UL 9540A Testing and Results

Excepts from UL Test Report commissioned by NEC Energy Solutions
UL 9540A Testing...

- Answers the questions:
  - Does a thermal runaway condition propagate from one battery component to another?
    - Cell to Cell
    - Module to Module
    - Rack to Rack
  - Initiated in one component using an artificial thermal stimulus
  - Effects on neighboring components are observed
  - Effects of system mitigations are observed
A cell sandwiched between other cells is outfitted with a film heater to initiate a thermal runaway condition

Nearby cells temperatures are monitored
The exterior temperatures of the module are also monitored.
The initiating module is placed in the third position up in the initiating rack.

Other modules’ front and back temperatures are monitored.
Target Rack Instrumentation Locations

- The temperatures on neighboring target racks are also monitored.
Mitigations in place:

- Clean agent fire suppressant triggered by smoke detectors
- Water spray triggered by heat sensitive nozzles
- Deflagration vents in case of explosion (not used)
Test Set-up Photos
Here we go...

- “Bring you to the precipice of life and death and then let you go into oblivion.”
Here we go...

- \(~6 \, ^\circ\text{C/min}\)
- \(~33.5\) min of heating to hold temp of 210 \(^\circ\text{C}\)
- Thermal runaway at 34 min, 42 sec clock time
- Thermal runaway behavior consistent with previous LG cell, module and unit tests
UL 9540A Installation Level Large-Scale Fire Test
## Event Timeline

<table>
<thead>
<tr>
<th>Event</th>
<th>Time (HH:MM:SS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test start</td>
<td>00:01:00</td>
</tr>
<tr>
<td>Heating Initiating Cell to Thermal Runaway</td>
<td>00:01:00 to 00:34:42</td>
</tr>
<tr>
<td>Smoke Detector Activation and Novec Discharge</td>
<td>00:35:18</td>
</tr>
<tr>
<td>Propagation Within Initiating Module</td>
<td>00:34:42 to 00:48:11</td>
</tr>
<tr>
<td>Propagation to Other Modules Within Unit</td>
<td>00:47:37 to 00:62:55</td>
</tr>
<tr>
<td>Sprinkler Operation and Waterflow</td>
<td>00:63:36</td>
</tr>
<tr>
<td>Decision to Terminate Test</td>
<td>00:66:20</td>
</tr>
<tr>
<td>Waterflow Discontinued – “Overhaul Monitoring”</td>
<td>00:72:42 – 18:45:00</td>
</tr>
</tbody>
</table>
Effects of Clean Agent Discharge

- Smoke detectors activated within 40 seconds of thermal runaway
- No flames observed before clean agent discharge
- Gas cooling, loss of visibility, well mixed room after clean agent discharge
- Gas composition monitoring equipment saturated with clean agent, loss of operability
- < 5 °C temperature rise near ceiling before clean agent discharge
Cell to Cell Propagation

- Propagation proceeded to all cells within the initiating module
- Propagation time period was 14 minutes
- Clean agent had limited effect on propagation speed and duration
Module to Module Propagation

- Confirmed propagation to 6 other modules within initiating rack
- No fire was observed
- Propagated modules were above and below initiating module
Effects of Water Spray Operation

- After clean agent discharge, CFAST simulations suggest heating of room consistent with a 5 kW wastepaper basket fire
- Single water nozzle above rack activated 63:26 minutes after initiation, and 26:54 after thermal runaway
- Cooled room to < 175 °C in less than 30 seconds
- Prevented other spray nozzles from activation
Effects on Target Racks Nearby

Prior to water spray operation, temperatures of nearby target racks were less than 55 °C.

- Water spray caused an immediate jump in some surface temperatures to 100 °C probably because of steam heat transfer.
- Internal temperature remained un-phased.
- Similar effects observed in other two target racks.
Effects on Nearby Wall

Nearby wall temperatures (12” away) increased to 300 °C

Water spray system immediately cooled those temperatures to < 97 °C
Post Test Conditions

Racks 1 - 3

Initiating Rack
Detection:
- No flames observed from thermal runaway prior to clean agent discharge
- Both smoke detectors activated in less than one minute after thermal runaway initiation

Suppression:
- After the clean agent discharge, CFAST modeling suggests hearing of room consistent with a 5 kW fire (typical wastebasket fire)
- Flames not observed and improbable after clean agent discharge
- 175 °F water nozzle head activated 27 minutes after thermal runaway initiated
- Spray from single water nozzle cooled room and precluded activation of other nozzles
- Clean agent prevented analysis of gasses after discharge
Summary of Test Observations

- **Deflagration:**
  - No deflagration activated
  - No flying debris or explosive discharge of gasses

- **Propagation to Target Racks**
  - Temperatures on and in neighboring target racks did not exceed 159 °C (the point at which the lithium ion cells would enter thermal runaway)

- **Propagation to Wall (for indoor combustible construction installations only)**
  - Max wall surface temperature of 300 °C immediately prior to water spray activation
  - Water Spray immediately reduced all wall temperatures to < 97 °C
Conclusions

- NEC Grid Battery System Design *meets* UL 9540A Test Criteria
  - With clean agent fire suppressant
  - With water spray suppression system

- Deflagration concerns
  - Large quantity of explosive gasses are present after cells enter thermal runaway.
  - Deflagration means must be employed in the absence of automatic ventilation means
  - Enclosures must be vented following such an event to eliminate explosion risk.
  - Availability of system data should be available to first responders if requested.