TEST METHOD FOR SIMULATING INTERNAL SHORT CIRCUITS IN LITHIUM ION CELLS

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Corporate Research

The Seventh Triennial International Fire &
Cabin Safety Research Conference

Field Failures

Since 2006, reports of failure but not much detail

- Highly publicized failure of laptops powered by lithium ion batteries including fire and explosion
- Reports of home fires caused by lithium-ion batteries in devices during usage or charging
- Cargo airplane fires involving bulk transport of lithium ion cells and NTSB investigation of passenger 787 plane
- Electric vehicles are based on lithium ion cell chemistries sometimes utilizing several thousands of commercial, off the shelf (COTS) cells
- In some cases, it has been noted that defects lead to internal short circuit (ISC) and thermal runaway




CPSC Recall Data (1/2008-3/2012)

Identifying lithium-ion cells as the battery type (compiled by UL staff)

467	**Number of Reported Incidents**
2,056,318	**Quantity of Product Recalled**
353	**Number of Incidents with Fire/Burn Hazard**

Battery can overheat posing a fire hazard

GM VOLT BATTERY INCIDENT

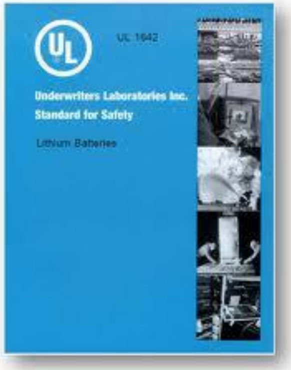
Incident: NHTSA post-crash fire (June 2011)

Cause: As a result of the crash, a stiffener damaged some batteries and ruptured coolant system inside battery compartment leading to short circuit.

To keep the battery operating safely, the Volt battery system “has more parts than the *rest of the car combined*, including 600 seals and cooling components.”

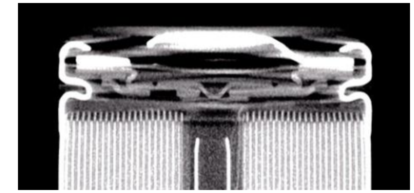
RESEARCH OBJECTIVE

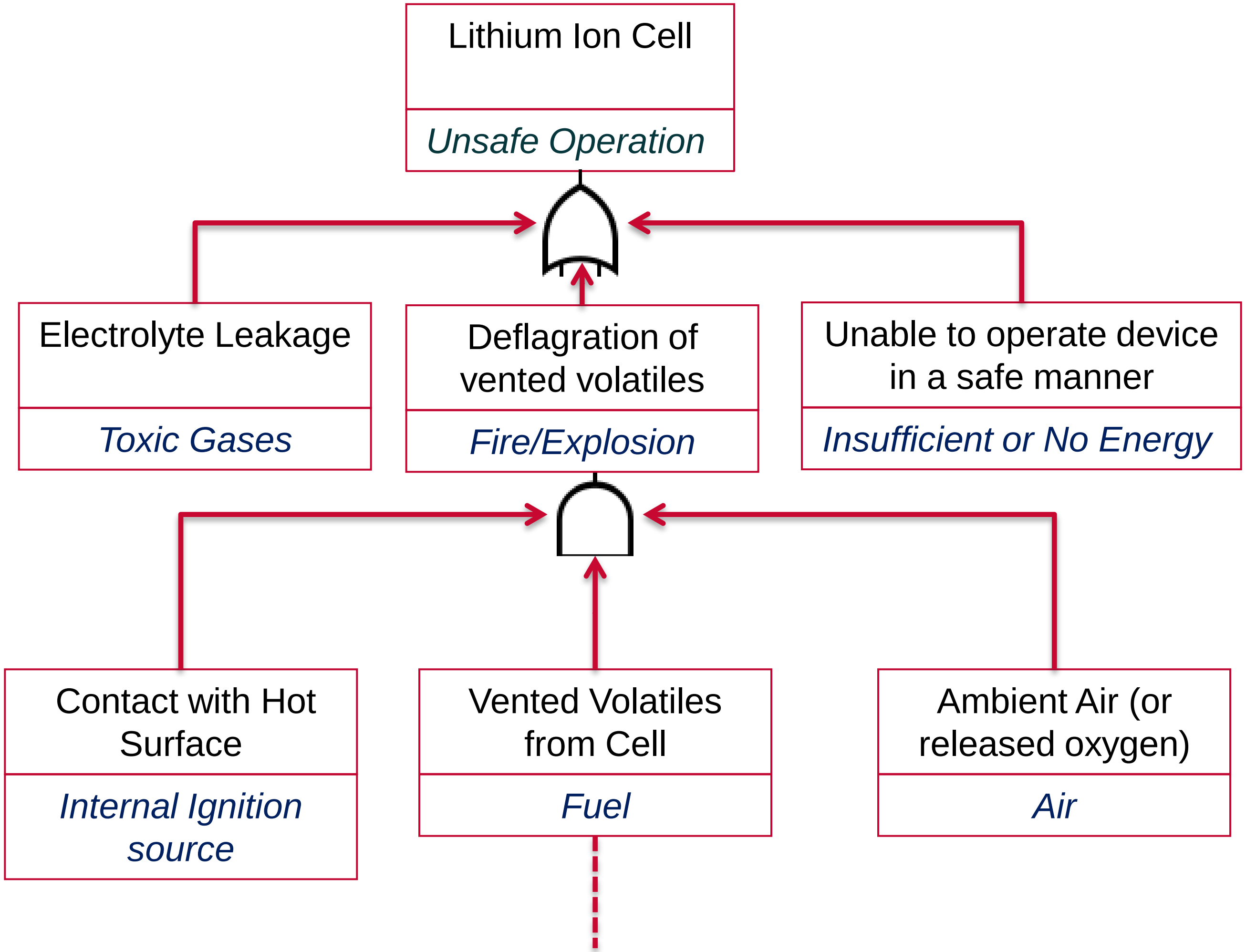
Consider the need for a new test for UL 1642 to address field failures of lithium ion cells



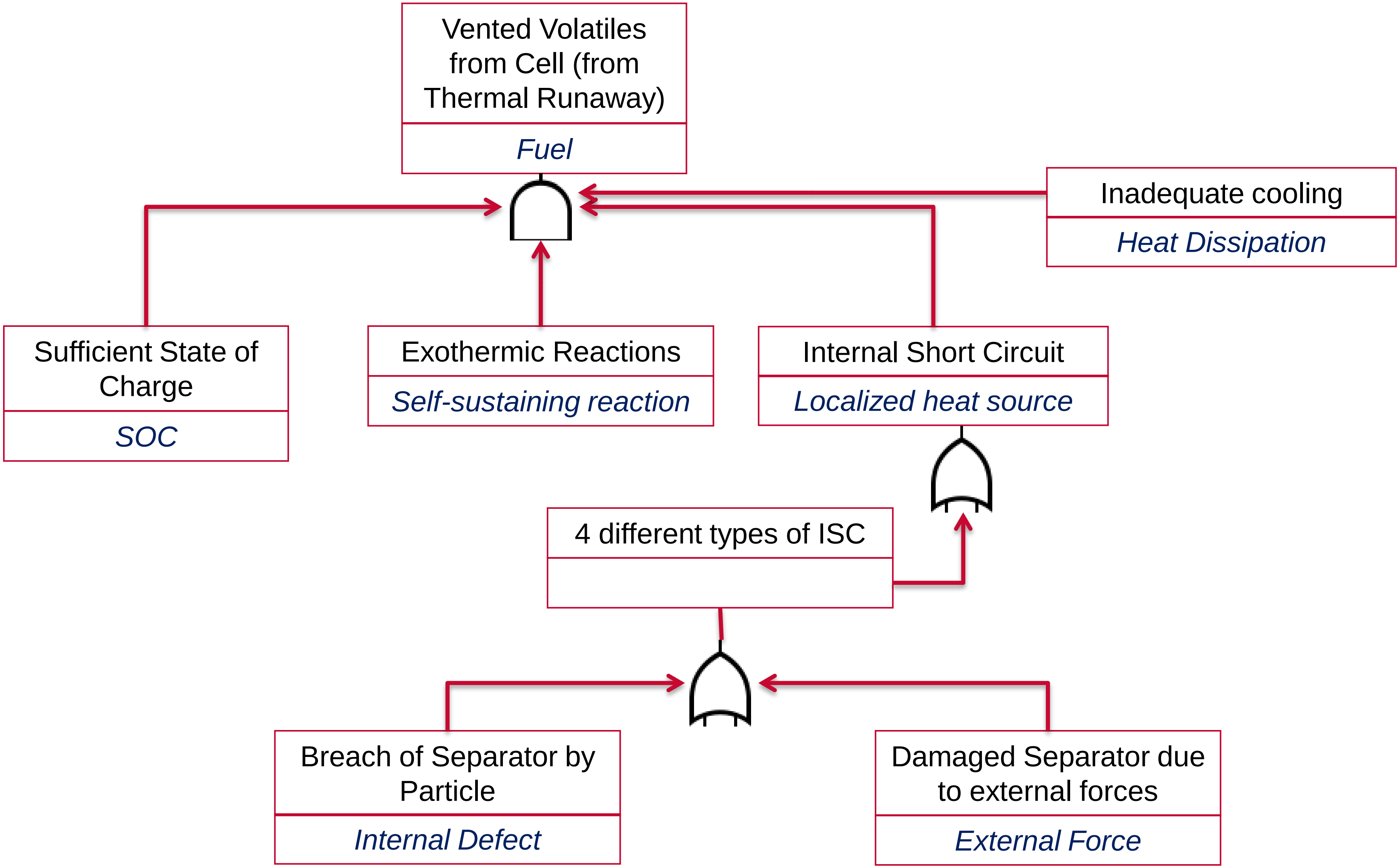
Focus Area: <u>Internal Short Circuit of a Cell</u>

FAULT TREE ANALYSIS



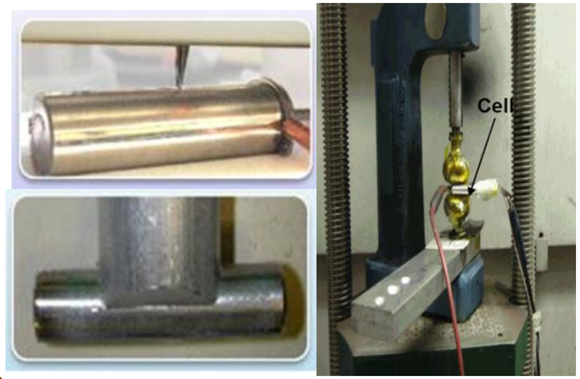


Deeper into the FTA



Internal Short Circuit (ISC)

EXTERNAL FORCE
- *Crush*
- *Penetration*
- *Indentation*
- *Vibration*



INTERNAL DEFECT
- *Manufacturing*
- *Aging (overcharging, etc.)*

ISC

Localized Temperature Increase

Exothermic Reactions

Heat Dissipation

- 'Safe Failure'

Thermal Runaway

- Fire
- Explosive release of gases
- Leakage
- Cell to Cell propagation

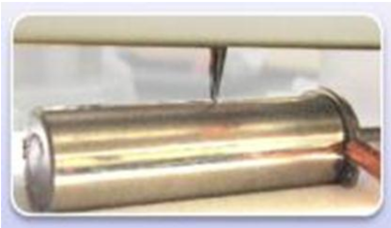
UL 1642 Testing Task Group

OBJECTIVE

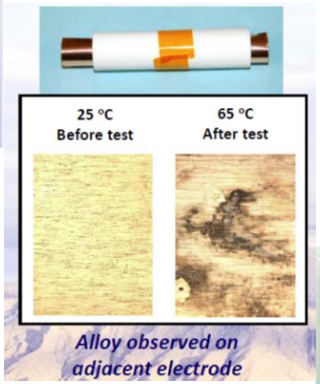
Help support review and revision of an ISC test method that might be *suitable* for battery safety standard

BSCI
Dell
Dupont
E-One Moli
Exponent
Ford Motor Company
IBM
ITRI
Motorola
NASA
ORNL
Panasonic
SNL
SONY
UL (chair)
CDC-NIOSH

Review of ISC Test Methods



Slow Speed
Nail Penetration
Test
ITRI

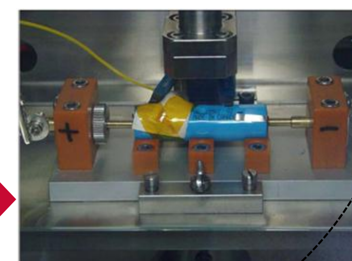


Low-Melting Point
Metal/Alloy Triggered
ISC Test
SNL/NREL

Forced ISC Test
BAJ

Pinch Test
ORNL

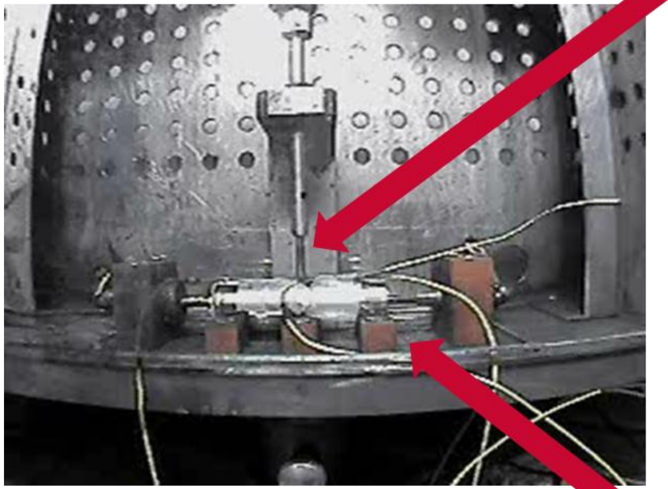
Indentation Induced
ISC Test
UL/NASA



Indentation Induced ISC Test

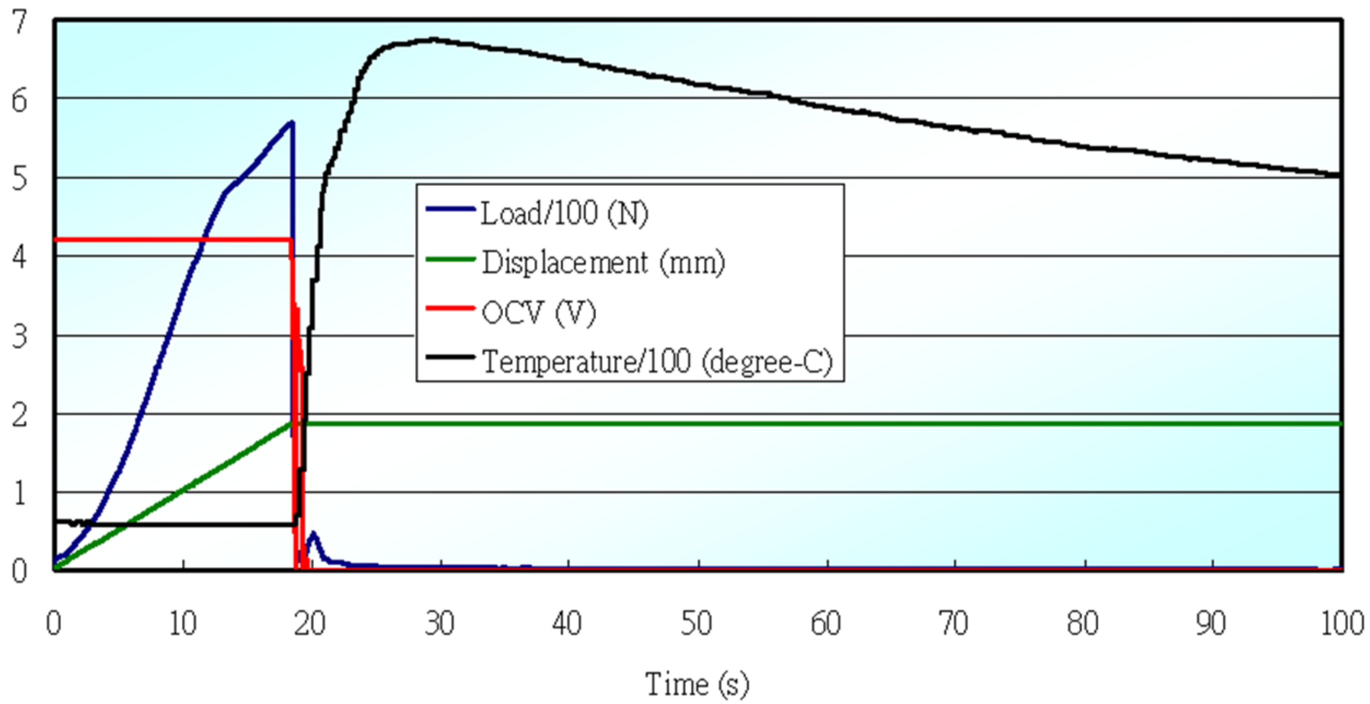
- **Features of New Test Method**
  - Localized indentation of cell without penetration
  - Controlled speed and temperature conditions
  - Specified state of charge (SOC) and cycle life of cell
  - Measure cell surface temperature, open circuit voltage (OCV), displacement and force of indenter along with visual observations
  - Induce failure to assess performance of cell

Indenter moving at specified speed

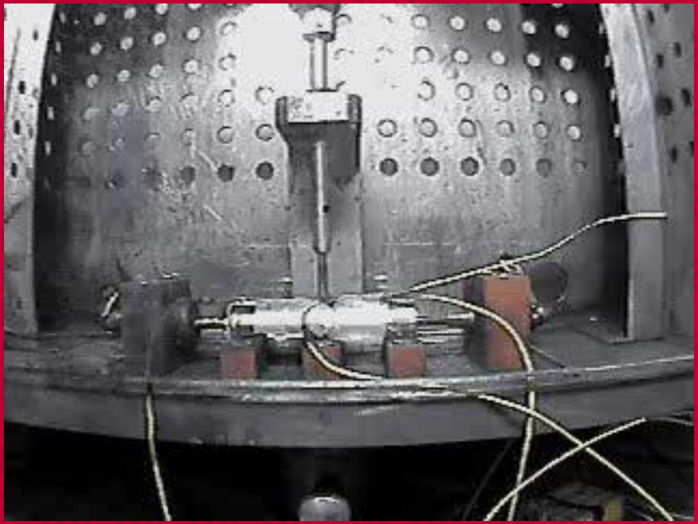


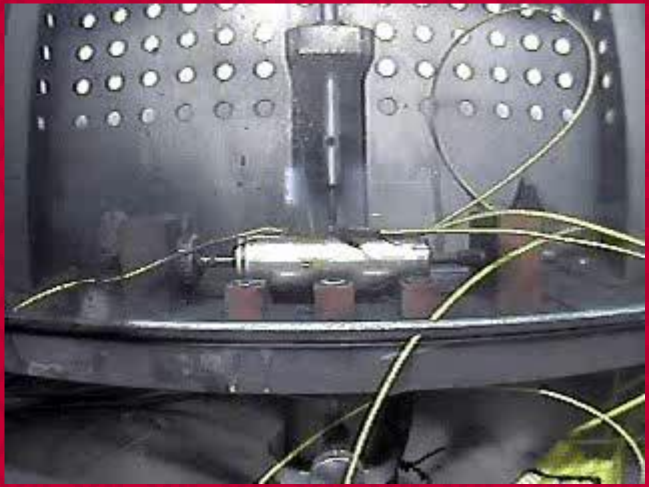
Battery specimen held in place

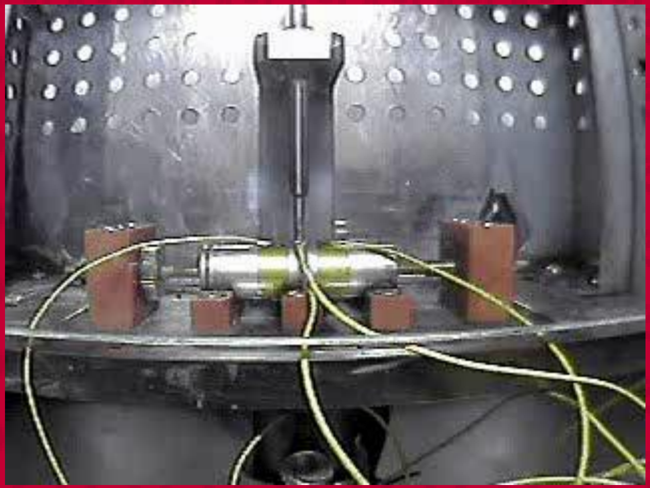
SAMPLE RESULTS



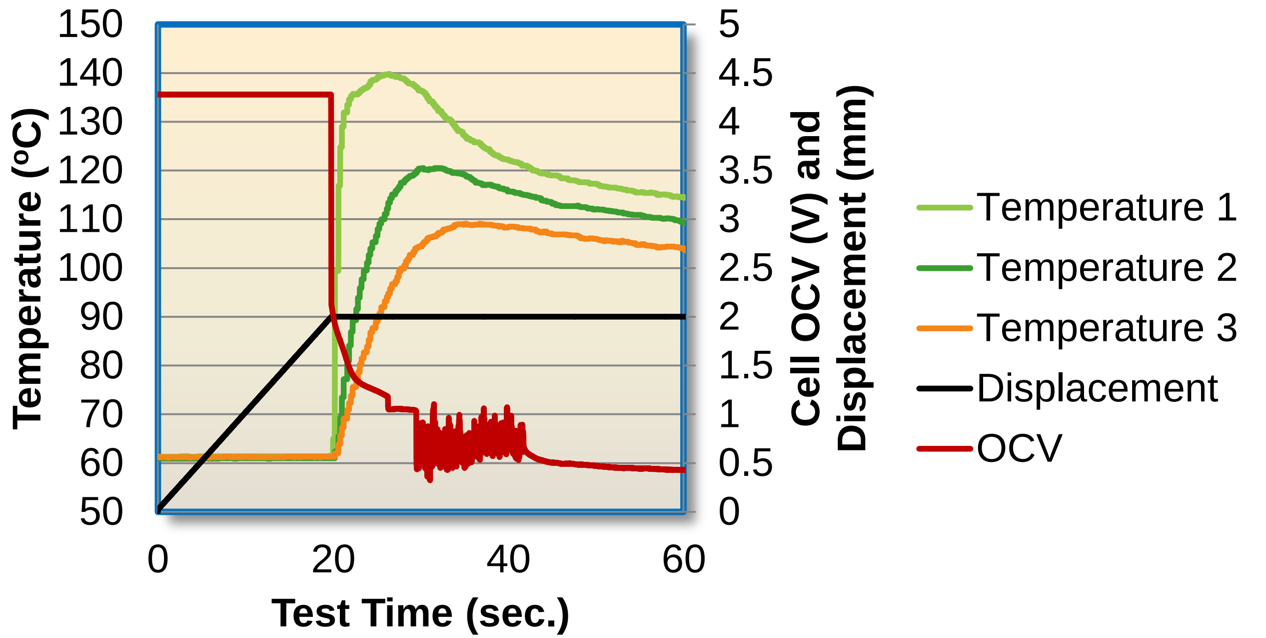
- Observed flames and smoke





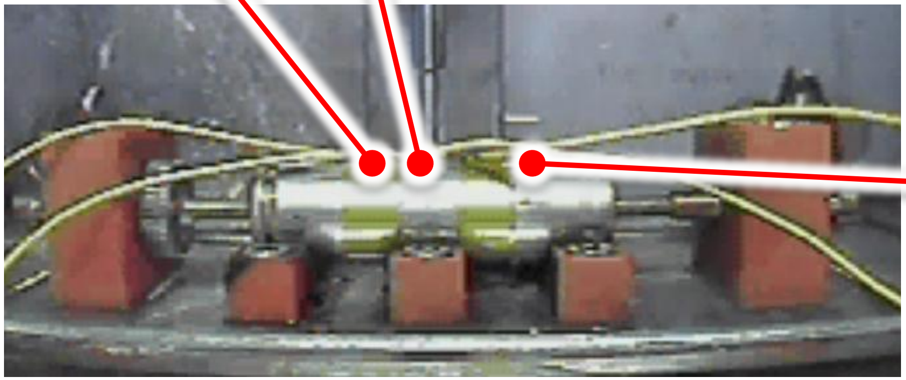


TEMPERATURE DISTRIBUTION



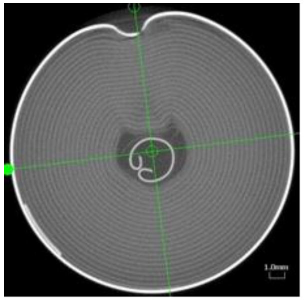
Temperature 1:
Closest to ISC point
Peak:
139ºC at 25 sec

Temperature 2:
Peak:
120ºC at 32 sec



Temperature 3:
Farthest to ISC point
Peak:
109ºC at 34 sec

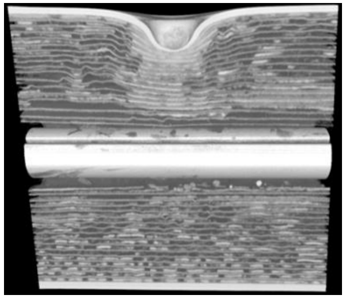
SIMULATING FIELD FAILURES

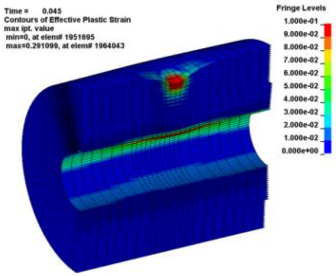


0% SOC

- Localized ISC (1-2 mm radius)
- Low impedance pathway
- Depth several layers
- Maintain heat transfer pathways (do not puncture cell)
- Location is near surface of cell

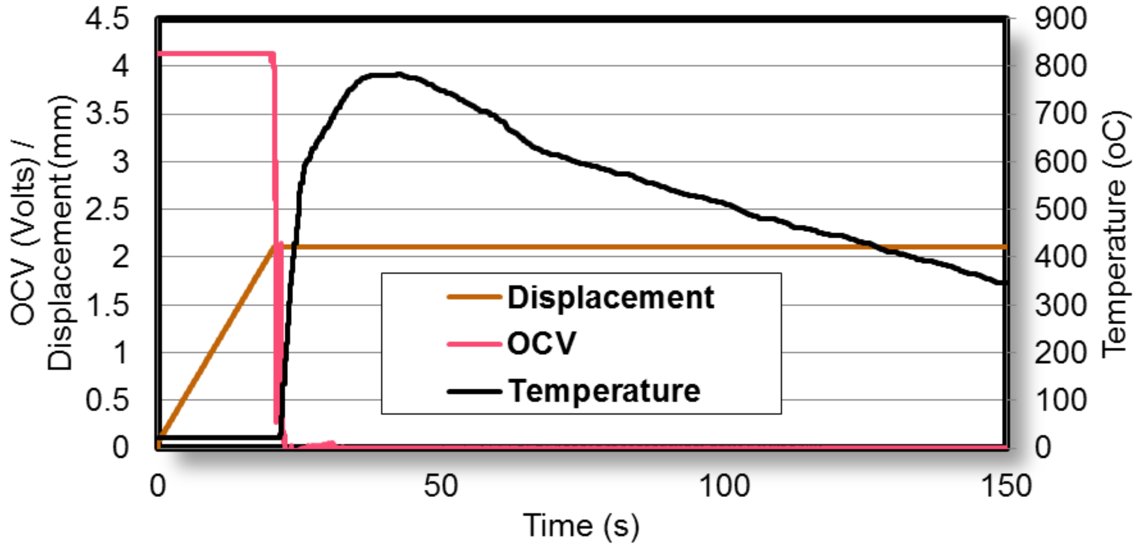
50% SOC



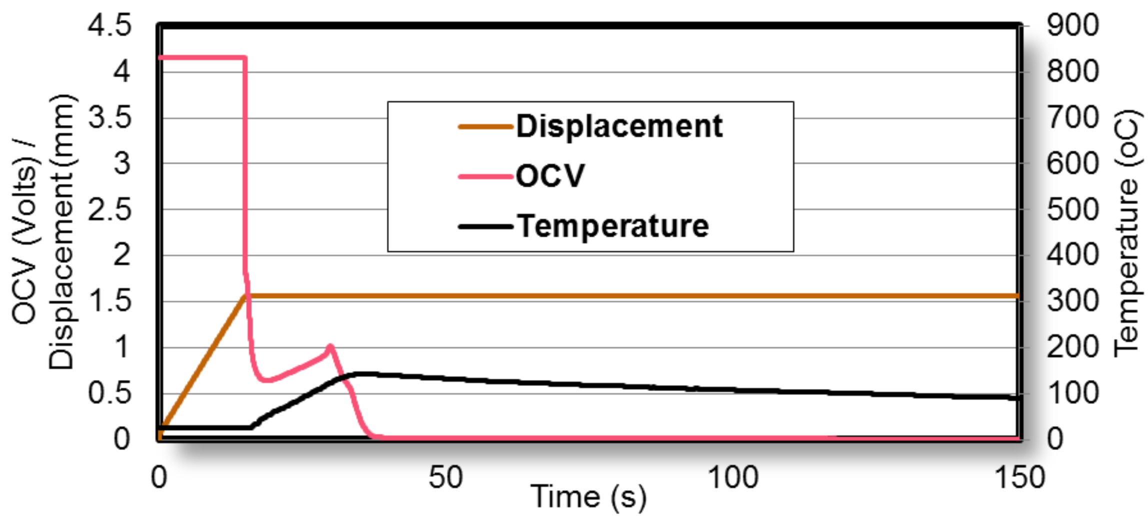


STOBA in 18650 Cells

18650-type NMC (1950 mAh) without STOBA additive
25˚C



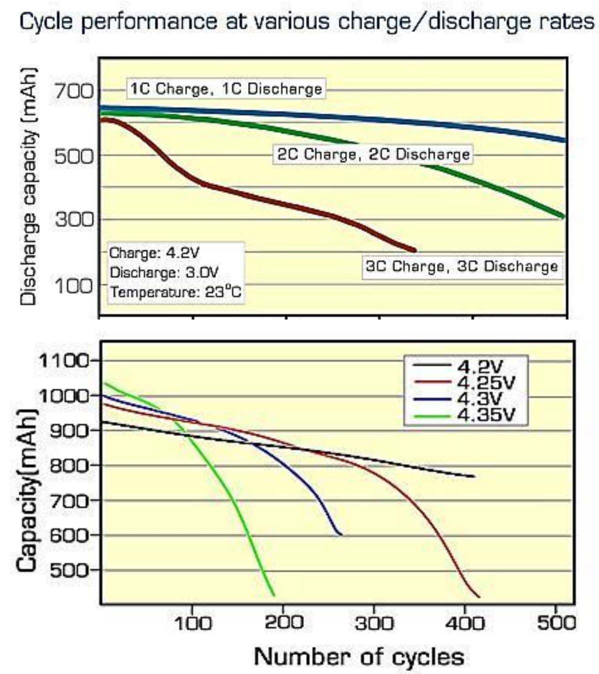
18650-type NMC (2000 mAh) with STOBA additive
25˚C



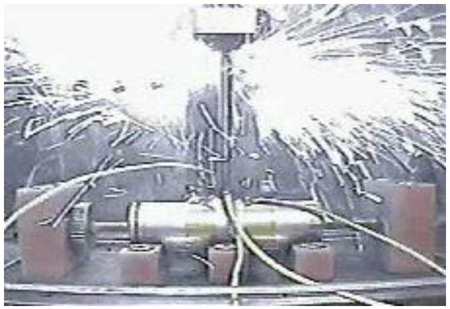
AGING EFFECT ON SAFETY

- Capacity deterioration
- Power loss

- Material degradation
- Internal pressure increase
- Impedance increase

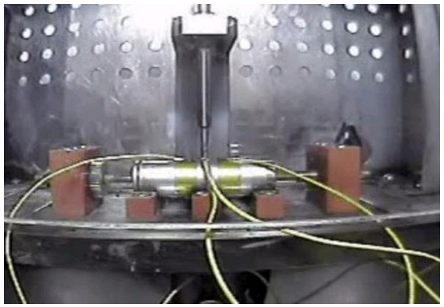


AGING EFFECTS ON ISC

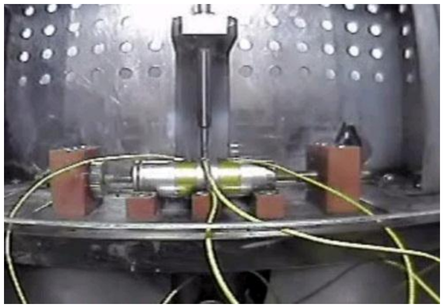


New Cell
100% fails (N=3)

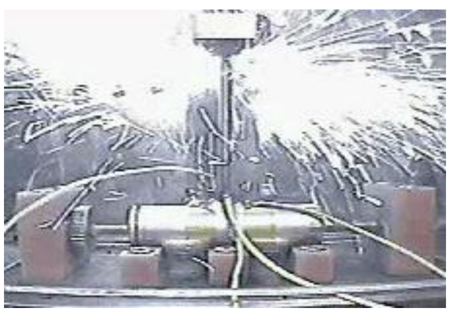
45°C



200 Cycle Aged Sample
1 cell pass and 1 cell fail

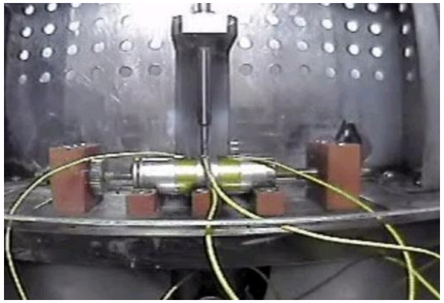


400 Cycle Aged Sample
2 cells pass

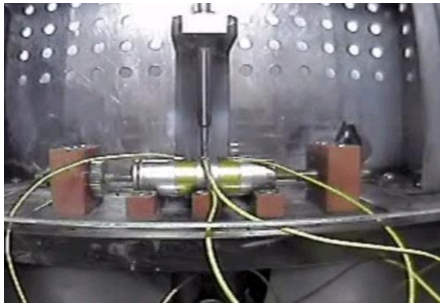


New Cell
100% fails (N=3)

20°C

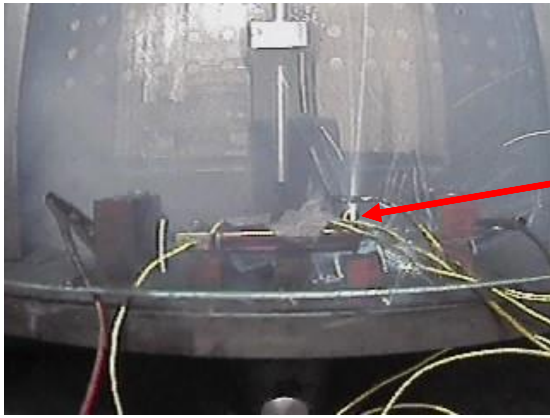


100 Cycle Aged Sample
1 cell pass and 1 cell fail



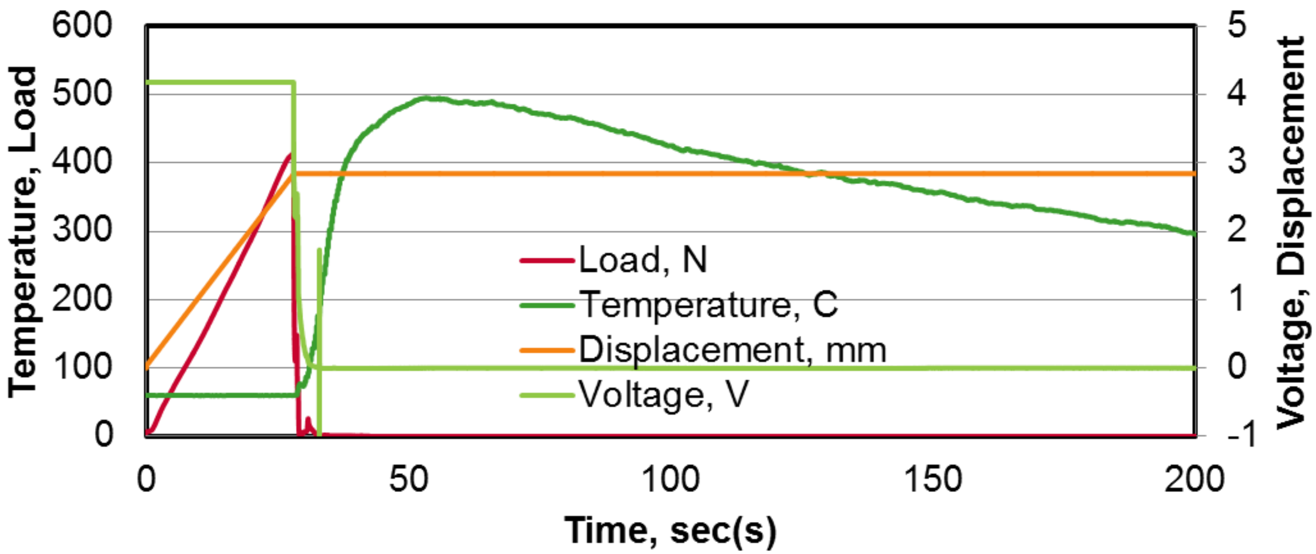
400 Cycle Aged Sample
2 cells pass

Prismatic Cells



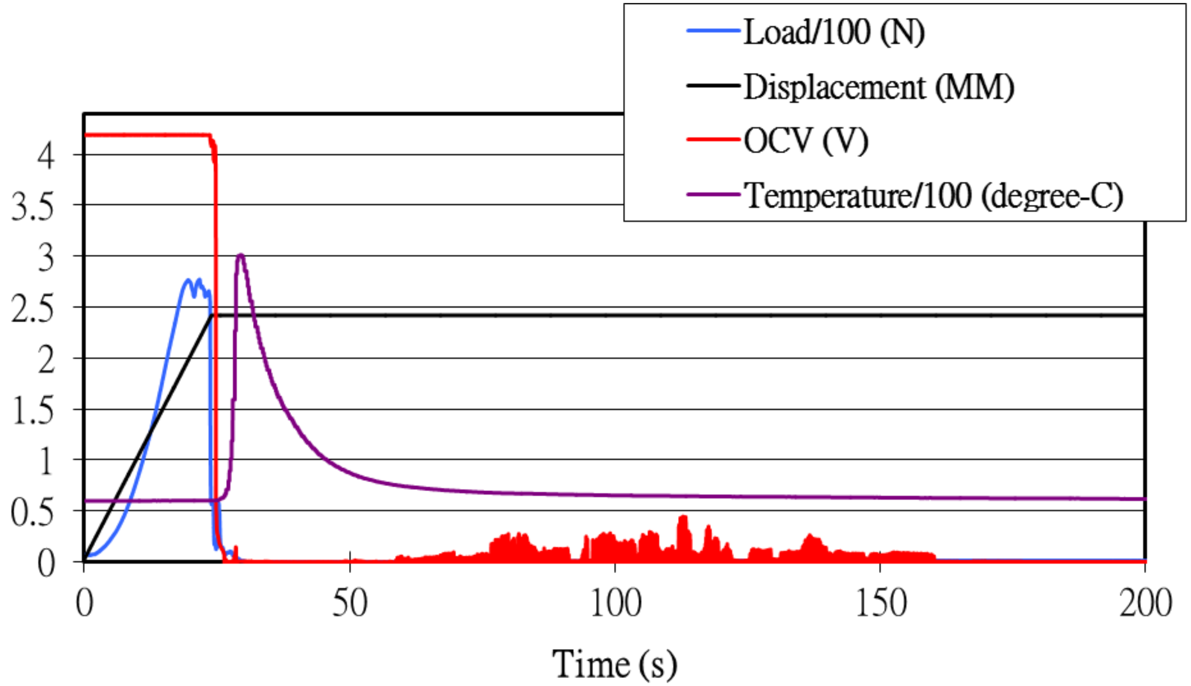
Cell expanded, fire and spark

Cell casing was punctured



Lithium cobalt oxide, 1900 mAh, 4.25 V

POUCH CELLS

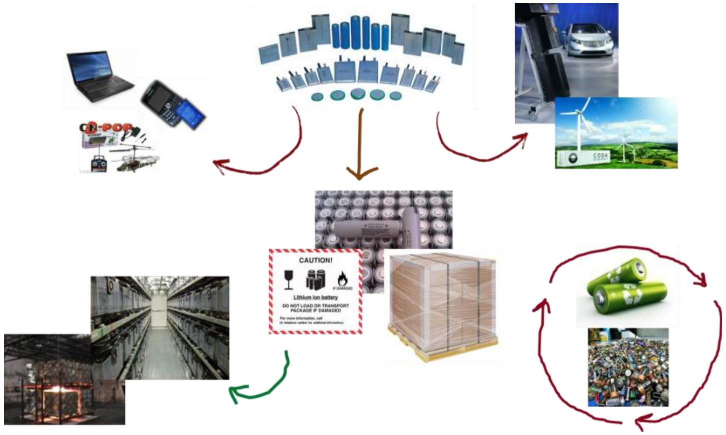


Casing is punctured by indenter (load drops before OCV drop)

Lithium cobalt oxide, 2150-3800, mAh, 4.25 V

CHALLENGES

- UL is considering safety aspects of lithium-ion cells from the single cell to large number of cells throughout the lifecycle.



- Challenges to lithium-ion battery safety testing include:
  - Access (cost) to large number of cells and/or large format batteries
  - Battery technology is still evolving and there is no single representative cell type
  - Sound safety laboratory protocols for testing program especially for many cells, modules, and packs.

SUMMARY

At the cell level, UL is working on developing a new ISC test method for battery safety standard (UL 1642)

- *Simulates internal short circuit by creating a small localized defect in separator*
- *Induce failure of the cell for cylindrical, prismatic, and pouch*
- *Sensitive to design changes that affect safety performance*
- *Method suitable for standards testing*

UL is actively improving existing standards and developing new standards building on cell safety all the way to battery system safety

- *Large format focus (UL 2580, UL 2271, UL 1973)*
- *Revising cell requirements to address specific applications*
- *Verifying cell operating region*
- *Ensuring system maintains cell operating region*
- *System FMEA/Functional safety*

THANK YOU.