DGP-WG/15-IP/12
20/5/15

DANGEROUS GOODS PANEL (DGP)
WORKING GROUP MEETING (DGP-WG/15)

Montreal, 27 April to 1 May 2015

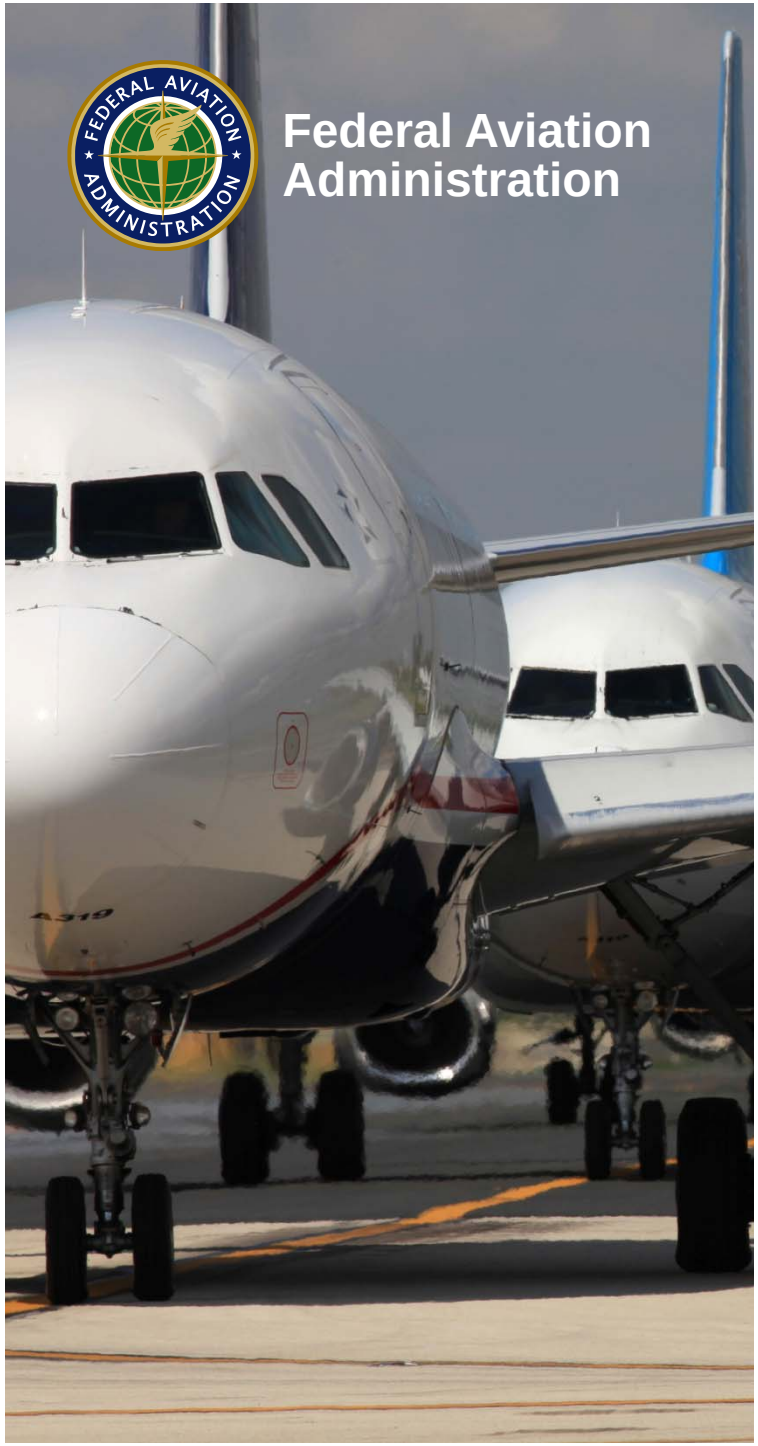
Agenda Item 5: Development of mitigating measures to address risks associated with the transport of lithium batteries including measures that address recommendations from the Second International Multidisciplinary Lithium Battery Transport Coordination Meeting

5.6: Miscellaneous lithium battery issues

PRESENTATION ON THE FAA LITHIUM BATTERY TESTING UPDATE

(Presented by C. Glasow)

FAA Lithium Battery Testing Update



Presented to: ICAO Dangerous Goods Panel

By: FAA Fire Safety

Date: April 27, 2015

Methods of inducing Thermal Runaway

- **Cells are forced into thermal runaway for two purposes**
  1. To evaluate the cell hazards, including:
     - Case temperature
     - Vent gases
     - Flammability
     - Propagation
  2. To evaluate the effect of the thermal runaway on the local environment including:
     - Packaging
     - Adjacent cargo
     - Cargo compartment structure
     - Suppression system effectiveness

Induced Thermal Runaway

- **Cells can be induced into thermal runaway by several means, including:**
  - Over charging
  - Shorting
  - Rapid discharge
  - Physical damage
    - Crushing
    - Puncturing
  - Heating
    - Most reliable method

Heating Methods

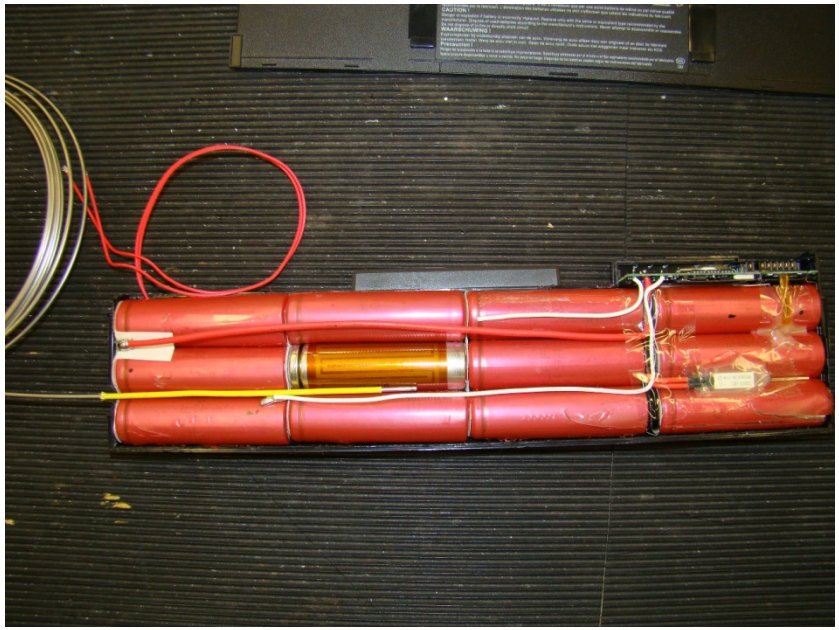
- **Alcohol Fire**
  - Low intensity flame
  - Temperatures similar to suppressed cargo compartment
  - Ignition source for vented gases and electrolyte
  - Good method for evaluation of cell hazard potential

Heating Methods

- **Cartridge Heater**
  - Used to simulate the temperature profile of a cell in thermal runaway
  - Comes in various sizes and wattage
  - Similar surface temperature to an ion cell in thermal runaway
  - Replaces a cell in shipment
  - Heats adjacent cells, inducing thermal runaway
  - Suitable for tests where the removal of one cell is insignificant
  - Bulk shipment tests

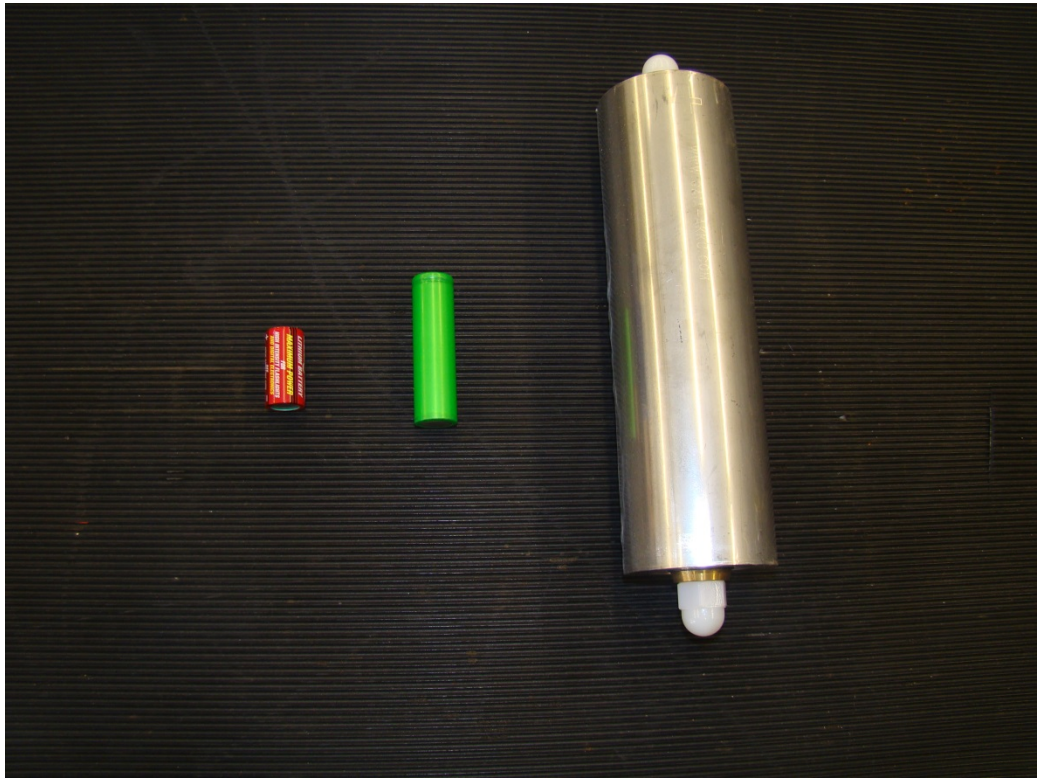
Heating Methods

- **Thin film heater**
  - Use where the removal of a cell would have a significant effect
  - Easily fits within a battery pack, can heat an individual cell
  - Good form factor for polymer, prismatic or coin cells
  - Has no thermal mass
  - Can control rate of heating
  - Lower maximum temperature



Cell types

- Cells come in various sizes and chemistries
- Cell hazard varies by chemistry, size and cell construction and manufacturer



Large Format Cells

- **Single cell presents a significant hazard**
- **Large format batteries can be made up of any size cell**

Large format

Cells vs Batteries

Fire Containment Tests

5000 Lithium-ion Batteries in a FCC

- Test conducted on March 2014
  - Setup involved a metal frame that supported the FCC and backup water suppression systems.
  - Batteries were placed in a steel pan. Balance of cargo cardboard boxes filled with shredded paper.
  - Thermal runaway initiated with a cartridge heater.
  - FCC contained the battery fire for the period of 4 hours.
- Repeated test without metal frames

5000 Lithium-ion Batteries in a FCC

Setup

5000 Lithium-ion Batteries in a FCC Without Support Frame

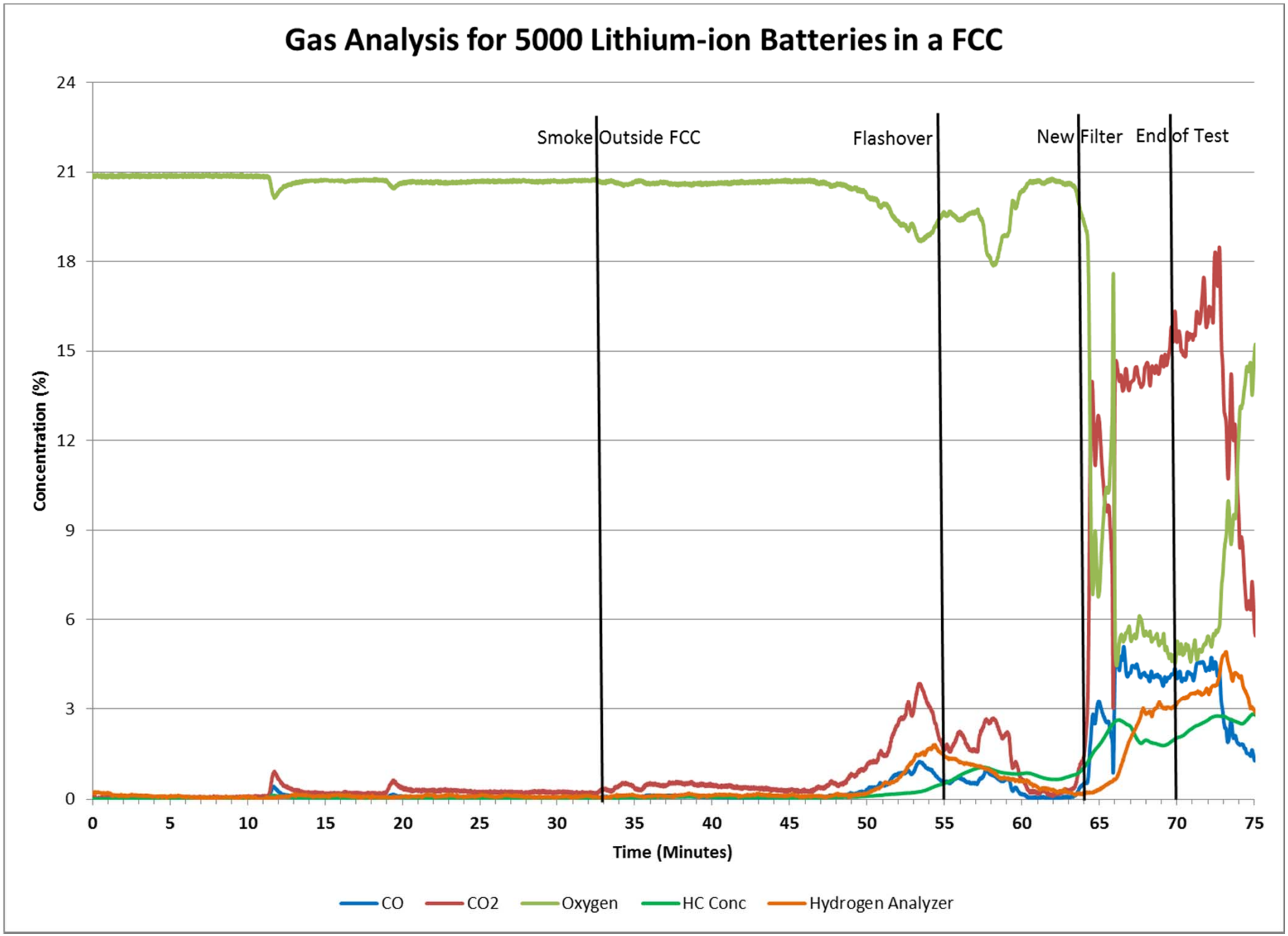
Summary of Events:

-First Signs of Smoke outside @ ~33 Minutes

-Cartridge Heater Unplugged @ ~53 Minutes

-Flashover @ ~55 Minutes

-Test Terminated @ ~70 Minutes


Gas Analysis for 5000 Lithium-ion Batteries in a FCC
Smoke Outside FCC
Flashover
New Filter
End of Test
Concentration (%)
Time (Minutes)
0
3
6
9
12
15
18
21
24
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
CO
CO2
Oxygen
HC Conc
Hydrogen Analyzer

5000 Lithium-ion Batteries in a FCC

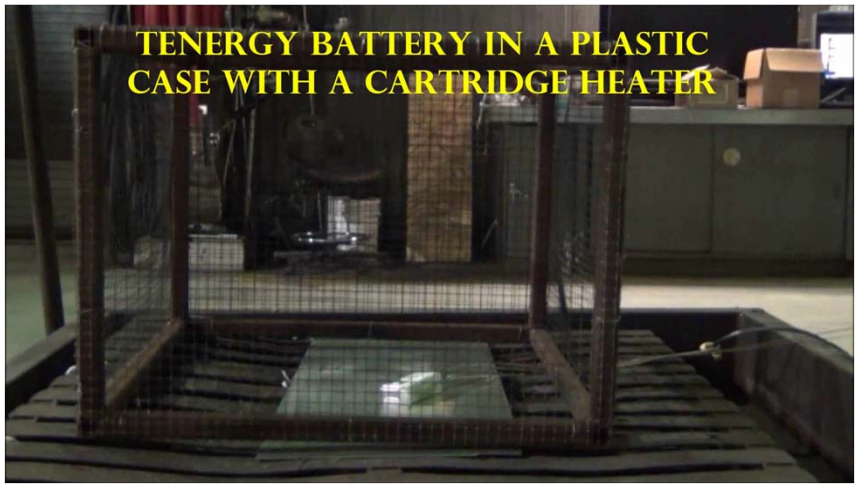
- Test revealed that a FCC cannot always contain a lithium-ion battery fire.
- Fire was observed to escape from underneath the FCC.
- Batteries were escaping the bounds of the FCC creating potential ignition sources.

Thermal Propagation in Plastic Case Storage Boxes

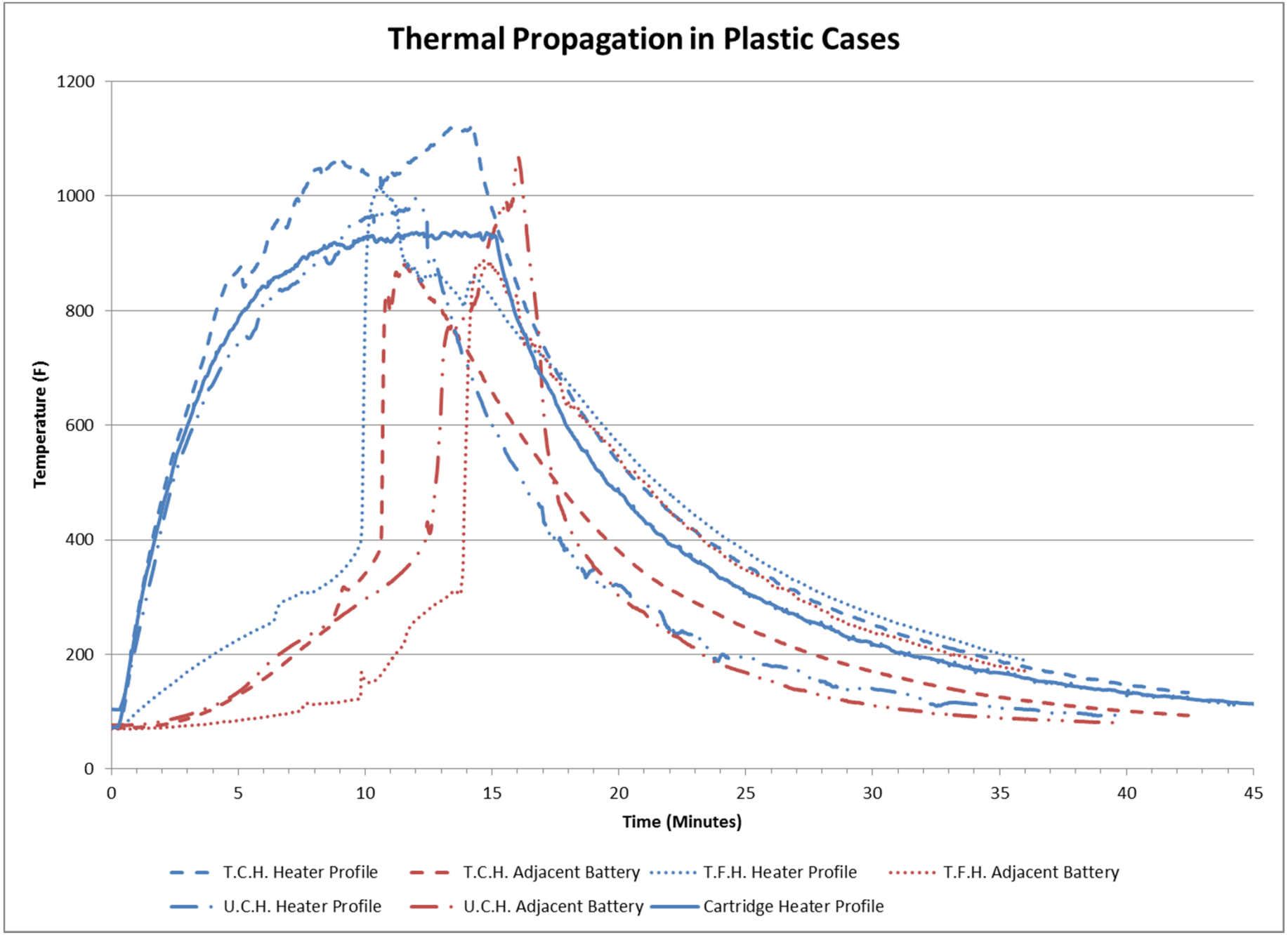
- Bulk packaging
- 2 18650 cells in a plastic storage case
- Shipped in a cardboard box as an “Over-pack”, 192 cells per over-pack

Thermal Propagation in Plastic Cases

Tenergy Battery in a Plastic Case with a Cartridge Heater @ 50% SOC



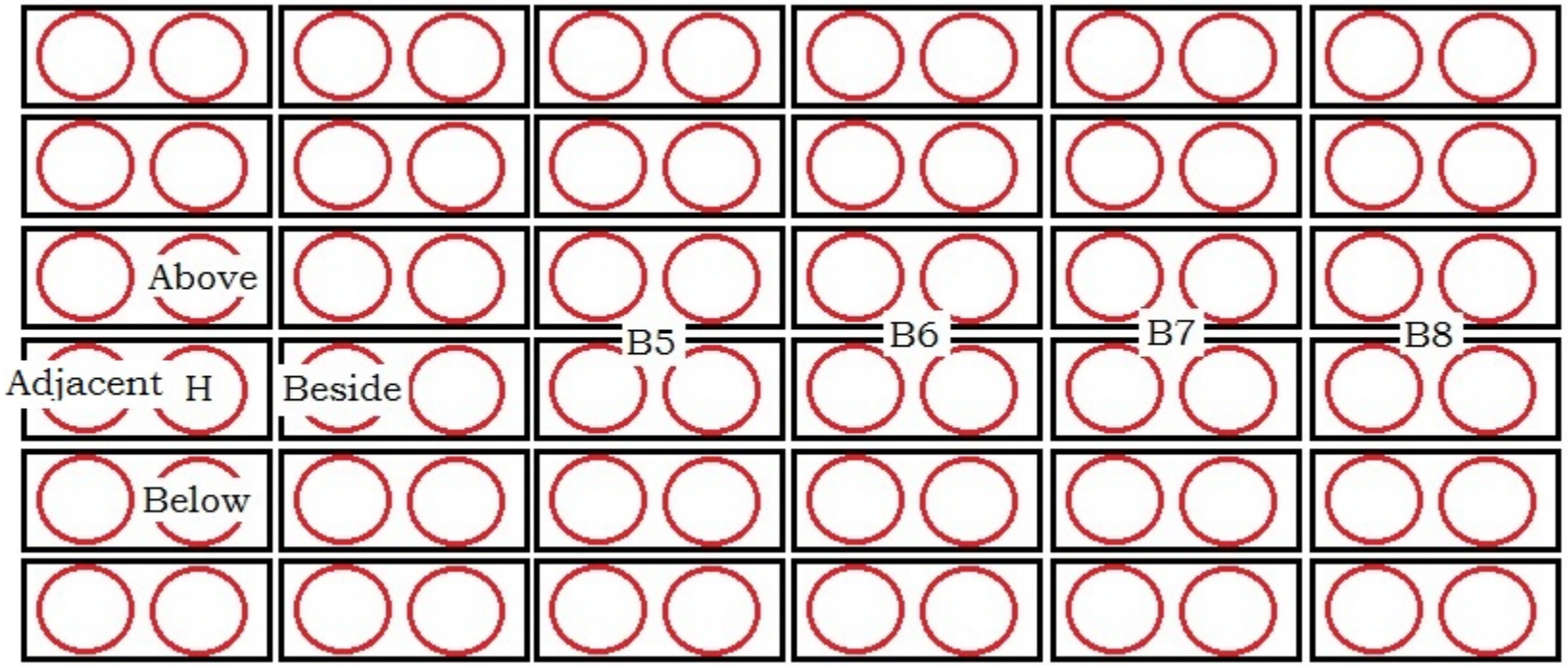
Ultrafire Battery in a Plastic Case with a Cartridge Heater @ 50% SOC


Thermal Propagation in Plastic Cases
Temperature (F)
1200
1000
800
600
400
200
0
0
5
10
15
20
25
30
35
40
45
Time (Minutes)
T.C.H. Heater Profile
T.C.H. Adjacent Battery
T.F.H. Heater Profile
T.F.H. Adjacent Battery
U.C.H. Heater Profile
U.C.H. Adjacent Battery
Cartridge Heater Profile

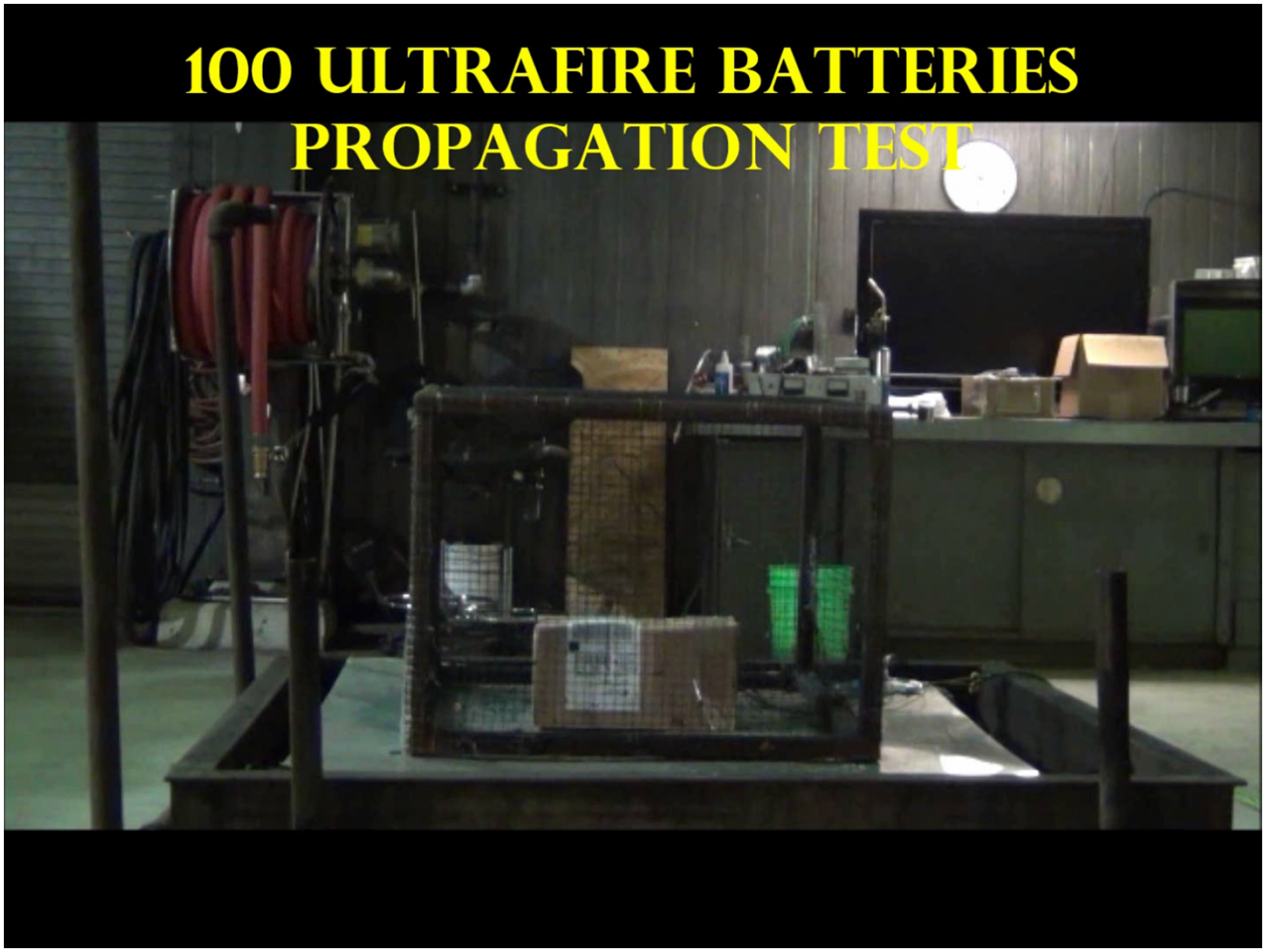
100 Ultrafire Li-ion Batteries

Test Instrumentation

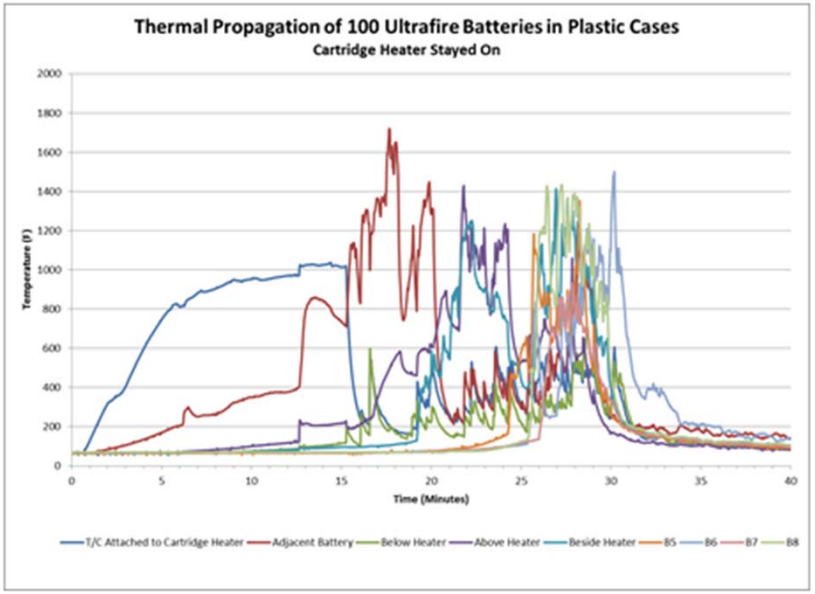
Thermocouple Locations

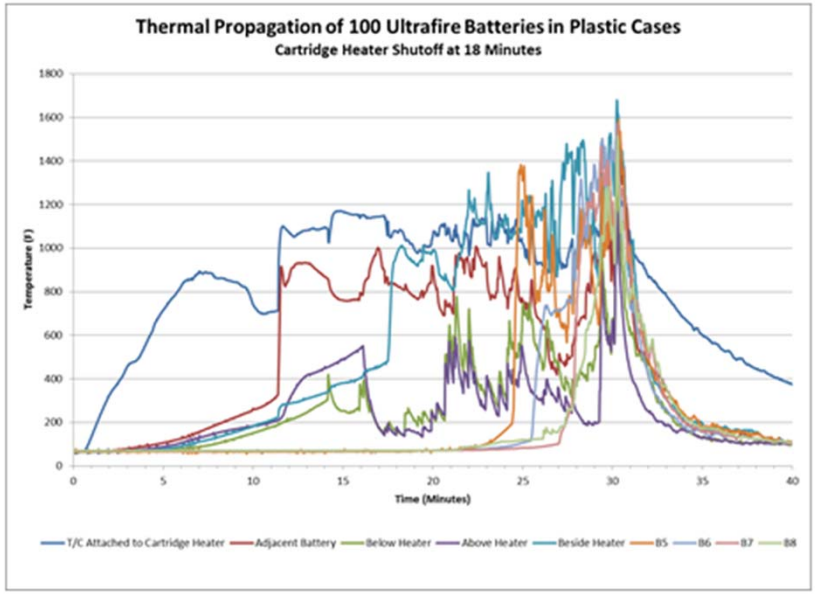


100 Ultrafire Batteries Propagation Test



Thermal Propagation of 100 Ultrafire Cells in Plastic Cases, Heater On vs Heater Off



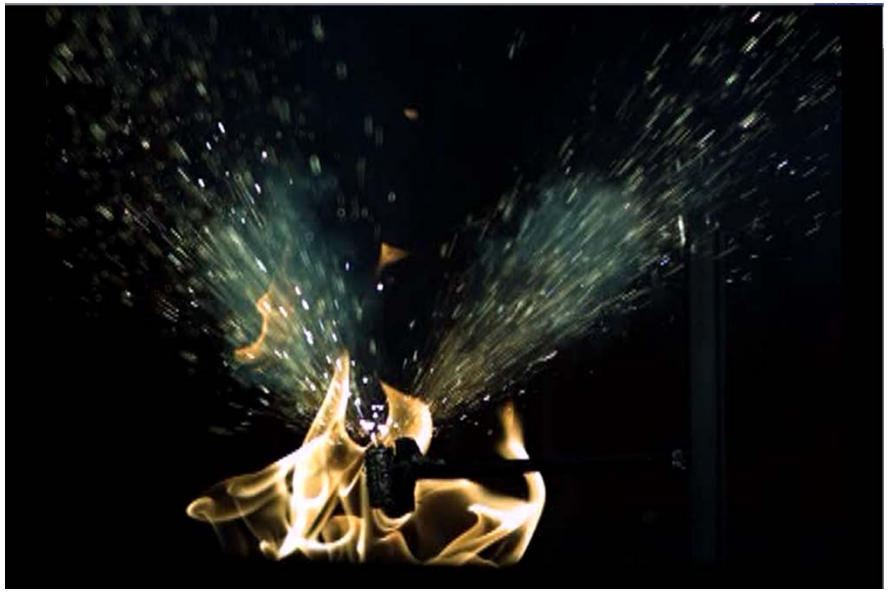


Thermal Propagation in Plastic Cases

- Plastic cases did not prevent the propagation of thermal runaway to adjacent battery cases.
- Plastic cases provided more heat and fuel to the fire increasing the intensity of the battery fire.

Lithium Battery Thermal Runaway Vent Gas Analysis

Federal Aviation Administration



Presented to: DGP, Montreal

By: FAA Fire Safety

Date: 04-27-2015

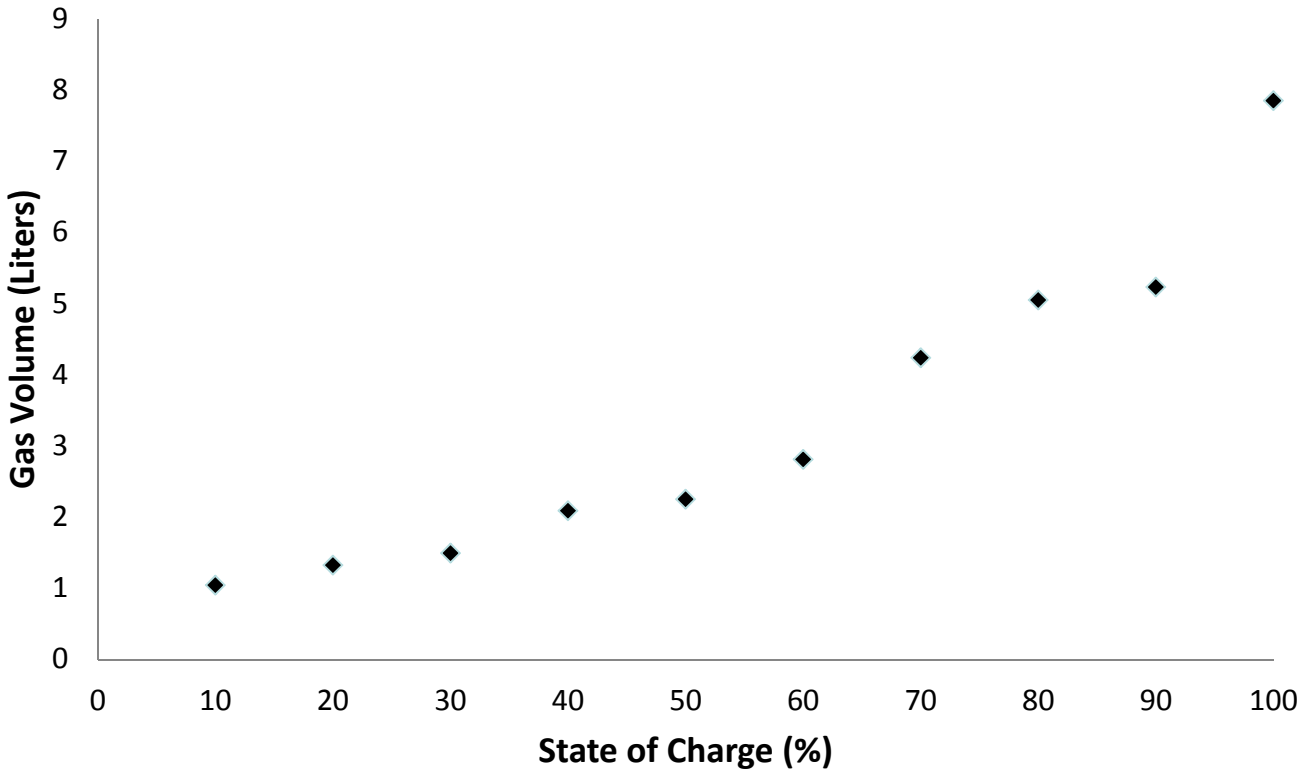
Introduction

- **Three test Setups.**
  1. **Small Scale** tests with multiple cell chemistries and SOC to analyze hazard.
  2. **Small Scale** tests with LiCoO2 chemistry to determine pressure rise vs. concentration of vent gas.
  3. **Large scale** tests with lithium-ion cells to verify the hazard on a full scale and evaluate the effectiveness of Halon 1301 at suppressing combustion.

Small Scale Tests (Vent Gas Analysis)

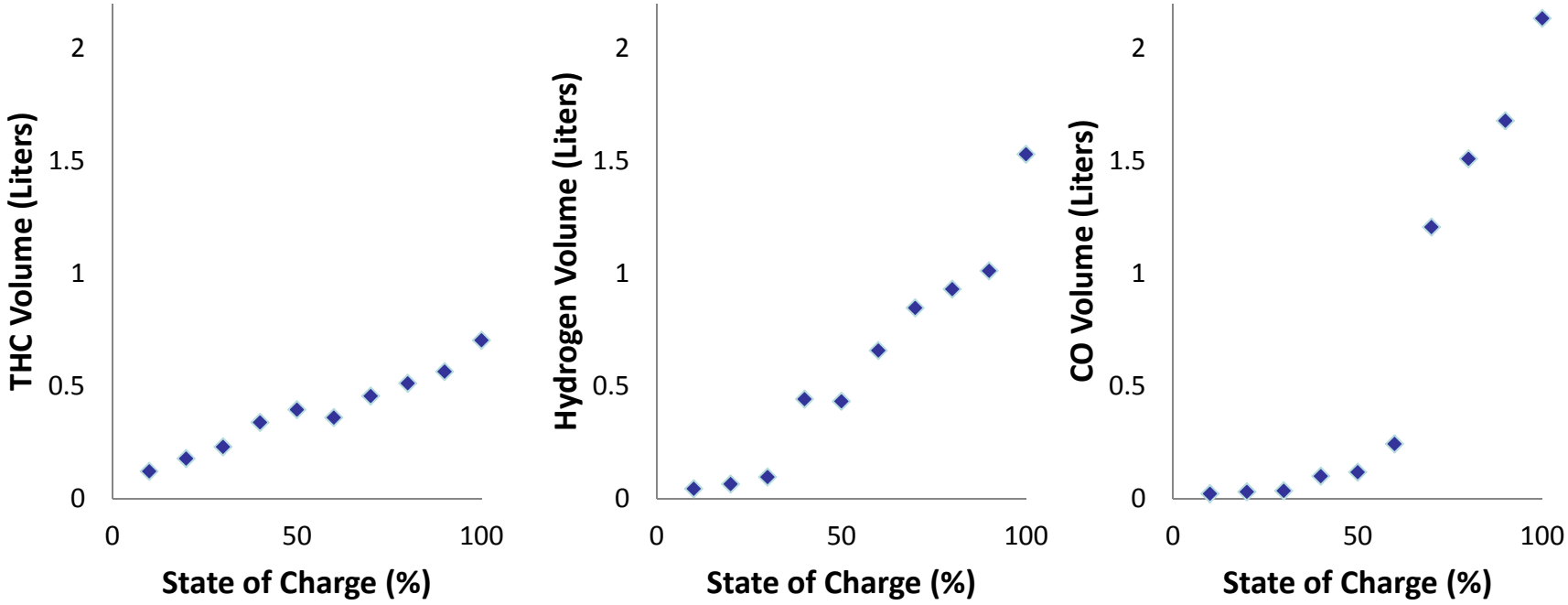
- **Tests were carried out in a smaller 21.7L combustion sphere to characterize the type and quantity of gasses emitted.**

Results: State of Charge ($LiCoO_2$)



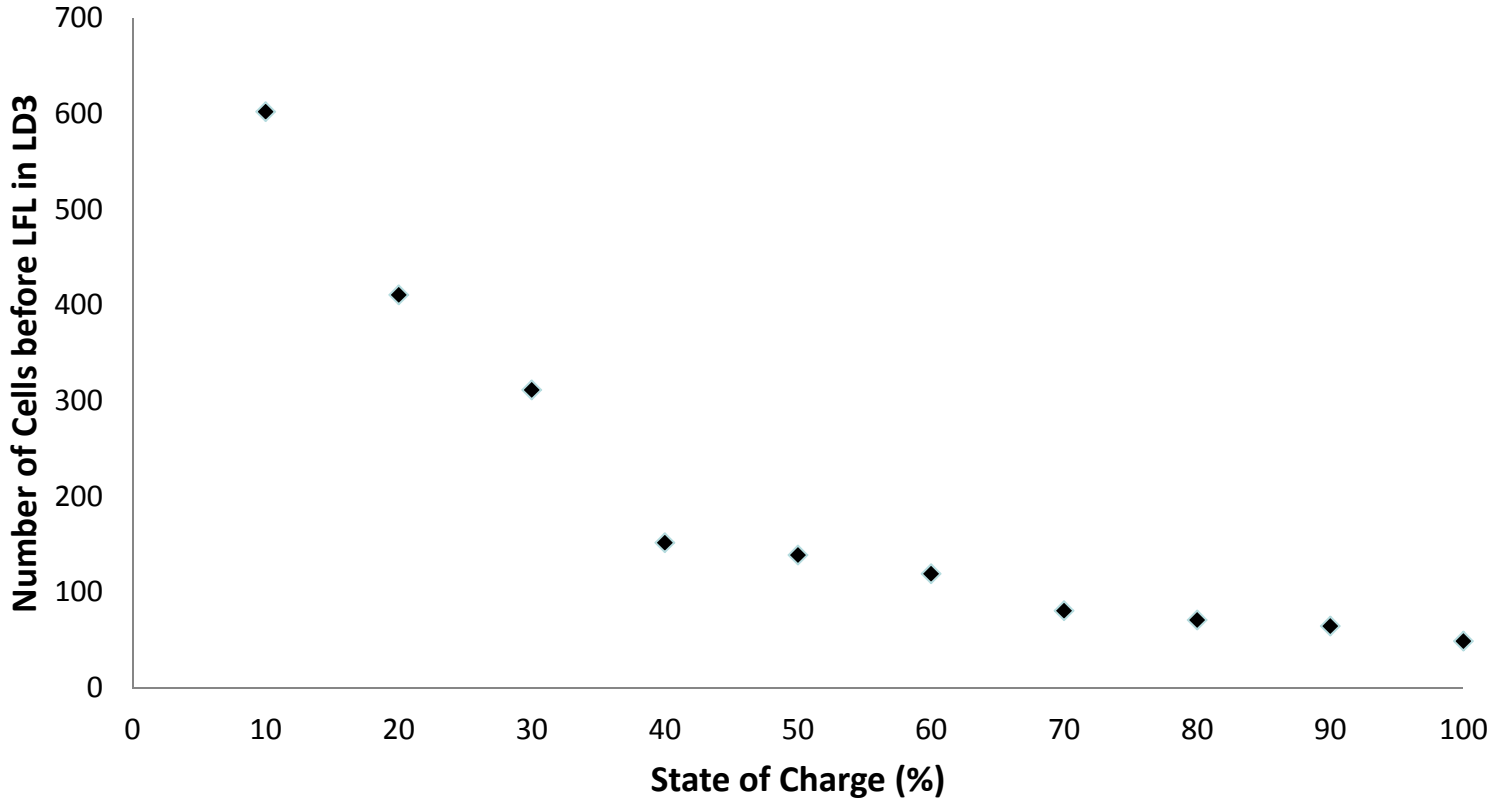
Gas volume emitted increases as SOC increases.

Results: State of Charge ($LiCoO_2$)



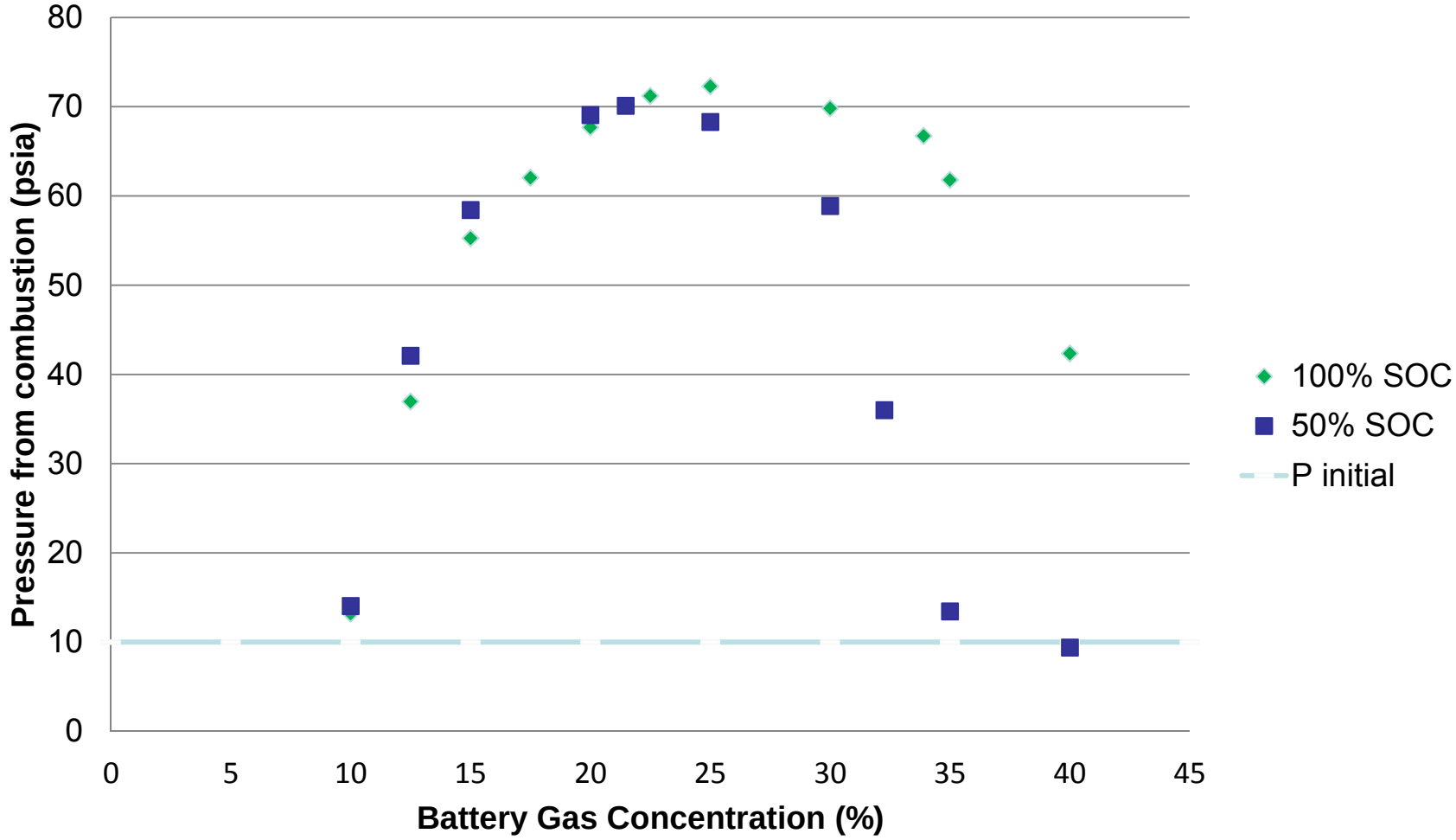
- THC, H_2, and CO increased as Charge increased.

Lower Flammability Limit



The calculated number of cells required for an explosive mixture in an LD3 (150ft³) decreases as SOC increased.

Pressure Rise (small scale)



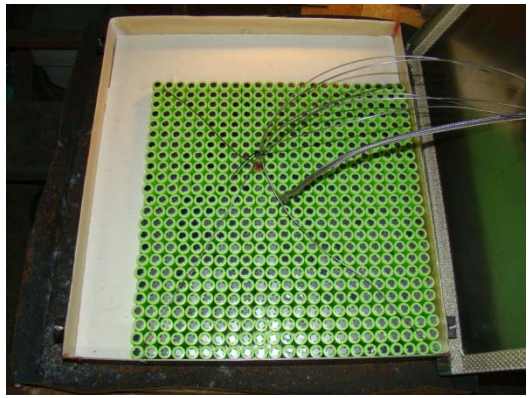
Pressure Chamber (Large Scale Tests)

Number of Cells Required (large scale test)

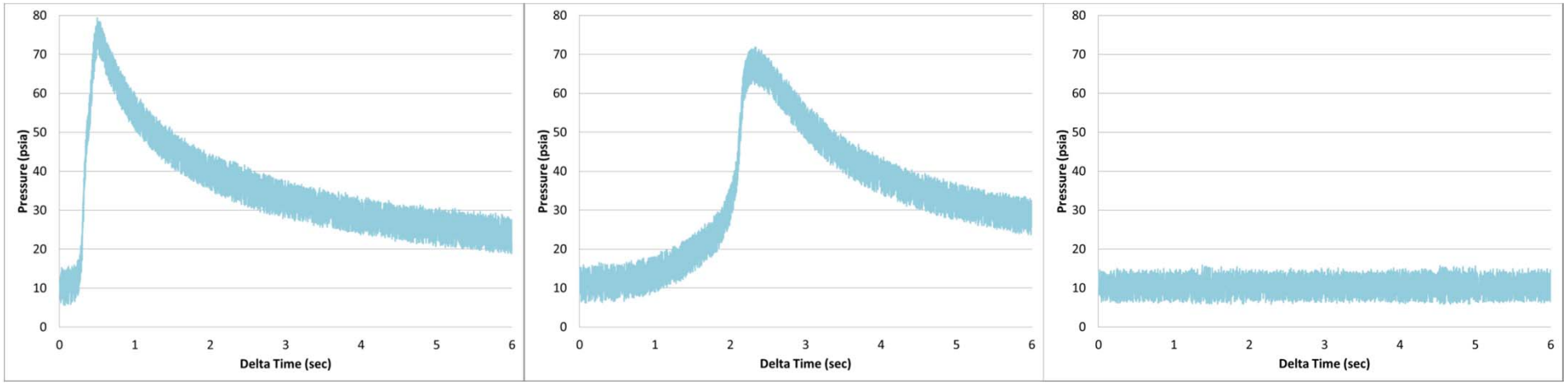
- **Stoichiometric equation was used to determine the required vent gas concentration for cells at 50% SOC to be 12.4%. Calculation assumes:**
  - Conc. THC ≈ Conc. C_3H_8 = 17.55%
  - Conc. H_2 = 19.22%
  - Conc. CO = 5.2%
- **550 cells produce 1237.39 liters or 12.34% concentration in the 10m^3 chamber.**

Setup of Large Scale Tests

- A cartridge heater was placed in the center of a 550 cell array.
- Type-k thermocouples were attached to cells at each of the 4 corners and one was attached adjacent to the cartridge heater.
- The array of cells was enclosed in a steel container with a chimney to create a rich fuel mixture and prevent premature ignition.
- A spark igniter was installed in the center of the chamber.
- Additional instrumentation:
  - 2 THC analyzers at different heights to check for stratification.
  - An H2 analyzer.
  - A CO, CO2, O2, Halon 1301 analyzer
  - An LFL analyzer.



Results (Large Scale Tests)



Test without suppression

Test with 5.28% Halon

Test with 10.43% Halon

Elapsed time from spark ignition

Results (Large Scale Tests)

	Predicted Concentration (from small scale tests) 8.8m^3 chamber	Actual Concentration (No Halon)	Actual Concentration (5.28% Halon)	Actual Concentration (10.43% Halon)
THC	2.47%	2.5%	2.77%	3.2%
H_2	2.7%	2.74%	3.5%	3.54%
CO	.705%	1.4%	1.5%	2.04%
CO_2	3.58%	3.97%	3.42%	4.73%

Takes into account items in the chamber that would reduce the chambers effective volume.

Summary

- Volume of gas emitted from cells increased as SOC increased.
- THC, H_2 and CO increased as SOC increased.
- The number of cells required to reach an explosive concentration in an LD3 decreased as SOC increased.
- Vented gas composition can vary with differing cell chemistries.
- Combustion of vented gasses from the Li-Ion cells tested produced a pressure pulse of 75psia.
- Halon 1301 was less effective than previously thought at preventing combustion of battery gasses.
- Small scale tests reasonably predicted gas concentrations for large scale tests.

Questions?

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