# Materials and Designs for the Mitigation of Thermal Runaway Propagation – An Update

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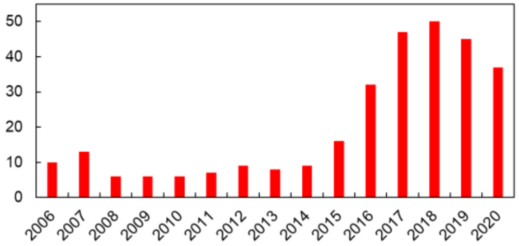
UNDERWRITERS LABORATORIES™

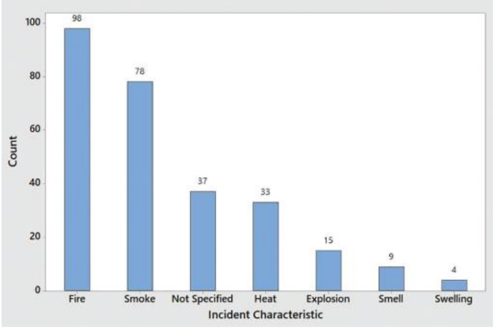
# Introduction

- Thermal runaway in lithium-ion cells and batteries has been an area of significant safety concern.
- Thermal runaway may occur from off-nominal conditions due to mechanical, electrical, or thermal hazards.
- Heat released from thermal runaway and propagation may lead to catastrophic incidents.
- Restrictions based on state of charge (SOC) are in place for transporting batteries.
- Multiple incidents involving batteries have necessitated propagation prevention measures to limit damages.
- The goal of this work is to study the efficacy of commercially available materials that would prevent thermal runaway propagation or contain it within shipping container.

Events with smoke, fire, extreme heat or explosion involving lithium batteries reported by FAA[1]




Incident characteristics of thermal runaway events in U.S. commercial aviation[2]




1. https://www.faa.gov/hazmat/resources/lithium_batteries/media/Battery_incident_chart.pdf
2. Kapp EA, Wroth DS, Chapin JT. Analysis of Thermal Runaway Incidents Involving Lithium Batteries in U.S. Commercial Aviation. *Transportation Research Record*. 2020;2674(11):584-592.

# Work Plan and Test Variables

The test articles are 18650 Li-ion cells

Configuration: 25P (25 cells in parallel); 25 single cells

SOC: 100%; 33%

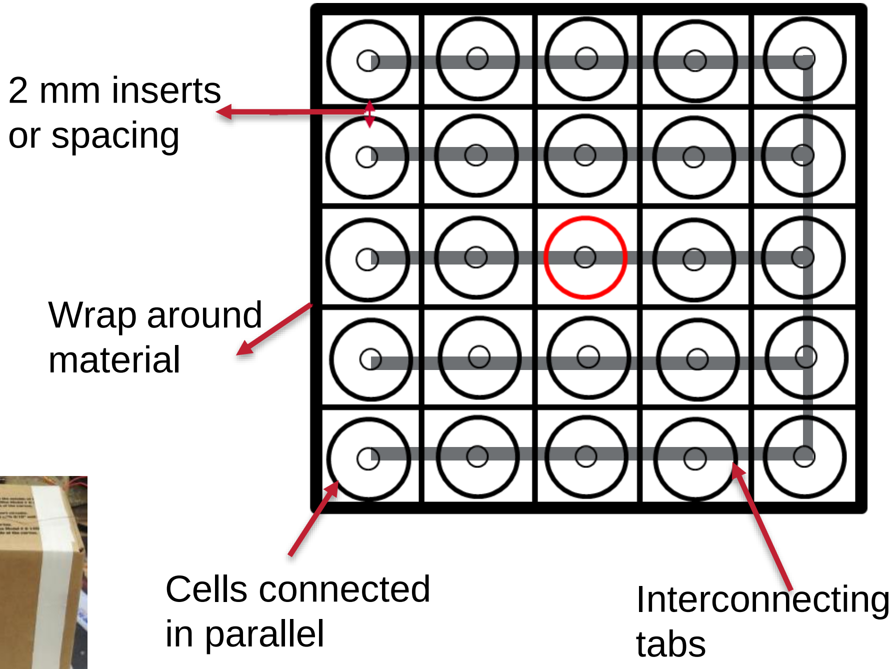
Trigger cell location: center

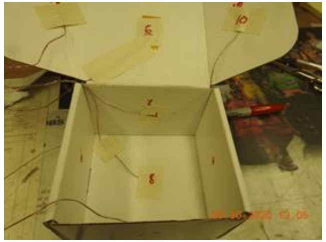
Materials to study Propagation Mitigation: Eight manufacturers (A, B, C, D, E, F, G, H)

Target heating rate for trigger cell: 10 °C/min; flexible tape heater

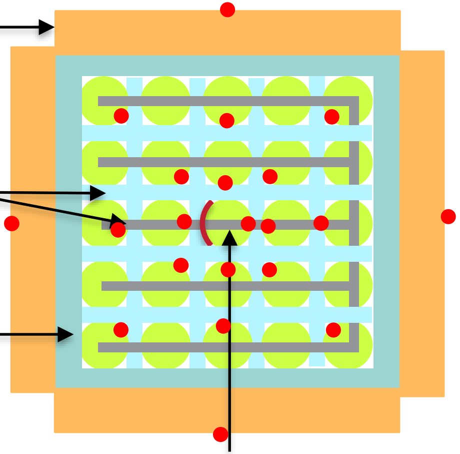
Corrugated generic packaging box; UN-rated box

## Test Article Configuration



# Test Article Configurations Showing Typical Thermocouple locations




Bottom of the configuration with inserts between cells


Top of the configuration with connected cells in block material

Test configurations with different mitigation materials

Insulation layer between the top of the cells and the package


**Mitigation Strategies:**

- Low conductivity thermal barrier between cells
- High conductivity heat dissipation
- Heat sink and fire retardation

# Past Work – Tests at 100% SOC

Pre-test Post-test

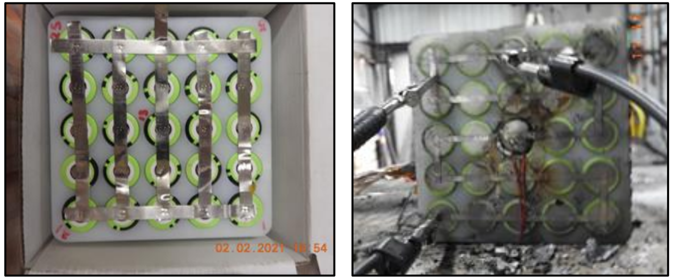
Manufacturer A

Manufacturer C

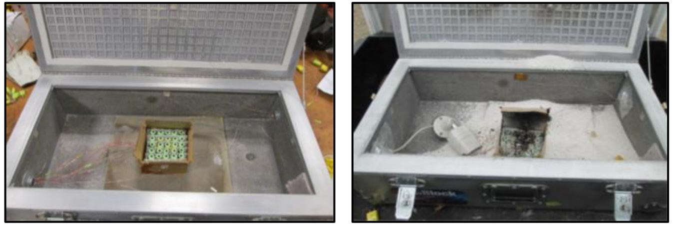
Manufacturer D

Full propagation of thermal runaway

Pre-test Post-test



Manufacturer B

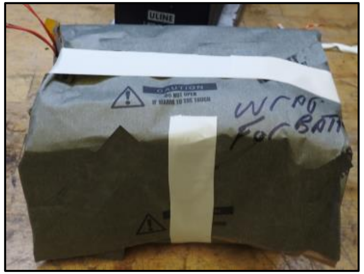


Manufacturer E

No thermal runaway propagation

# 100% SOC Tests

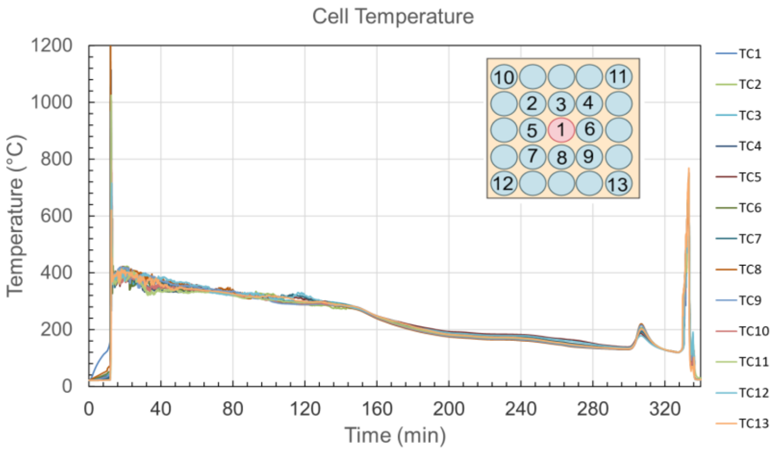
# Manufacturer F – 100% SOC 25P Cell Configuration

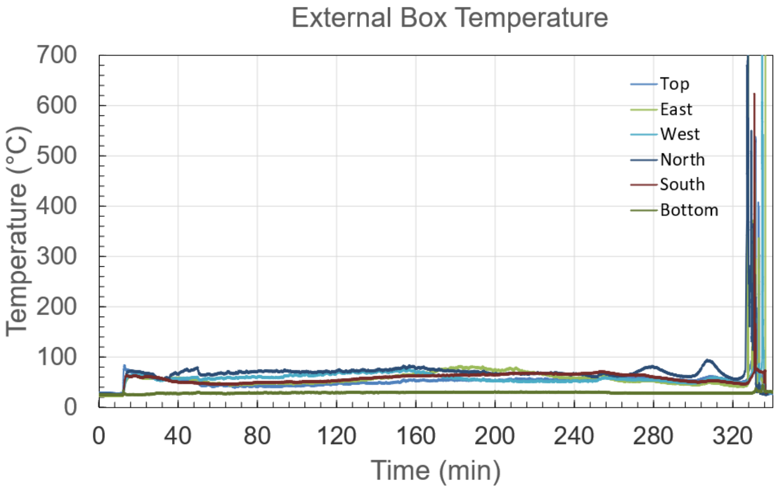





**Pleated wrap material**
**Sleeves around cell**
**16”x16”x16” container with liners and pleated wraps**

# Manufacturer F – 100% SOC 25P Cell Configuration



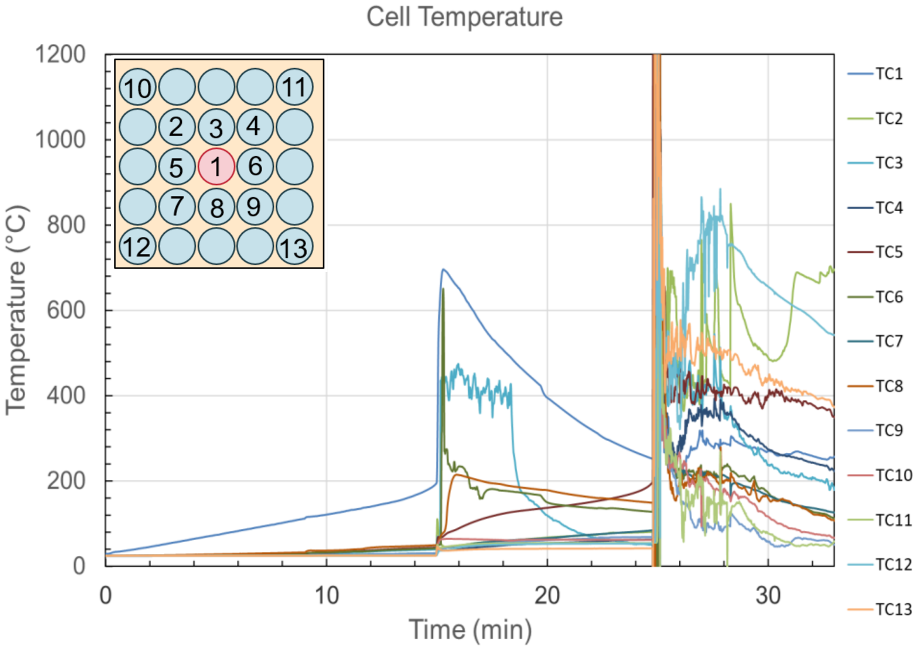




- Full propagation of thermal runaway
- 5+ hours from trigger cell thermal runaway to box burnout/deflagration

# Manufacturer F – 100% SOC 25P Cell Configuration

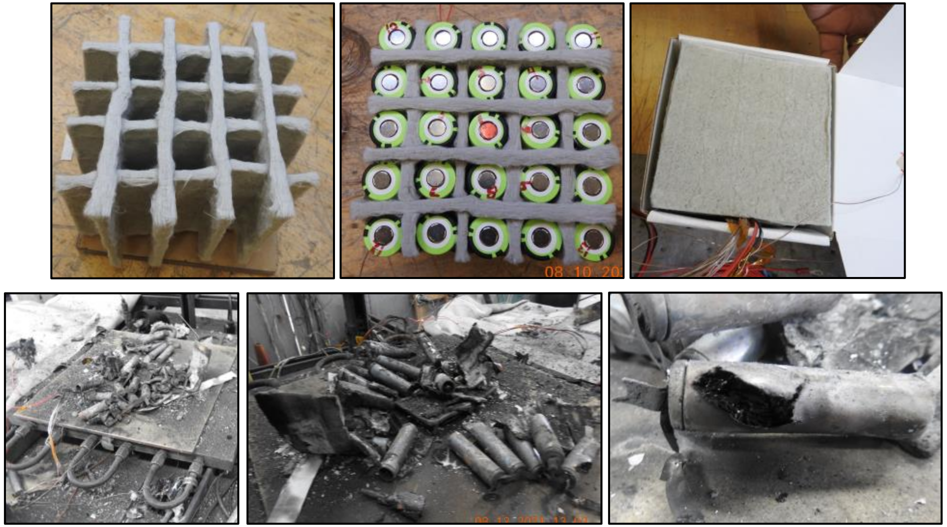

- Full propagation of thermal runaway
- Box expansion and opening; delayed deflagration of box

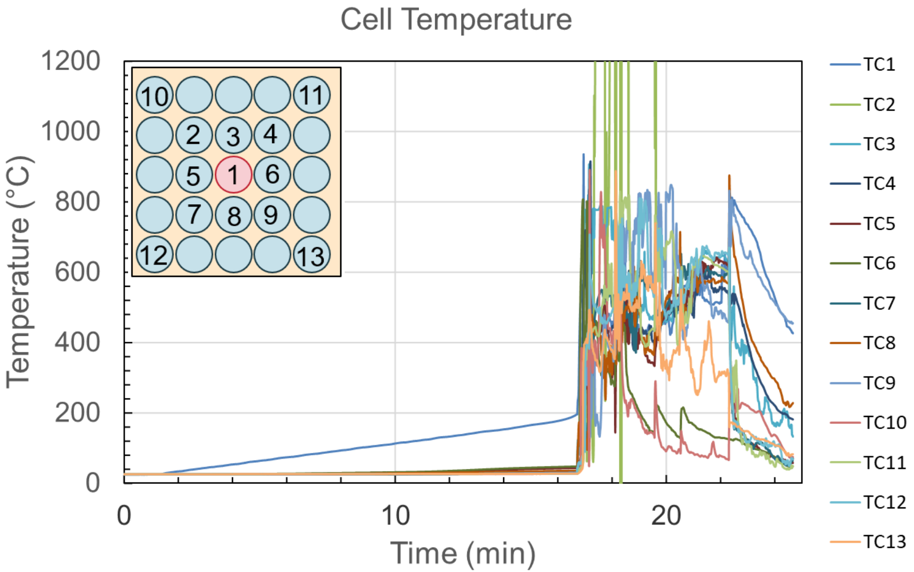
# Manufacturer G – 100% SOC 25P Cell Configuration




- 2mm insulation material configurated in grid pattern
- Full propagation of thermal runaway
- Multiple cells with sidewall rupture

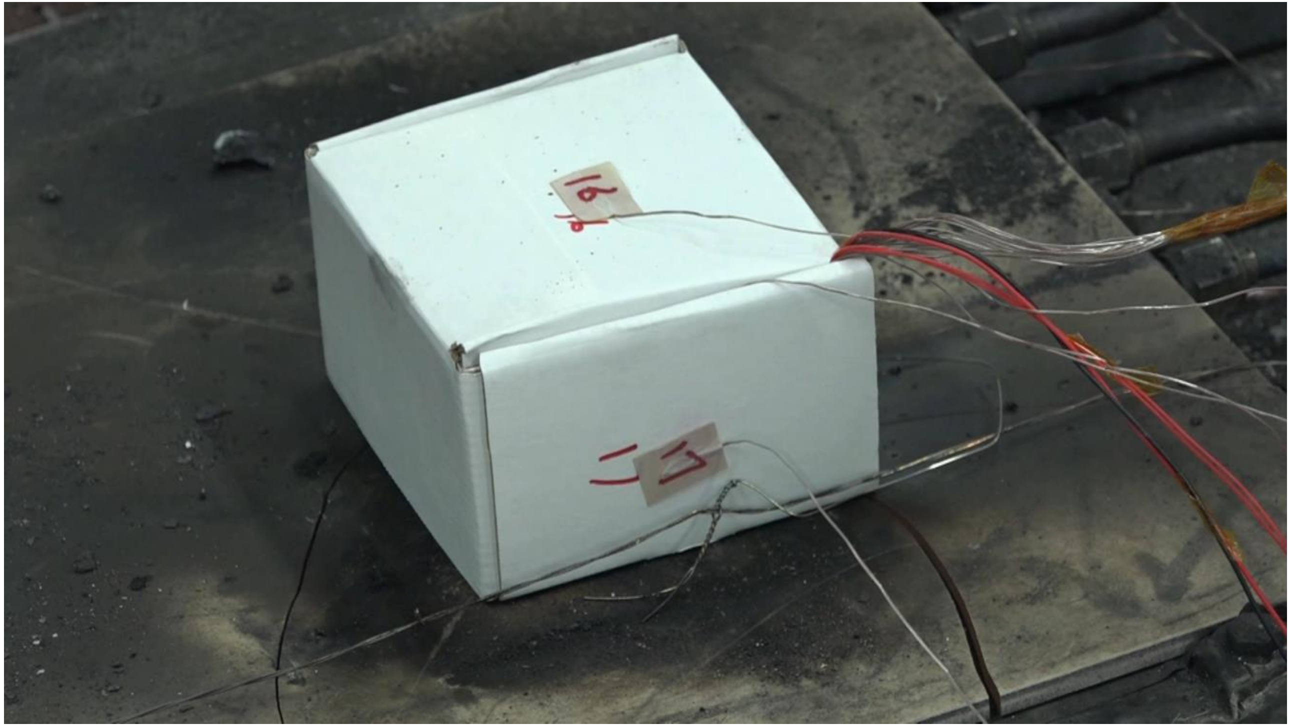
# Manufacturer G – 100% SOC 25P Cell Configuration






- 4mm insulation material configurated in grid pattern
- Full propagation of thermal runaway
- Multiple cells with sidewall rupture

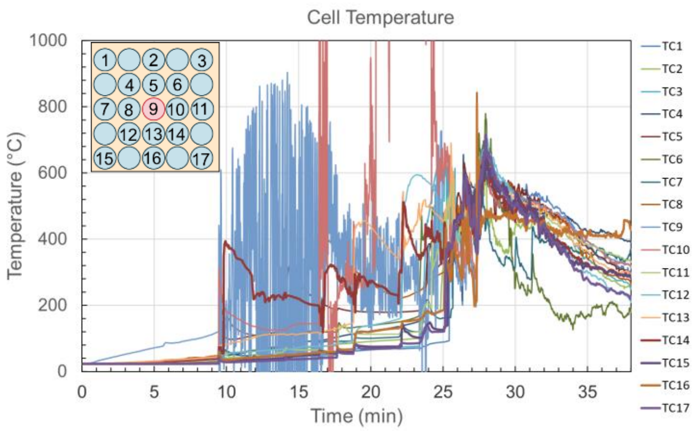
# Manufacturer G – 100% SOC 25P Cell Configuration



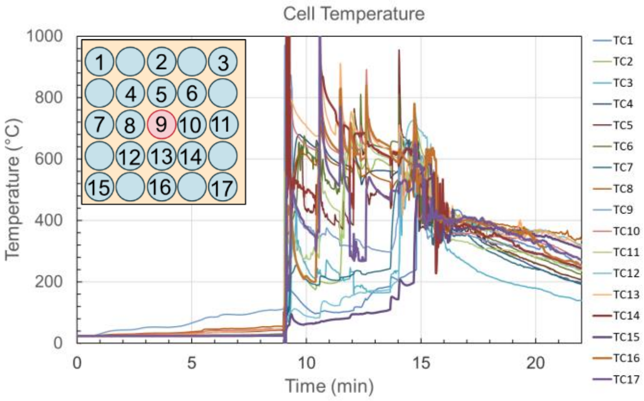
- 4mm insulation material configurated in grid pattern
- Full propagation of thermal runaway

# Manufacturer H – 100% SOC 25P Cell Configuration

## Regular box

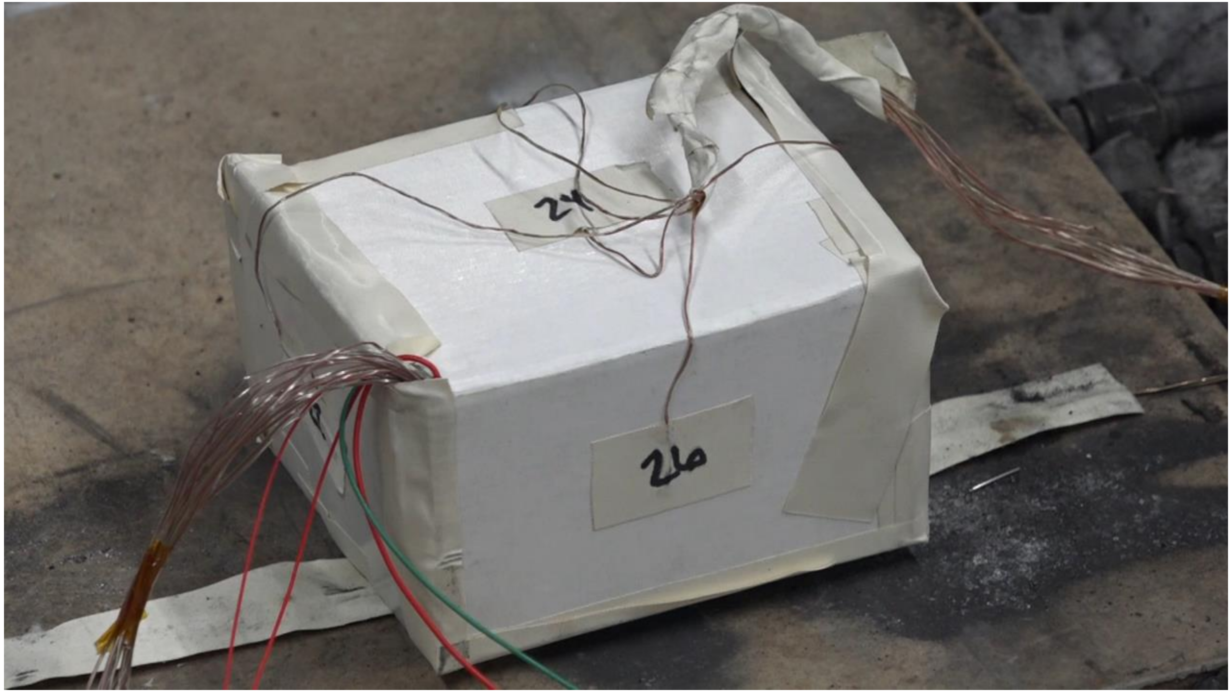



## UN-rated box




- Intumescent coating on intercell separators and box
- Full propagation of thermal runaway; fire
- Expansion of intumescent coating; fluffy

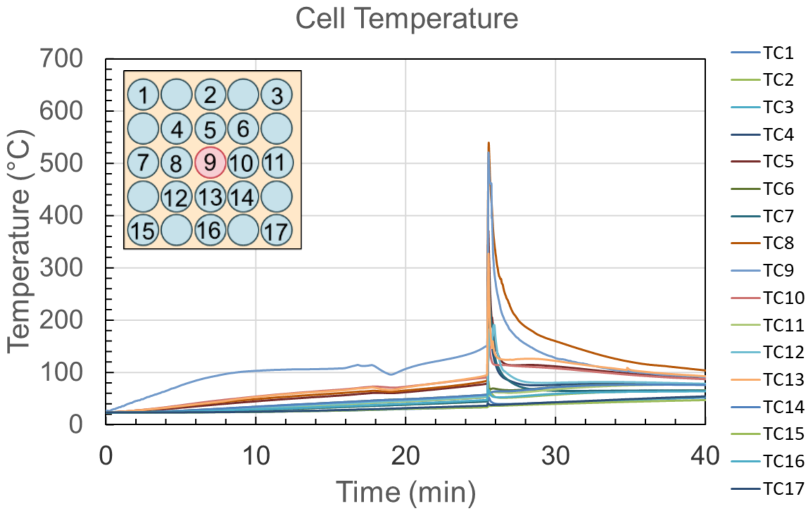
# Manufacturer H – 100% SOC 25P Cell Configuration



- Intumescent coating on intercell separators and box
- Full propagation of thermal runaway; fire
- Expansion of intumescent coating; fluffy

# 33% SOC Tests

# Manufacturer B – 33% SOC 25P Cell Configuration

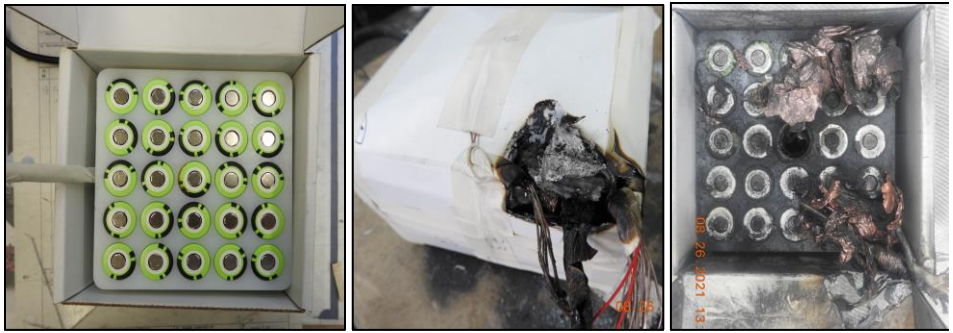


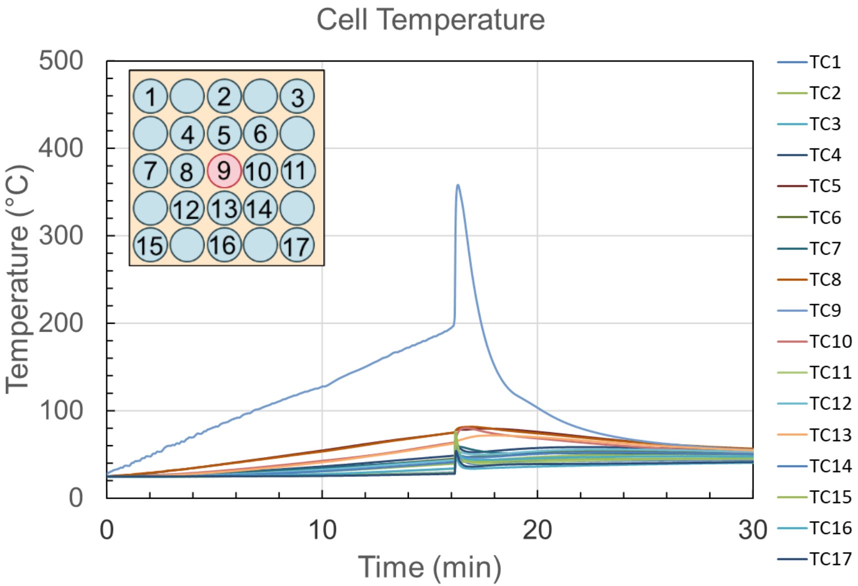

- Block/Mold with 2mm wall between cells
- Gas and electrolyte release
- Lower post-test voltage on 4 neighboring cells

# Manufacturer B – 33% SOC 25P Cell Configuration

- Block/Mold with 2mm wall between cells
- Gas and electrolyte release

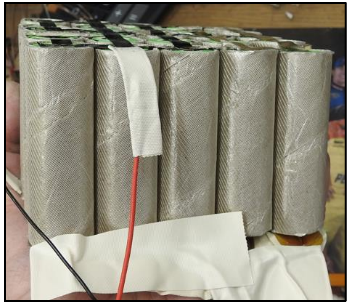
# Manufacturer B – 33% SOC 25 Single Cell Configuration

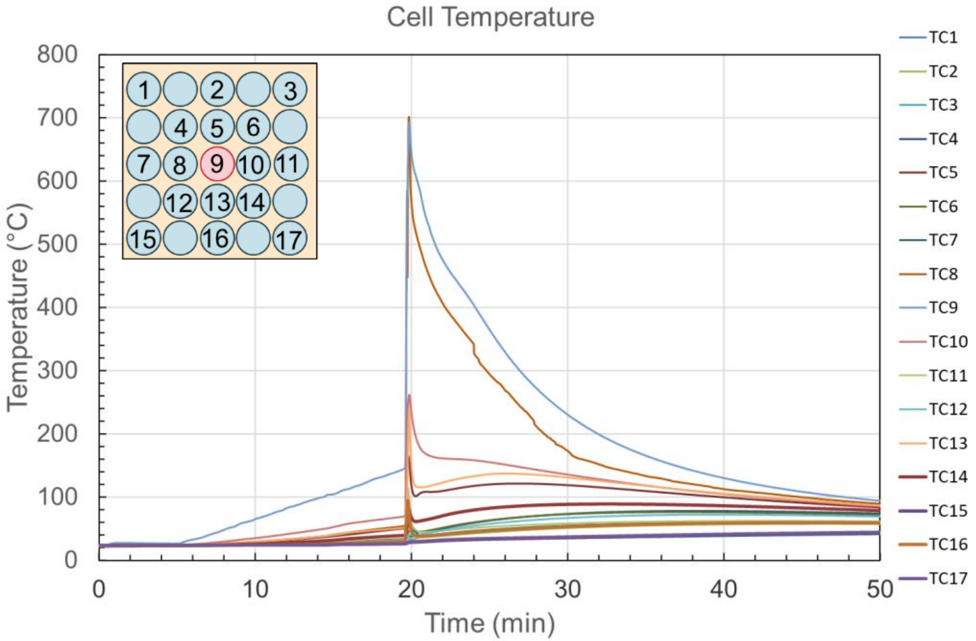





- Single cell configuration
- Trigger cell ejection from block; fire
- No propagation of thermal runaway

# Manufacturer C – 33% SOC 25P Cell Configuration



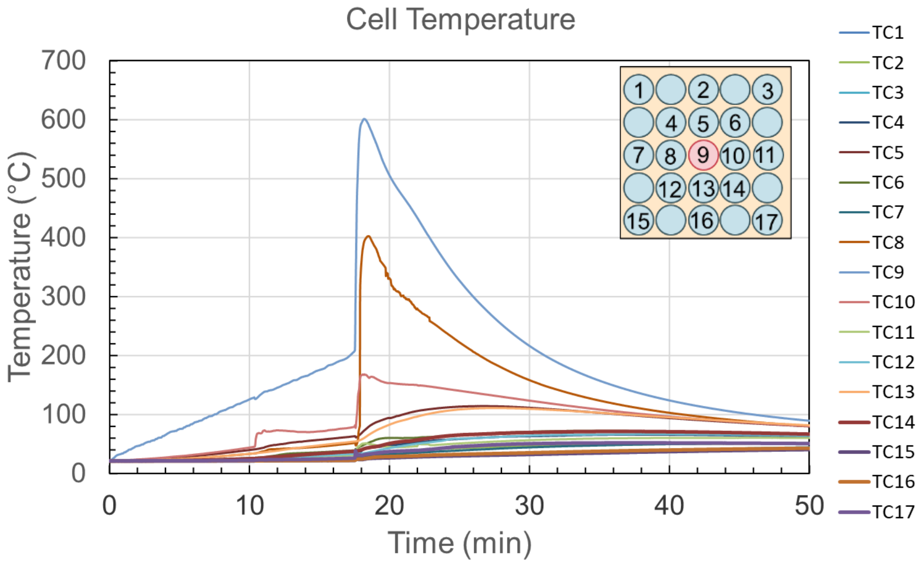



- Flexible mica type tubes on each cell; mica flame barrier on top
- No propagation from trigger cell to neighboring cell
- Electrolyte leak from the trigger cell was observed inside and under the box

# Manufacturer C – 33% SOC 25P Cell Configuration

- Flexible mica type tubes on each cell; mica flame barrier on top
- No propagation from trigger cell to neighboring cell
- Electrolyte leak from the trigger cell was observed inside and under the box

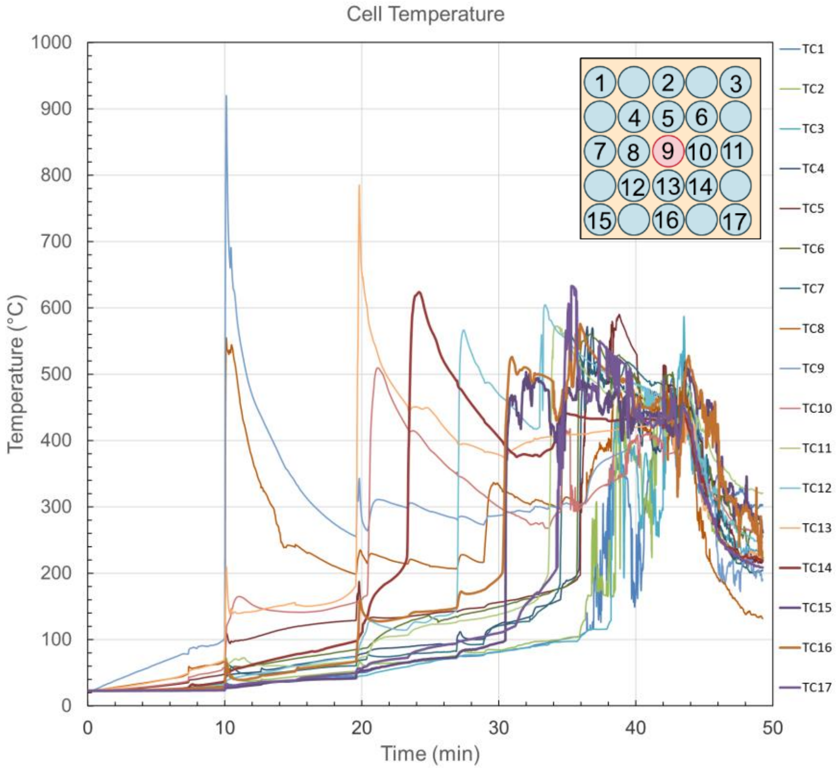
# Manufacturer C – 33% SOC 25 Single Cell Configuration




- Flexible mica type tubes on each cell; mica flame barrier on top
- Fire following trigger cell; box fire
- No propagation from trigger cell to neighboring cell
- All cells recorded maintained pre-test voltage after the test
- Electrolyte leak from the trigger cell was observed inside and under the box

# Manufacturer D – 33% SOC 25P Cell Configuration



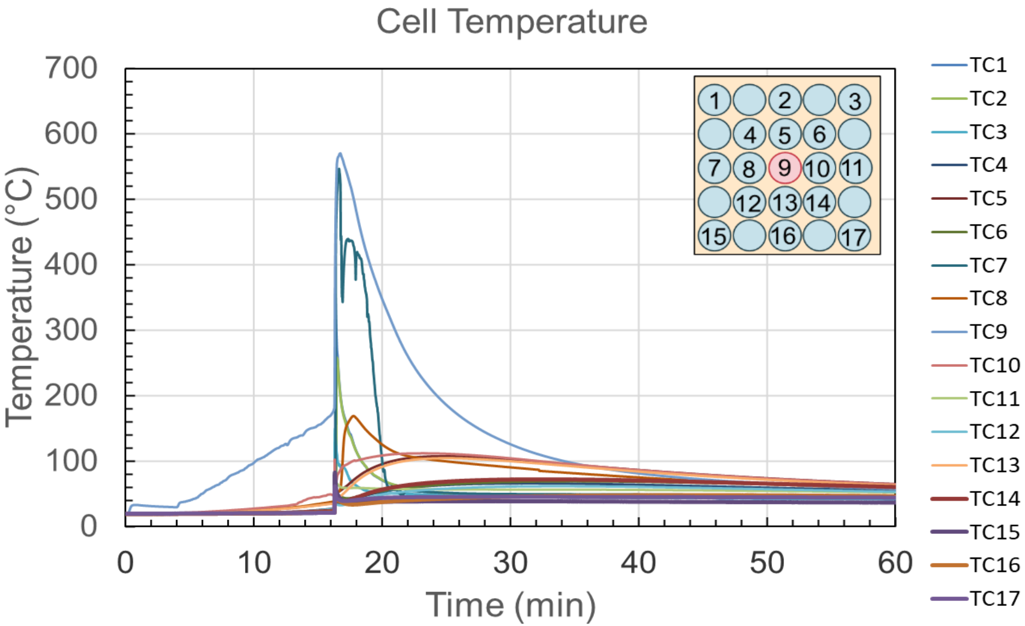



- Intumescent material; 2mm separators
- Heavy gas and electrolyte release
- Full propagation of thermal runaway; fire

# Manufacturer D – 33% SOC 25P Cell Configuration

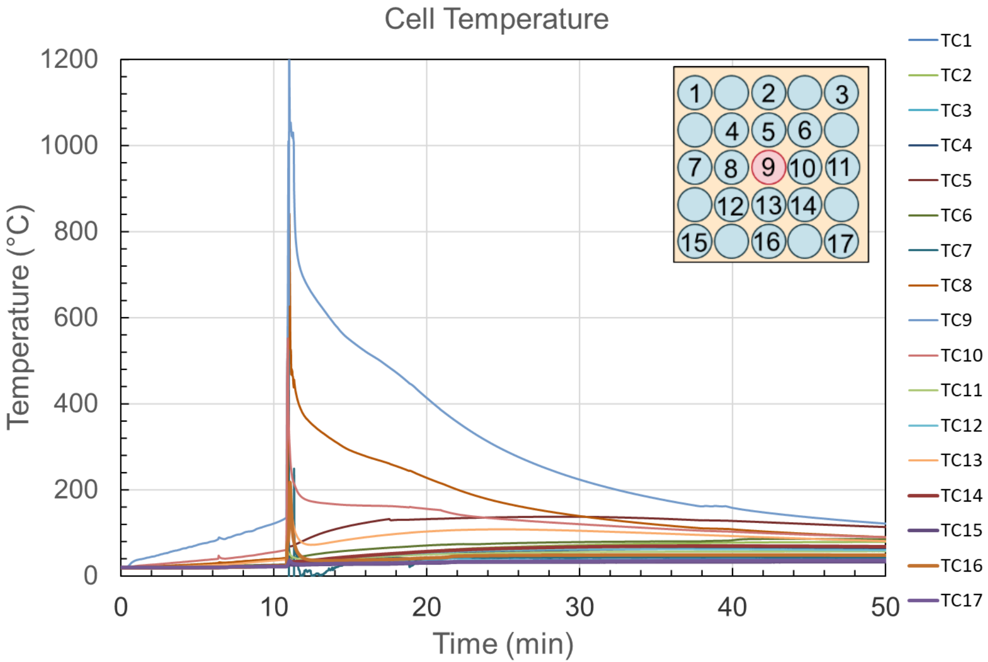
- Intumescent material; 2mm separators
- Heavy gas and electrolyte release
- Full propagation of thermal runaway; fire

# Manufacturer D – 33% SOC 25 Single Cell Configuration




- Intumescent material; 2mm separators
- Fire following trigger cell thermal runaway initiation
- No propagation of thermal runaway
- Lower post-test voltage on 3 neighboring cells

# Manufacturer G – 33% SOC 25P Cell Configuration

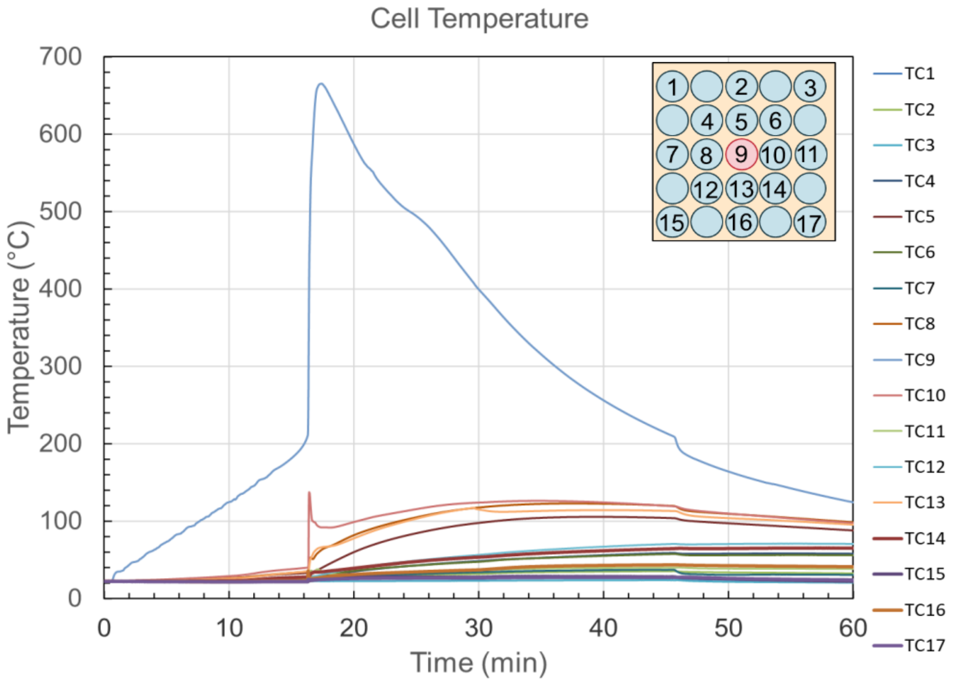



- 2mm insulation material configurated in grid pattern
- No thermal runaway propagation
- Electrolyte leak from the trigger cell was observed inside and under the box

# Manufacturer G – 33% SOC 25P Cell Configuration

- 2mm insulation material configurated in grid pattern
- Gas release after trigger cell went into thermal runaway
- Electrolyte leak from the trigger cell was observed inside and under the box

# Manufacturer G – 33% SOC 25 Single Cell Configuration




- 2mm insulation material configurated in grid pattern
- No thermal runaway propagation
- Electrolyte leak from the trigger cell was observed inside and under the box

# Properties of Materials Studied to-date

| Materials | Thermal Conductivity (W/m.K) | Phase Transition Temperature |
|---|---|---|
| **Manufacturer A** (Kaowool) | 0.06 (260 ºC)<br>0.12 (538 ºC) | - |
| **Manufacturer B** Block/Mold | 0.65 | 122 ºC |
| Pouch | 0.74 (xy plane) | 95-110 º C(Thermal Dissipation – 1600 - 2000 J/g) |
| **Manufacturer C**<br>Flexible Mica Tubes | 0.04 (22 ºC); 0.15 (816 ºC) | - |
| Flexible Flame Barrier | 0.2 (200 ºC); 0.35 (400 ºC) | - |
| **Manufacturer D**<br>Intumescent cell separators | 0.54 | Expansion Temp: 200 ºC |
| Intumescent flat sheets | 0.54 | Expansion Temp: 200 ºC |
| **Manufacturer G** | 0.024 (0 ºC)<br>0.054 (600 ºC) | - |

# Summary and Future Work

- Materials from eight different manufacturers have been studied to-date.
- Commercially available products and small size to fit a shipping package were chosen.
- Cells connected in parallel as well as single cells were studied in packaging configurations.
- At 100% SOC, materials from one manufacturer prevented propagation of thermal runaway in the configuration studied.
- The block/mold provided better efficacy at mitigating the propagation compared to interlocking separators or sleeves at 100% SOC and interconnected cells.
- Insulative materials were effective in preventing propagation at 33% SOC. Intumescent cell separators prevented propagation for single cells but full propagation occurred for test with interconnected cells.
- Better solutions to manage vented gases, liquid electrolyte, and ejected content are needed from mitigation materials for worst-case scenarios.
- Future work will involve working with other material manufacturers to find solutions.

# Acknowledgment

-Test team at NASA-JSC for carrying out the tests

-Material manufacturers for working with us to get the suitable materials and requested configurations

-Underwriters Laboratories for funding this work

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https://ul.org/what-we-do/electrochemical-safety