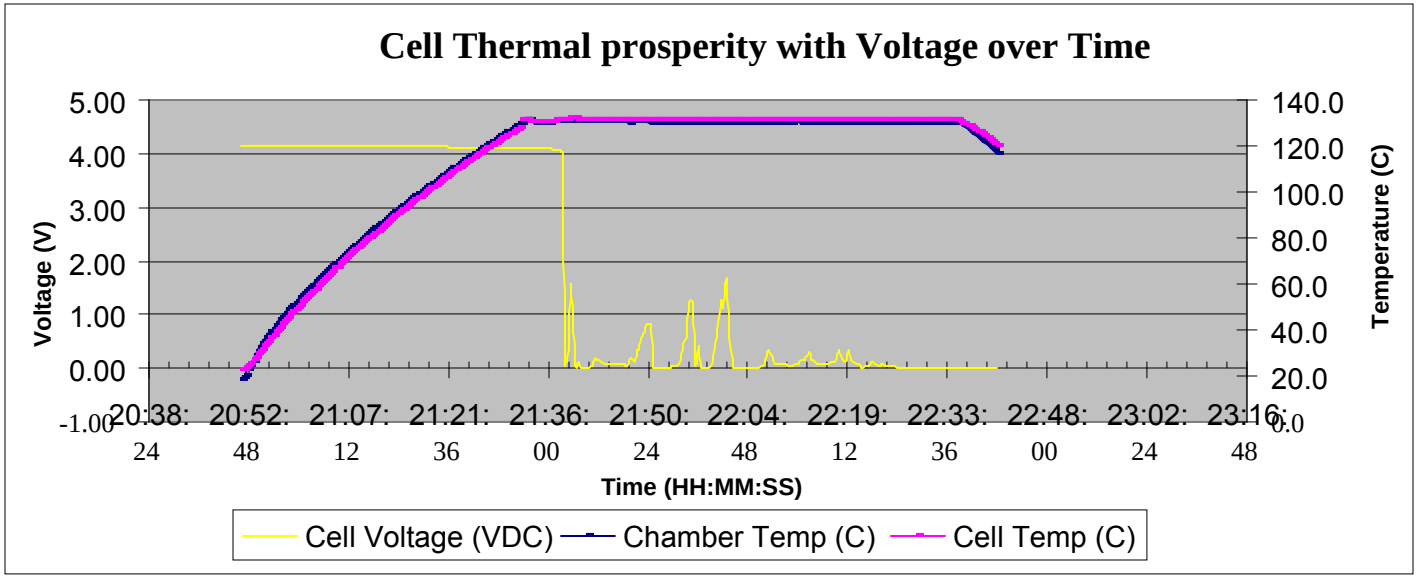
1. Process-1:Add additional evaluation criteria-2



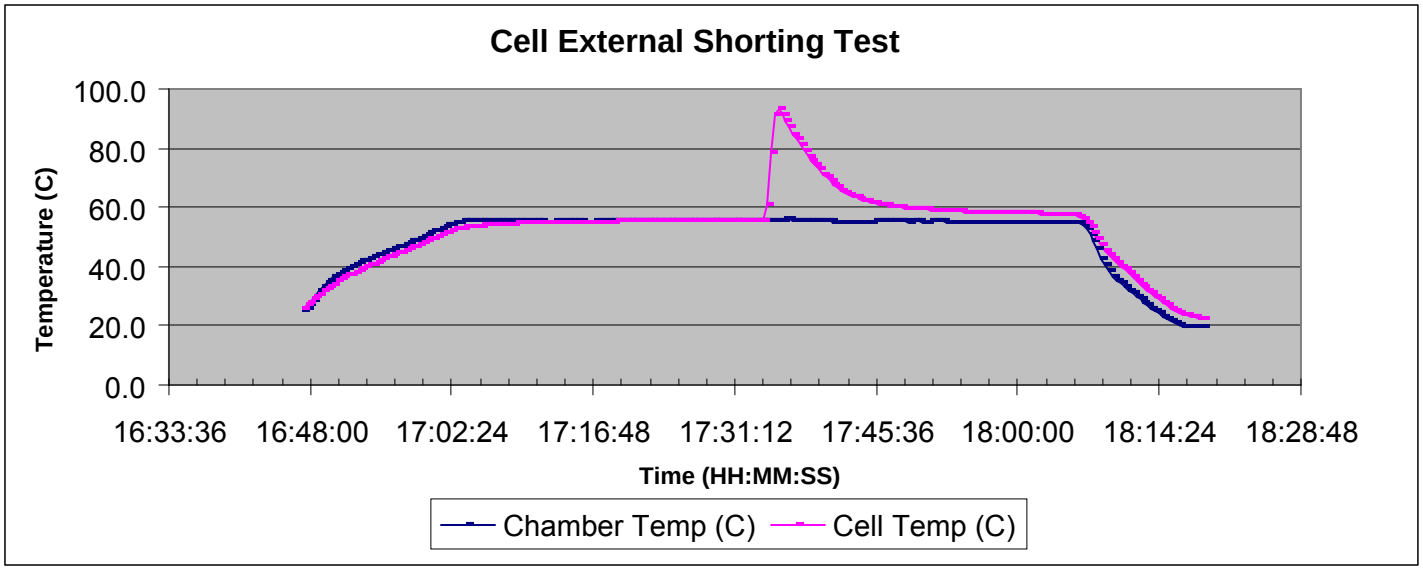
Pass/ Fail Criteria;

: Cell should Not Flame or Explode.

Add Voltage profile during Testing



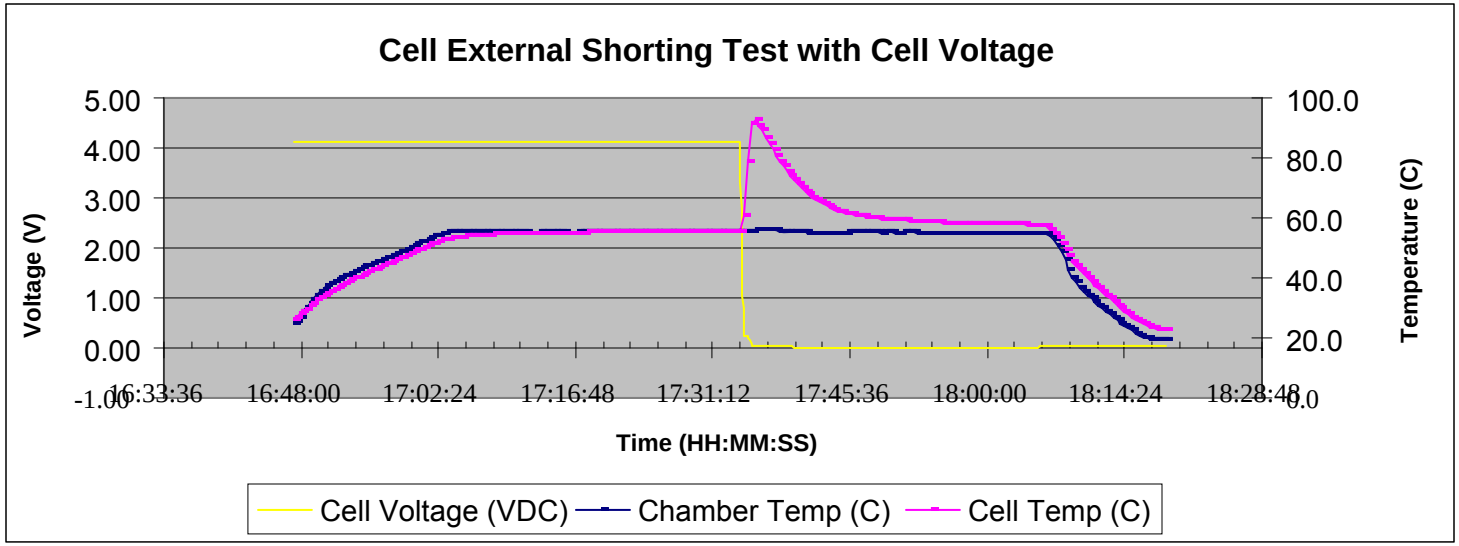
1. Process-1:Add additional evaluation criteria-3



Pass/ Fail Criteria;

- No Fire/ Explosion
- Max .Cell Temp. less than 150 C

Add Voltage profile during Testing



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2. Add more inspection items which is strongly related to the Cell safety

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

Vent Pressure Check Test
- **Cell Vent Mechanism**

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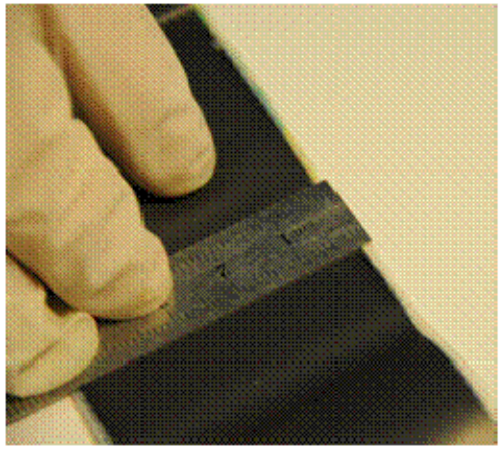
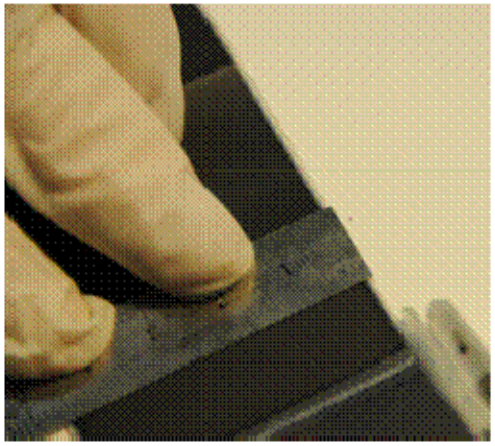
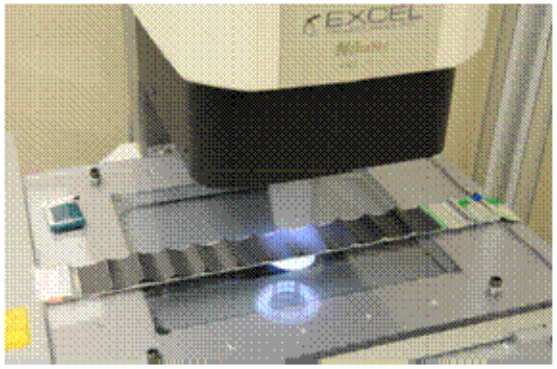
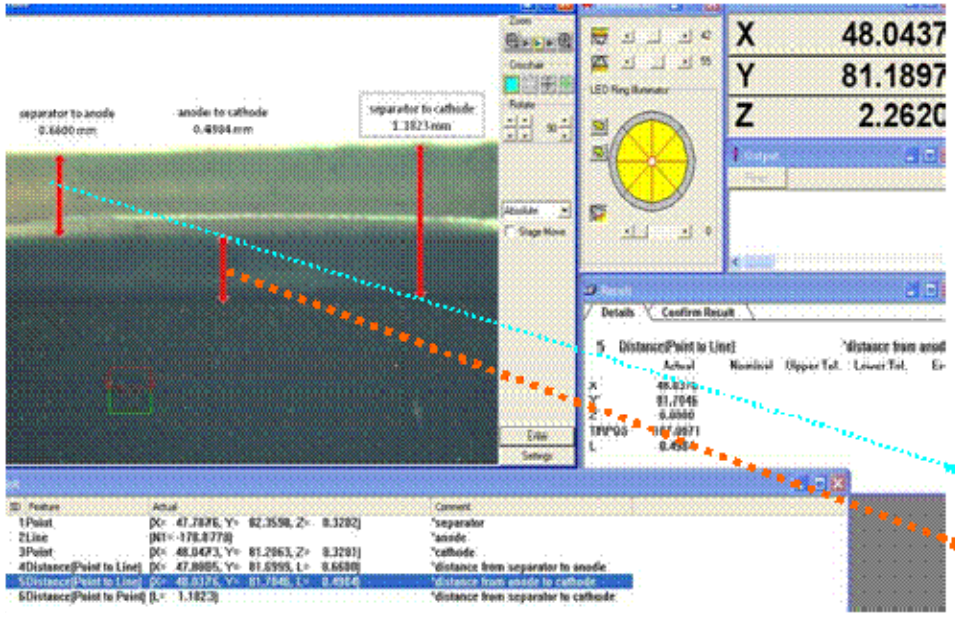
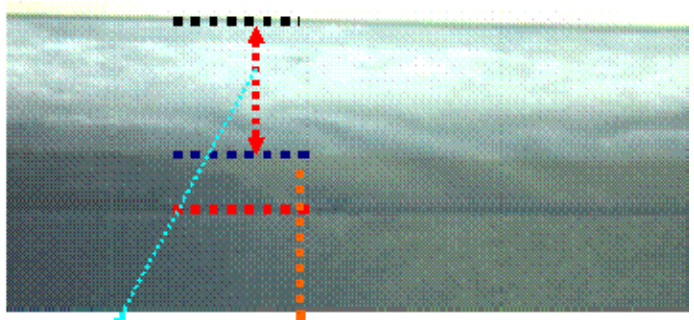
2-1. Cell Teardown and inspect cell design and manufacturing status.







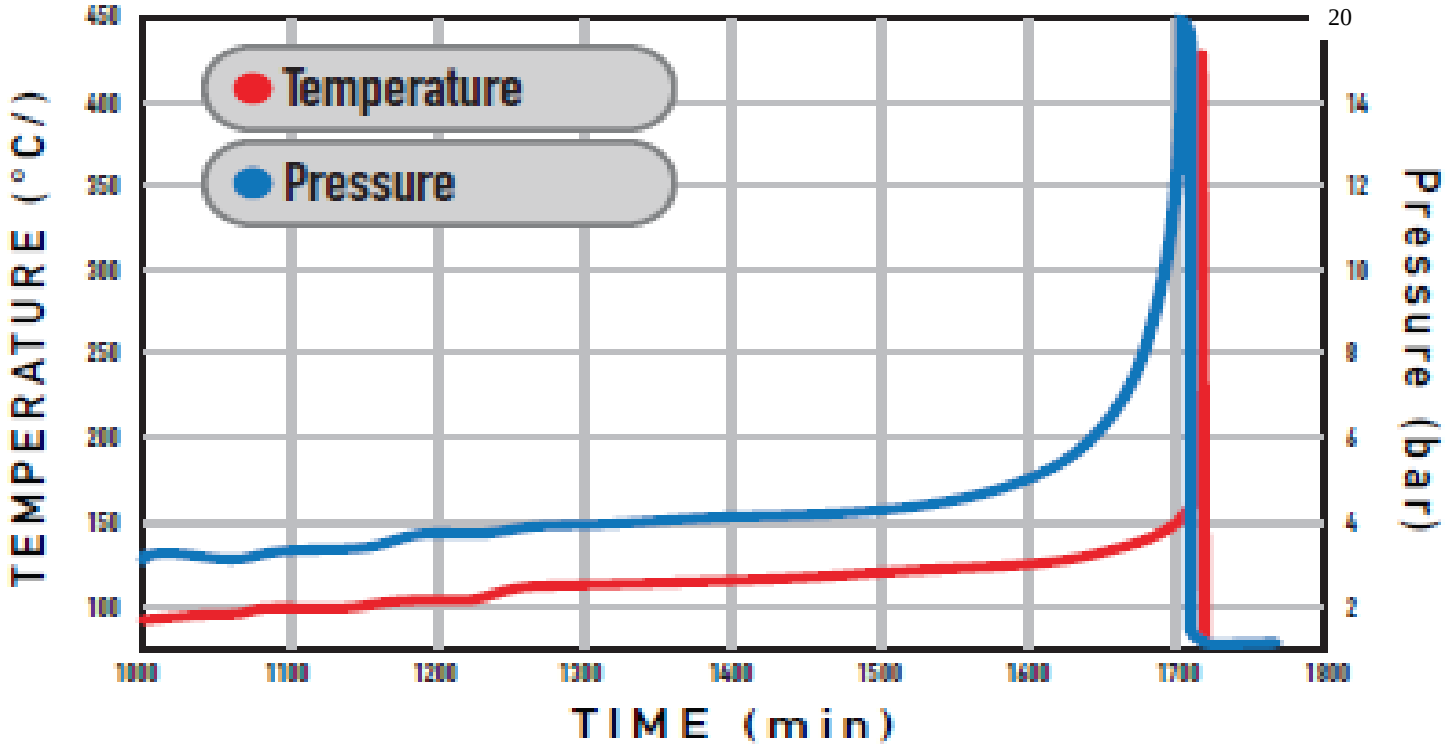




Gap Measurements	Distance (mm)
Separator-Anode	2.2514
Anode-Cathode	0.8781
Separator - Cathode	3.1590

2-2 Cell Vent Mechanism Test

Cell vent design is important to reduce the field incident by reducing vent pressure.



Vent pressure by Cell Type

Cell Type	Prismatic Cell	Pouch Cell	Cylindrical Cell
Pressure (Kgf/cm^2)	**3.5 ~ 15.0**	**4.0 ~ 12.0**	**15.0 ~ 34.0**

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Simulation and Validation of the FMEA RPN tool

to evaluate a Cell Risk Assessment

Process -2:
Calculate the Severity and Occurrence of each test item of a cell.

Process -3:
Calculate Criticality (=Severity x Occurrence) of a cell combining all test items.

Process -4:
Calculate Risk Priority Number.(Criticality of cell x Protection of a cell)

Sample Information

- **Certified 21 cell models :Test : Dec.2009 ~ Jan. 2012**

  - Cell design for Cell phone applications: similar performance

- **Capacity: 900 mAh ~ 1,500 mAh**

- **Charging Voltage : 4.2V (operate: 4.2 ~3.0V)**

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/					
												FMEA Number:	Insert FMEA#					
		Process										Page:	1	of	1			
Item:	Name/number of item	Responsibility:	Name									Prepared by:	who					
Model Years:	model years/programs	Key Date:	07/15/08									FMEA Date:	07/15/08					
Core Team:	Team members																	
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	Severity	Occurrence	Detection	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 occurence.	List detection activities to assure process adequacy and prevent or reduce occurence.		0	Design actions to reduce severity, occurence 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

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Introduction of FMEA_(Risk priority number (RPN) = O x S x D)

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

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Introduction of FMEA (Example) -3

FMEA on the service provided at the Special Olympics

Process function requirement	Potential failure mode	Potential effect(s) of failure	Severity	Class	Potential cause(s)/ mechanism(s) of failure	Occur	Current process control	Detect	RPN	Recommended action(s)	Responsibility and target complete date	Action results				
												Actions taken	Severity	Occurrence	Detection	RPN
Service desk	Cannot register in time	Complaints	5		Lack of language and communication skills, support of volunteers not sufficient	4	No plan on training content; training and volunteer support not sufficient	3	72	Make complete training plan, implement personnel training and provide enough volunteers						
Guest support	Lack of barrier-free facility	Inconvenience and injury	10		Cannot provide barrier-free facility	3	Providing barrier-free facility	7	210	Add barrier-free facility						
	Unclear signs	Can't find the room			Signs out of date and overdue; identification not removed	4	Post new signs			Periodic inspection and maintenance						
	Poorly planned equipment	Personal injury			Inappropriate equipment	3	Move, replace and/or improve equipment			Periodic inspection and repair						
Food service	Substandard food items	Disease or injury	5		No supplier control system, procedure or method of purchasing and/or inspection	3	Random purchasing and random inspection	3	72	Establish inspection procedure and method; strengthen outgoing product control						
					Food-preserving equipment and environment inconsistent with requirement	4	No requirements on storage equipment, maintenance or periodic cleaning of warehouse	7	210	Set requirements on storage equipment and environment; provide periodic maintenance						
	Food goes bad	Disease or injury	10		Raw material past shelf life	6	No control on the raw material	8	240	Periodic inspection						
					Packing damage		No control of packaging	3	120	Regular loading/unloading						
Medical service	Service not in time	Illness changes for the worse	10		No 24-hour service		12-hour service	3	180	Provide 24-hour service						

* Flexibility of RPN rating_ Example

Different Organization have different Criteria and hazard level= need Harmonization

Hazard Level	EUCAR Description	SAE J2464 Description	IEC Description
0	No effect	No effect	No effect
1	Passive protection activated	Passive protection activated	Deformation
2	Defect/Damage	Defect/Damage	Venting
3	Leakage (Δ mass < 50%)	Minor Leakage/ Venting	Leakage
4	Venting (Δ mass ≥ 50%)	Major Leakage/ Venting	Smoking
5	Fire or Flame	Rupture	Rupture
6	Rupture	Fire or Flame	Fire
7	Explosion	Explosion	Explosion

1. Modified FMEA RPN_(Risk priority number = O x S x P)

1) Modification -1:

Criticality = Severity x Occurrence

2) Modification -2:

Detection factor change to Protection

Protection Ratings are coming from Cell teardown inspection & a test.

2. Simulate RPN to the IEEE Cell Cattery Certification

1) Classification of Test Item

Risk priority number = O x S x P

No	Test Clause	Condition	Class
1	CRD4.2 Isolation Properties	80% +/- 5% SOC at 150°C, 10 Min. Temp. ramp Speed:5 ± 2°C/Min.	Criticality
2	Tear Down – Check Cell Design/Manufacturing -4.4 /4.5 Shrinkage Allowance, -4.9 Electrode Geometry -4.11 Electrode Tabs, -4.12 Application of Insulation, -4.14 Application of Supplementary Insulation, -4.36 Internal Short Avoidance -4.41 Positioning of Insulating Material	Check Cell design and manufacturing status	Protection
3	Tear Down after High temp. -Shrinkage Allowance	100% SOC / 110 ± 2°C Temp. ramp Speed:5 ± 2°C/Min.	Protection
4	CRD 4.16 Cell Vent Mechanism		Protection
5	CRD 4.50 Cell Thermal Test	100% SOC at 130 °C for 1 Hr. Temp. ramp Speed:5 ± 2°C/Min.	Criticality
6	CRD 4.52 Cycled Cell/ Short-Circuit Test 55°C		Criticality

* Criticality = Severity x Occurrence
* UN DOT and UL 1642/2054 are basic requirement.

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2. Simulate RPN to the IEEE Cell Cattery Certification

2) Classification of RPM Class

No.	Test Clause	Test Information	RPN Class
1	**Isolation Properties**	80% SOC,150 , 10 min.	**Criticality**
2	**Cell Thermal Test**	100% SOC, 130 , 60 min.	**Criticality**
3	**Cycled Cell/ Short-Circuit**	55°C, 80± 20 mohm	**Criticality**
4	Shrinkage Allowance: Room Temp. Electrode Geometry Electrode Tabs Application of Insulation Supplementary Insulation Internal Short Avoidance Positioning of Insulating Material Shrinkage Allowance: High Temp.	Check Cell Design/ Manufacturing accuracy & uniformity	**Protection**
5	Cell Vent Mechanism	Vent activation pressure	

* Criticality = Severity x Occurrence

3) Definition of RPN rating

No.	Test Clause	RPN rating
1	Isolation Properties	1. Cell Voltage: ≥3.8V and consistence between sample 3. Voltage: 3.8-1.0V and consistence between sample 5. Voltage:≤1.0V or In consistence between sample
2	Cell Thermal Test	1. Cell Voltage: ≥4.0V and consistence between samples 3. Voltage: 4.0-1.0V and consistence between sample 5. Voltage:≤1.0V or Inconsistence between sample
3	Cycled Cell/ Short-Circuit	1. Temp. ≤100 C and consistence between samples 3. Temp. 100-130 C and consistence between samples 5. Temp. ≥130 C or Inconsistence between sample
4	Shrinkage Allowance: Room Temp. Electrode Geometry Electrode Tabs Application of Insulation Supplementary Insulation, Internal Short Avoidance Positioning of Insulating Material Shrinkage Allowance: High Temp.	1. meet the criteria and consistence between samples and test items 3. meet the criteria and consistence between samples, Inconsistence between test items. 5. Inconsistence between samples and between test items.
5	Cell Vent Mechanism	

Simulation and Validation of the FMEA RPN tool

to evaluate a Cell Risk Assessment

Process -4:
Analyze the safety & reliability level of a cell from the Risk Priority Number

Summary and Future Plan

Summary And Future Plan

1. **Developed an effective Cell Risk Assessment tool with the CTIA certification (Under IEEE 1625/1725 Standard).**

   - by adding additional evaluation criteria of the test to the pass/fail criteria.

   - by add more evaluation items which is strongly related to the Cell safety.

   - by using well modified FMEA RPN (Risk Priority Number) tool

2. **This Cell Risk Assessment Tool/Process has high flexibility to modify**

   ➔ Can be easily adopted to most of the system and process

   - Cell phone/Notebook PC/Power toll/EV system Risk Assessment

   - Surveillance test: Sample in the Market like a FCC Surveillance test

3. **Develop a System Risk Assessment tool for Applications.**