



ICAO

UNITING AVIATION

FAA Lithium Battery Testing Update

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

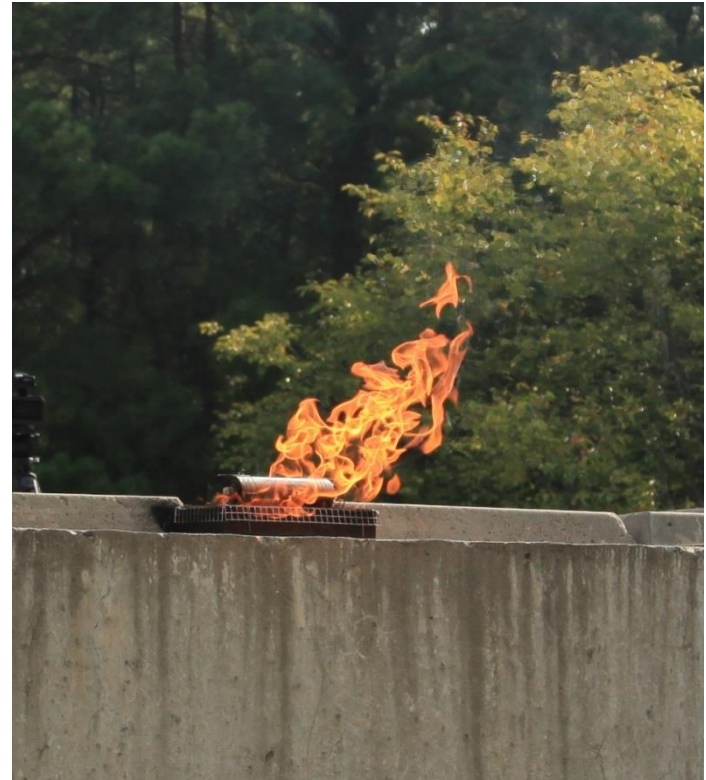
Induced Thermal Runaway

- 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



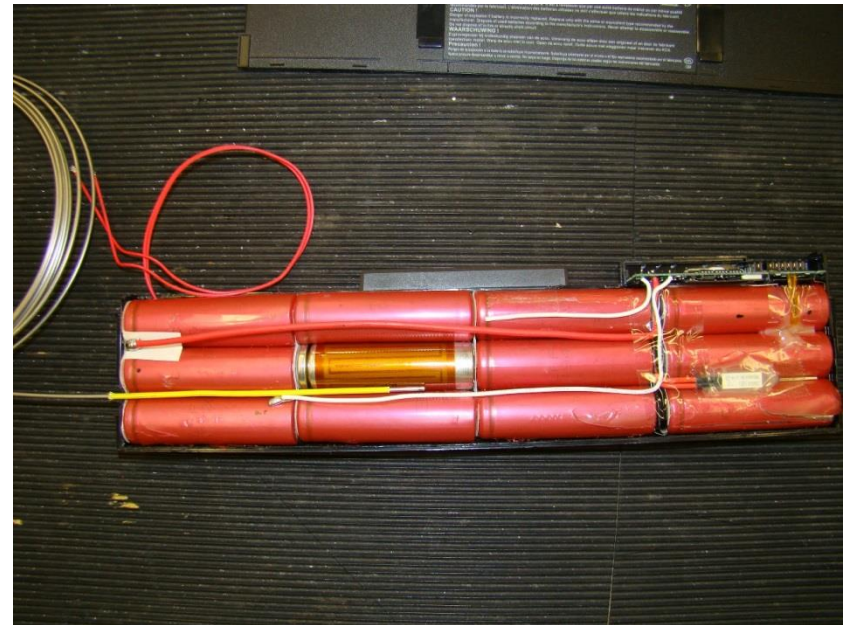
Heating Methods

- 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







Fire Containment Tests



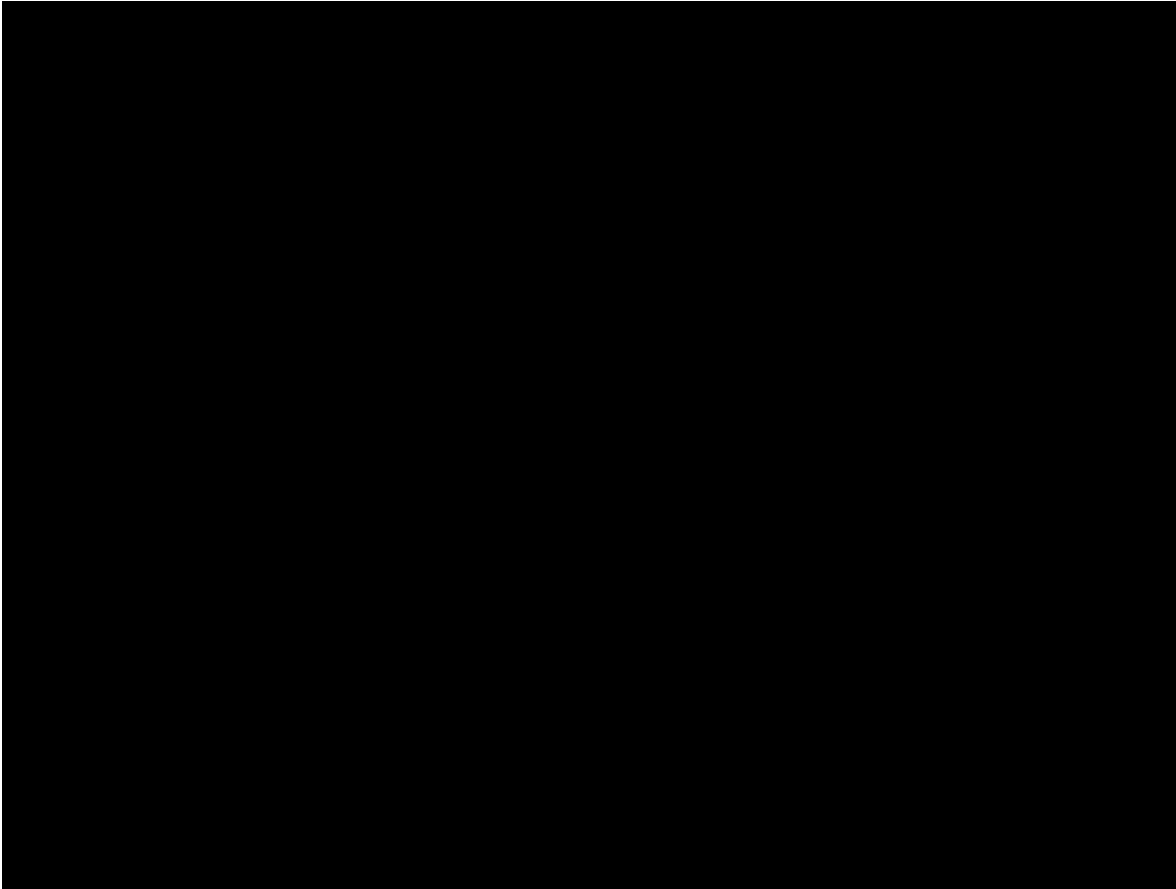
5000 Lithium-ion Batteries in a FCC

- 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



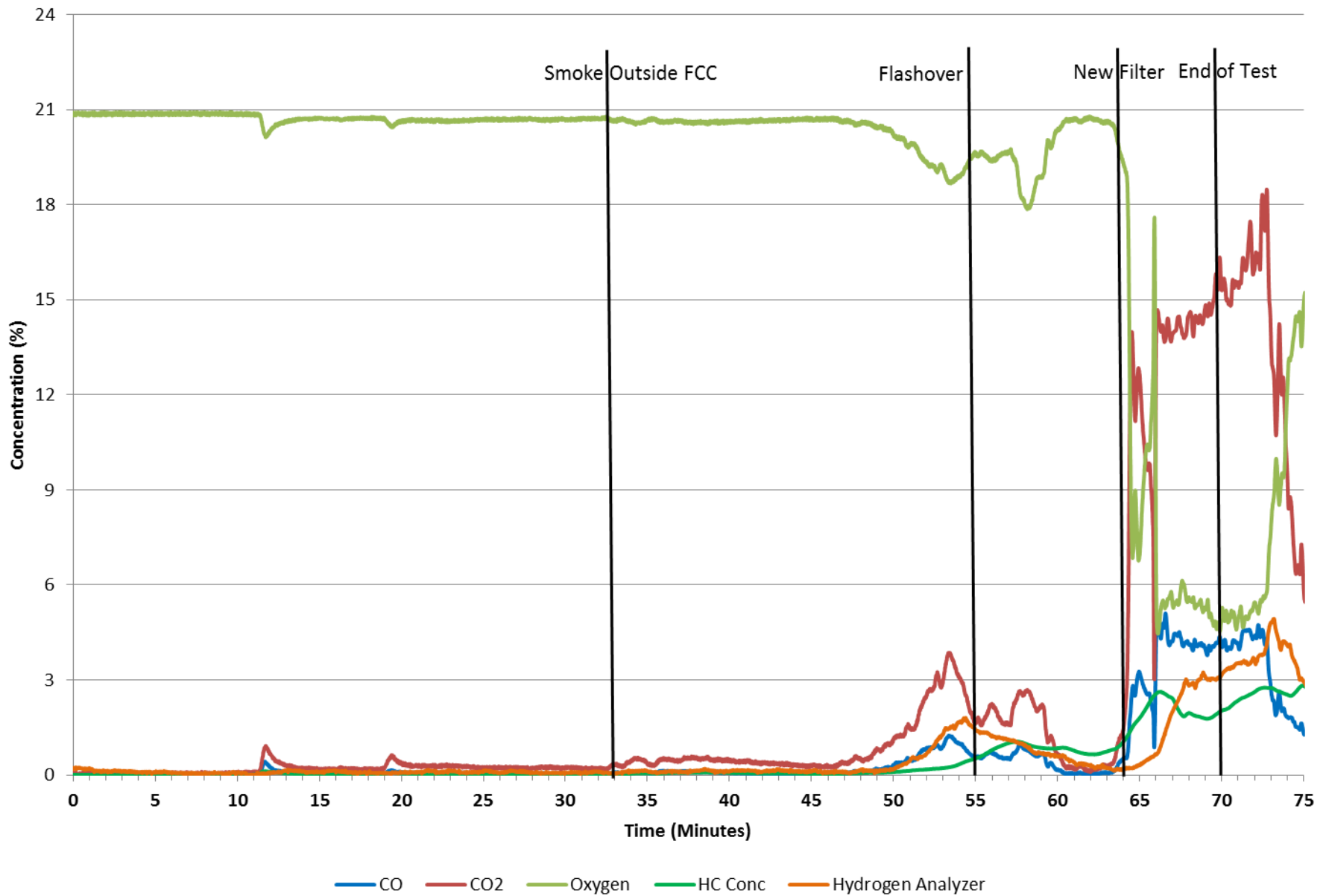
5000 Lithium-ion Batteries in a FCC Without Support Frame



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



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

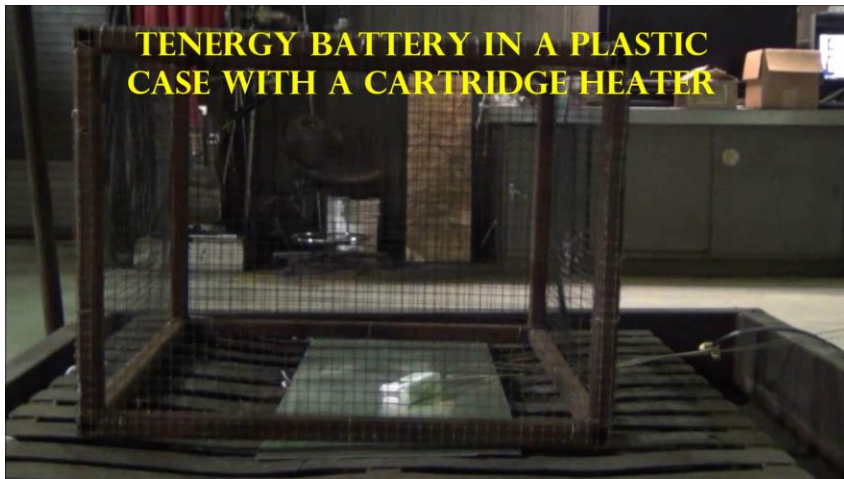
- Bulk packaging
- 2 18650 cells in a plastic storage case
- Shipped in a cardboard box as an “Over-pack”, 192 cells per over-pack



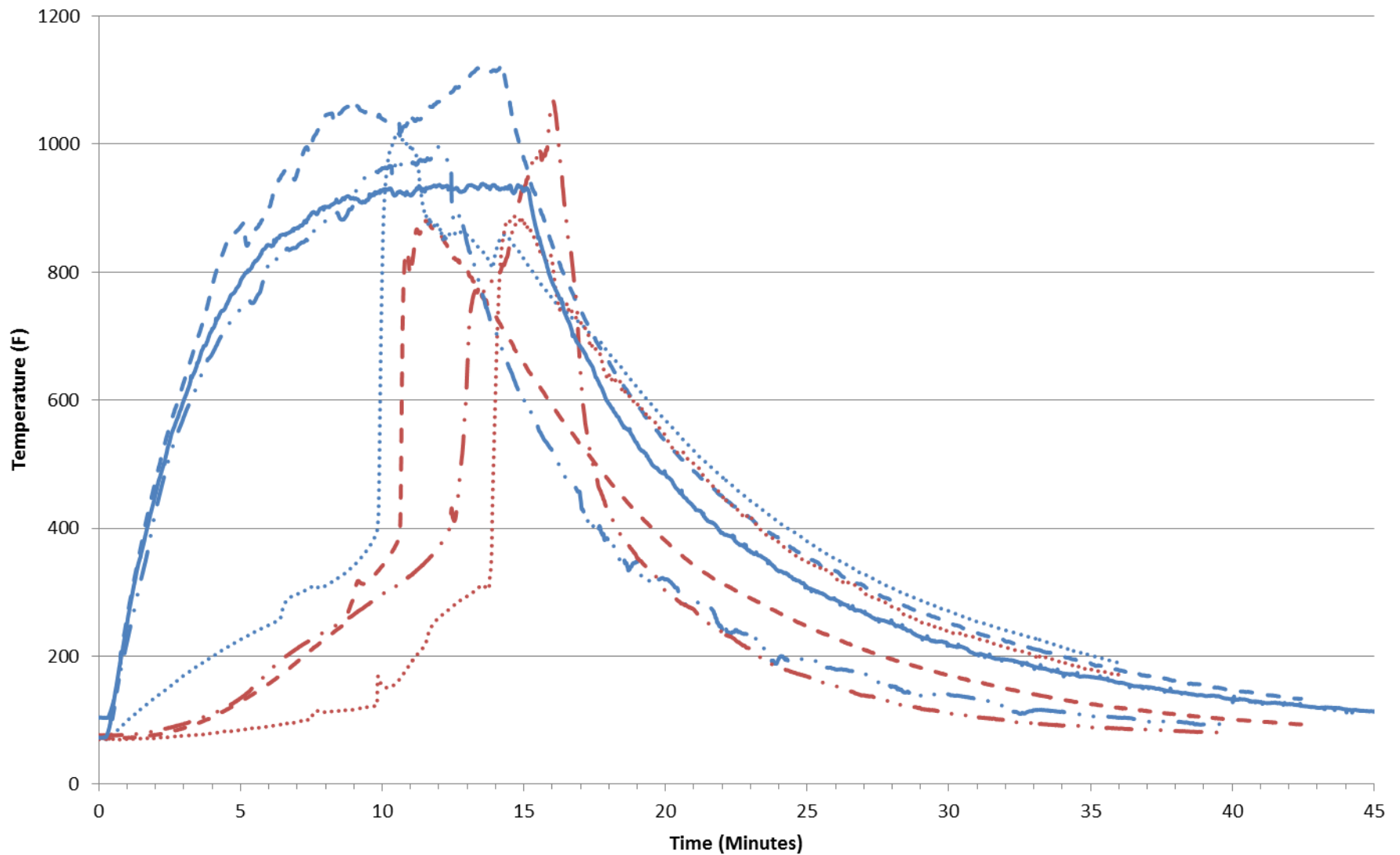
Thermal Propagation in Plastic Cases

**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



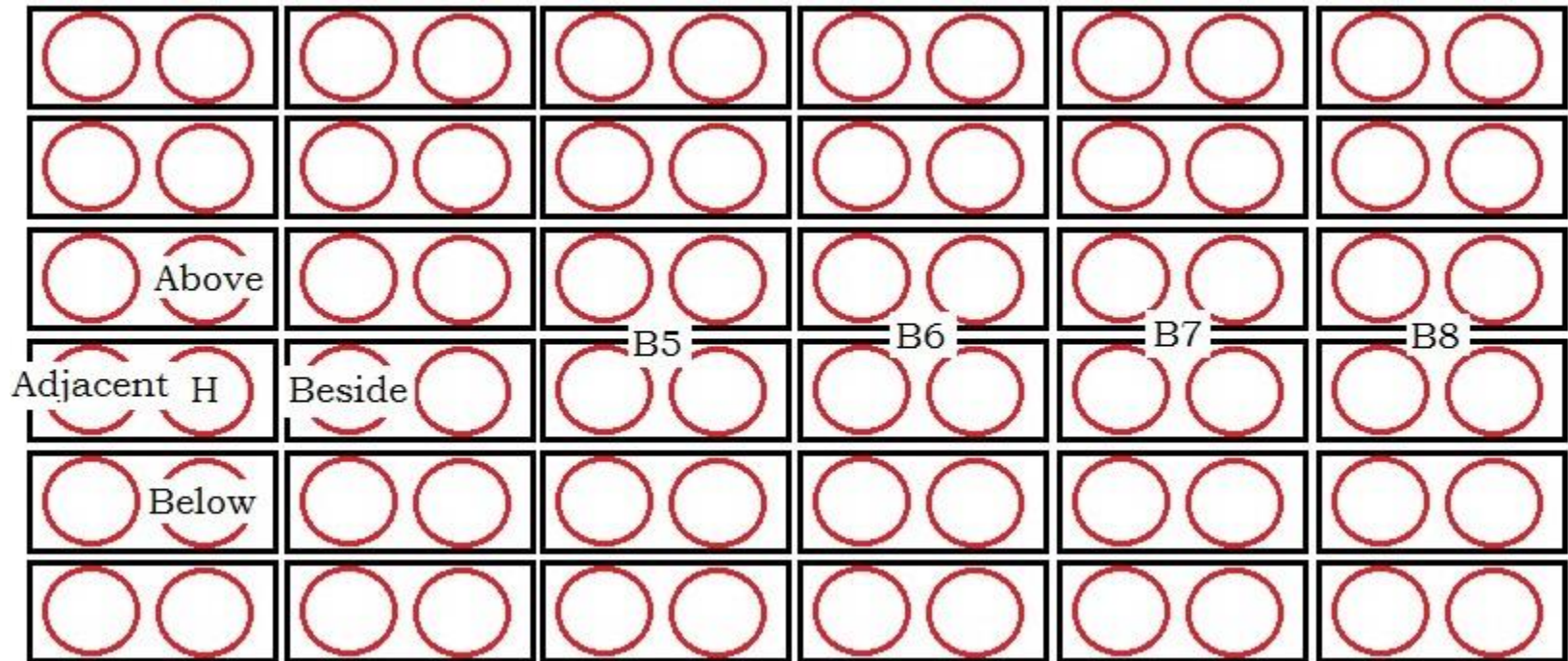
— T.C.H. Heater Profile - - T.C.H. Adjacent Battery T.F.H. Heater Profile T.F.H. Adjacent Battery
- · U.C.H. Heater Profile - · U.C.H. Adjacent Battery — Cartridge Heater Profile

100 Ultrafire Li-ion Batteries



Test Instrumentation

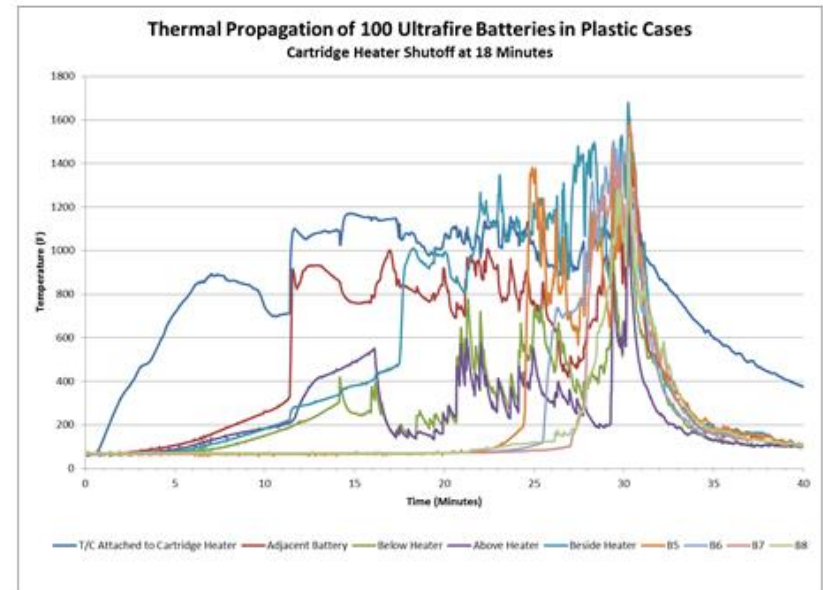
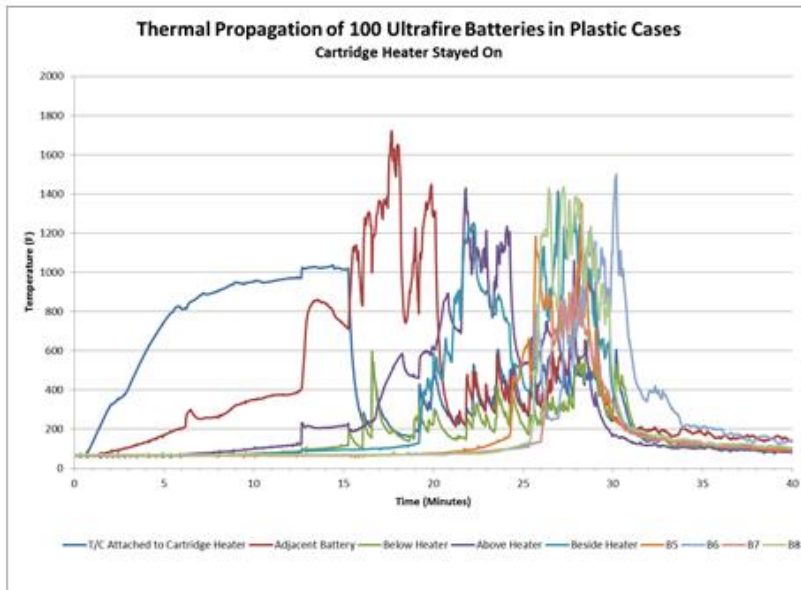
Thermocouple Locations



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



Introduction

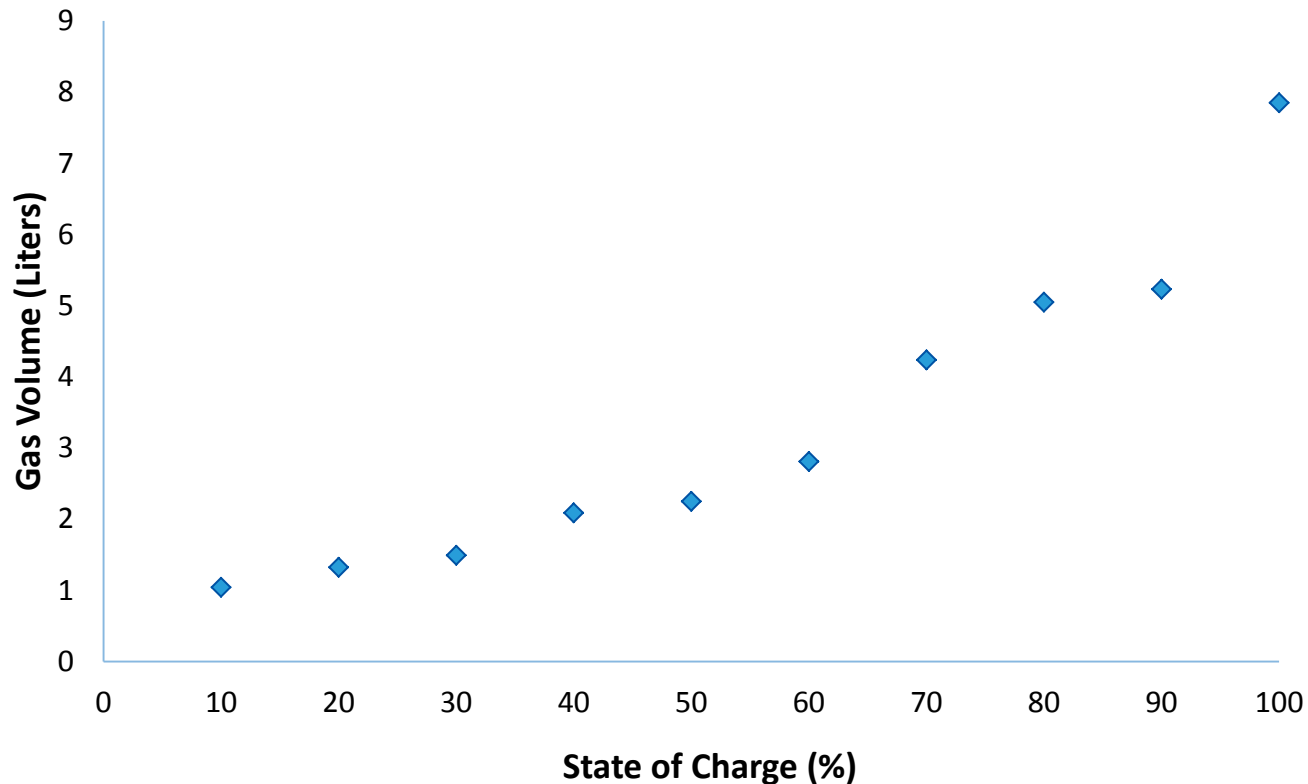
- Three test Setups.
 1. **Small Scale** tests with multiple cell chemistries and SOC to analyze hazard.
 2. **Small Scale** tests with LiCoO₂ chemistry to determine pressure rise vs. concentration of vent gas.
 3. **Large scale** tests with lithium-ion cells to verify the hazard on a full scale and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

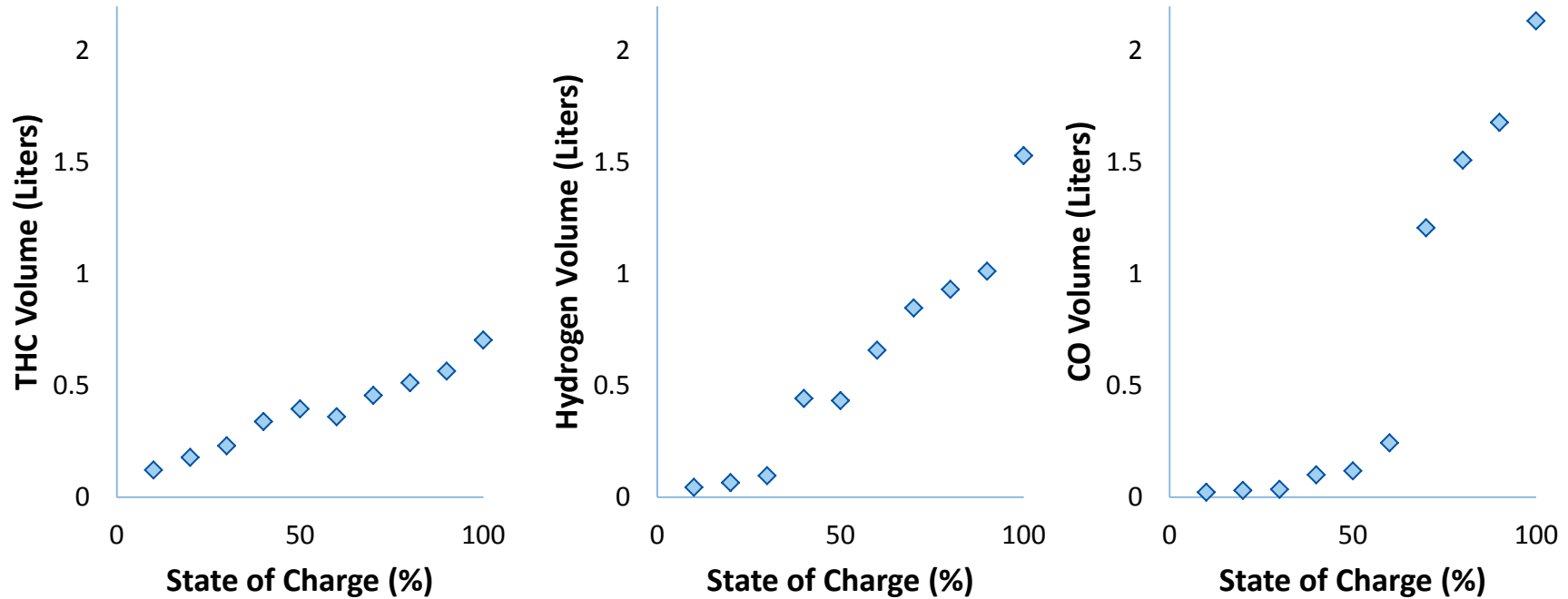


Results: State of Charge (LiCoO_2)

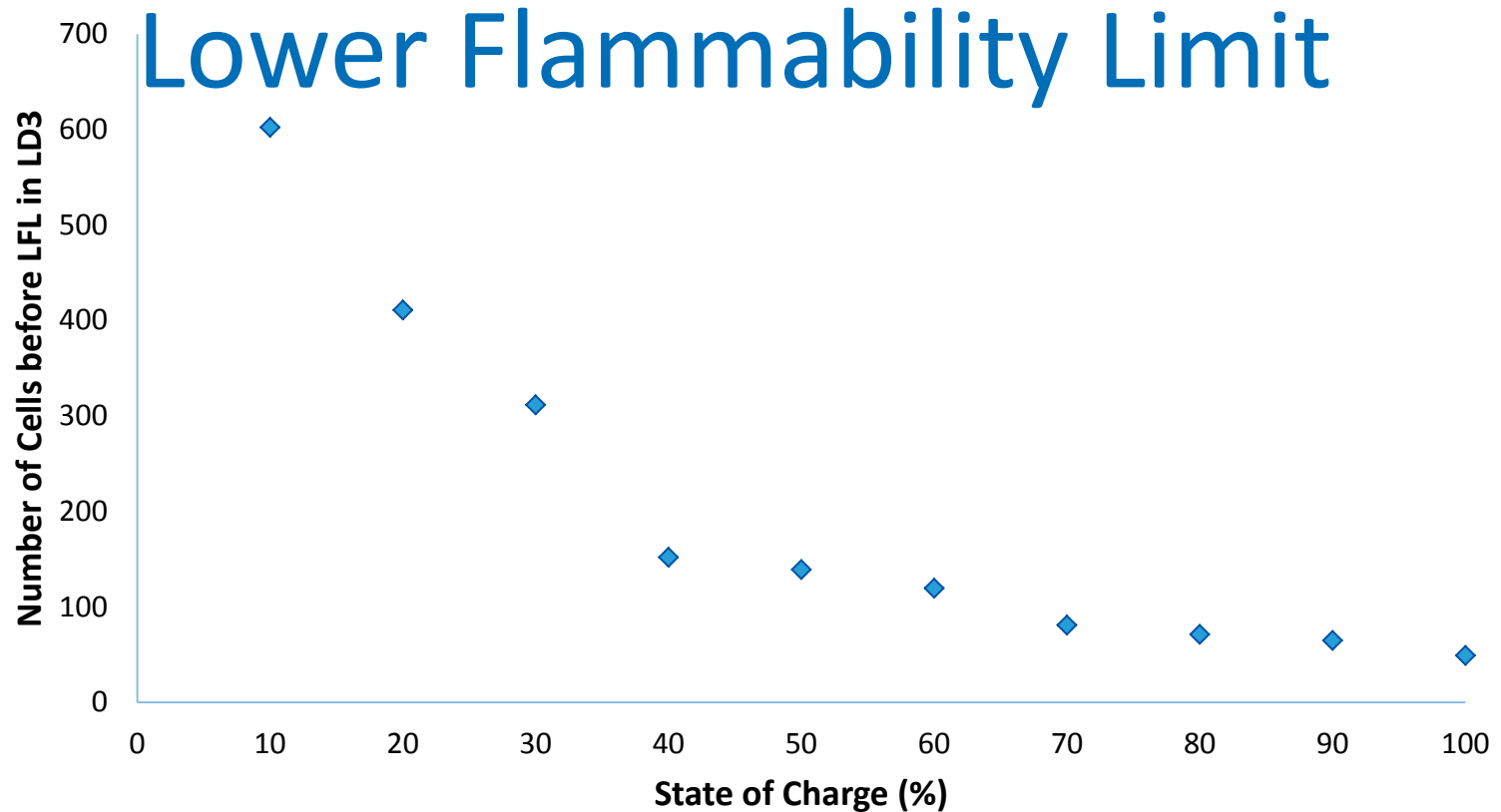


Gas volume emitted increases as SOC increases.

Results: State of Charge (LiCoO_2)

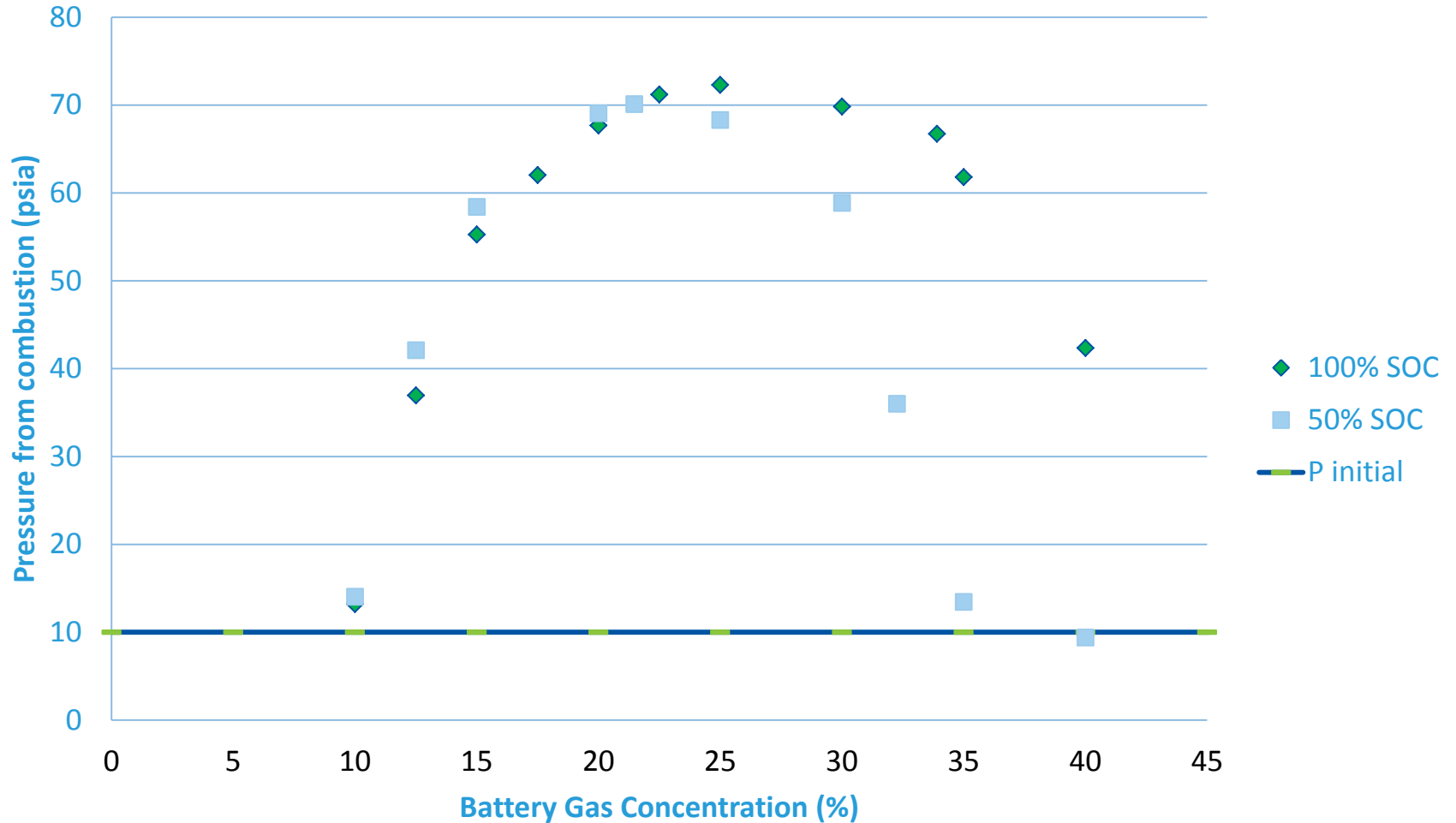


- THC, H_2 , and CO increased as Charge increased.



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)

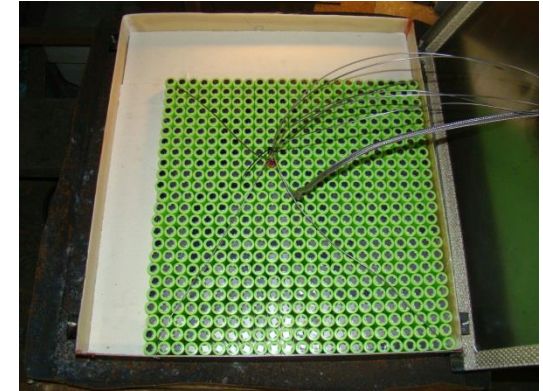


Number of Cells Required (large scale test)

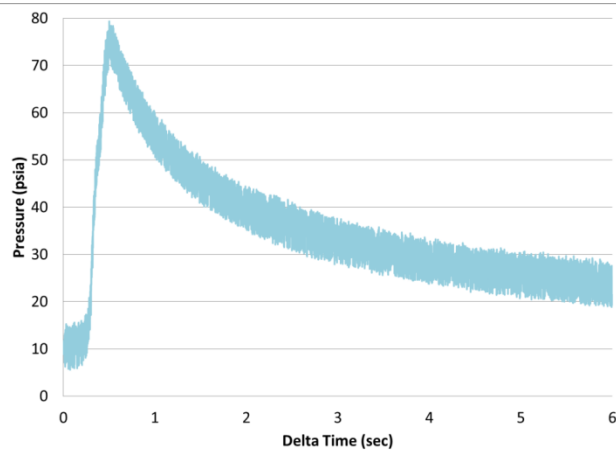
- Stoichiometric equation was used to determine the required vent gas concentration for cells at 50% SOC to be 12.4%. Calculation assumes:
 - Conc. THC \approx Conc. C_3H_8 = 17.55%
 - Conc. H_2 = 19.22%
 - Conc. CO = 5.2%
- 550 cells produce 1237.39 liters or 12.34% concentration in the $10m^3$ chamber.

Setup of Large Scale Tests

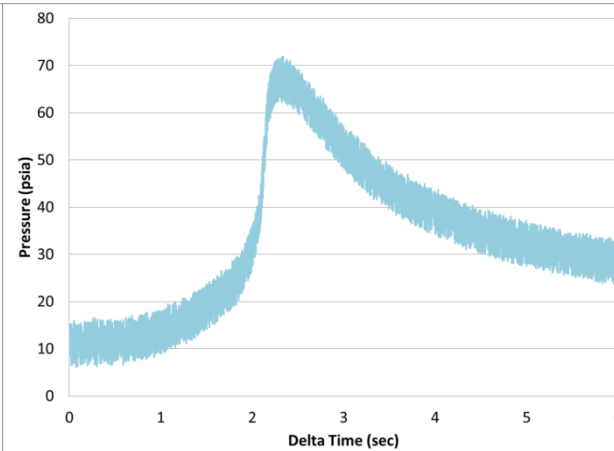
- A cartridge heater was placed in the center of a 550 cell array.
- Type-k thermocouples were attached to cells at each of the 4 corners and one was attached adjacent to the cartridge heater.
- The array of cells was enclosed in a steel container with a chimney to create a rich fuel mixture and prevent 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.



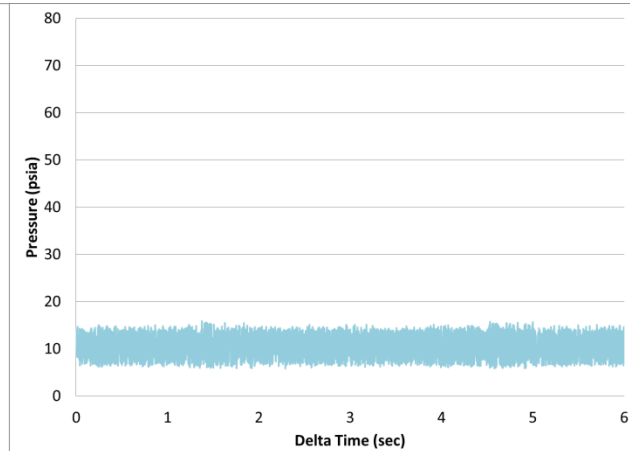
Results (Large Scale Tests)



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) <u>8.8m³</u> 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, H₂ 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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- <http://www.fire.tc.faa.gov/systems/Lithium-Batteries>
- <http://www.fire.tc.faa.gov/systems.asp>