Aircraft Lithium-Ion Battery Testing

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The Sixth Triennial International Fire and Cabin Safety Research Conference
Atlantic City, NJ
October 25-28, 2010

Background

- The FAA has performed research investigating the flammability characteristics, extinguishing system effectiveness, and battery failure mode of both primary lithium and rechargeable lithium-ion batteries used in laptops and other portable electronic devices.

  -Report #s DOT/FAA/AR-04/26 and DOT/FAA/AR-06/38

- The proposed use of Li-ion batteries onboard aircraft as power sources for engine or APU starting and other operations requires these battery systems utilize a larger number of cells, perhaps of various chemistries and a higher energy density.

- There presently is no FAA standard that regulates the operation and/or installation of Li-ion batteries onboard aircraft. There are however certain special conditions and issue papers

- The tests discussed here will hopefully aid in the development of such a regulation.

Background

- The potential hazards requiring examination:
  - How will they react in a fire situation?
  - What type of potential fire hazard do they pose themselves?
  - Are the protection circuits adequate?
  - Are the battery encasements adequate?
  - Is there a variation in safety performance among the numerous chemistry types?
  - Etc.

- Initial testing is designed to examine performance of individual battery cells.

- Further testing needed to examine battery systems including the charging/monitoring circuit, thermal protection circuit and battery encasement.

Battery Types

- Three battery manufacturers have submitted cells for testing

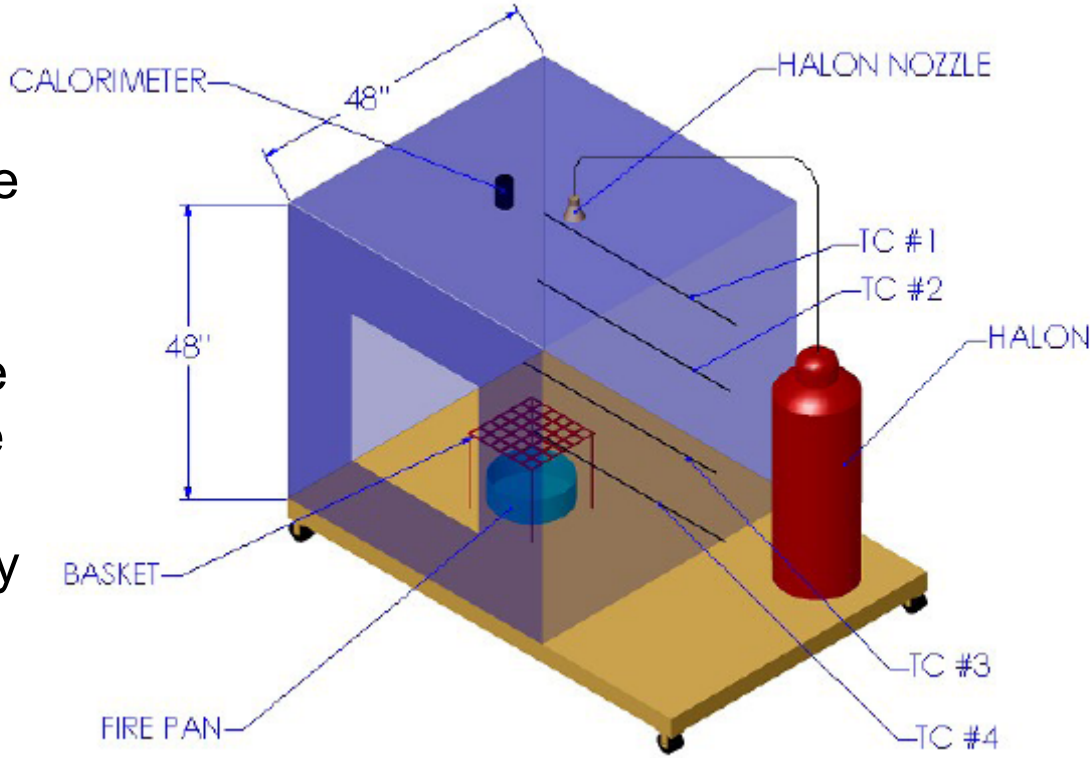
	Battery Cell 1	Battery Cell 2	Battery Cell 3
Battery Type	Cylindrical Li-ion	Cylindrical Li-ion	Li-Polymer
Battery Size	18650*	26650*	3 ½″ x 4″ x ¼″
Chemistry	Lithium Iron Phosphate	Lithium Iron Phosphate	Lithium Cobalt Dioxide
Capacity (mAh)	1150	2300	8000
Nominal Voltage	3.3	3.3	3.7
Charge Voltage	3.85	3.6	4.2

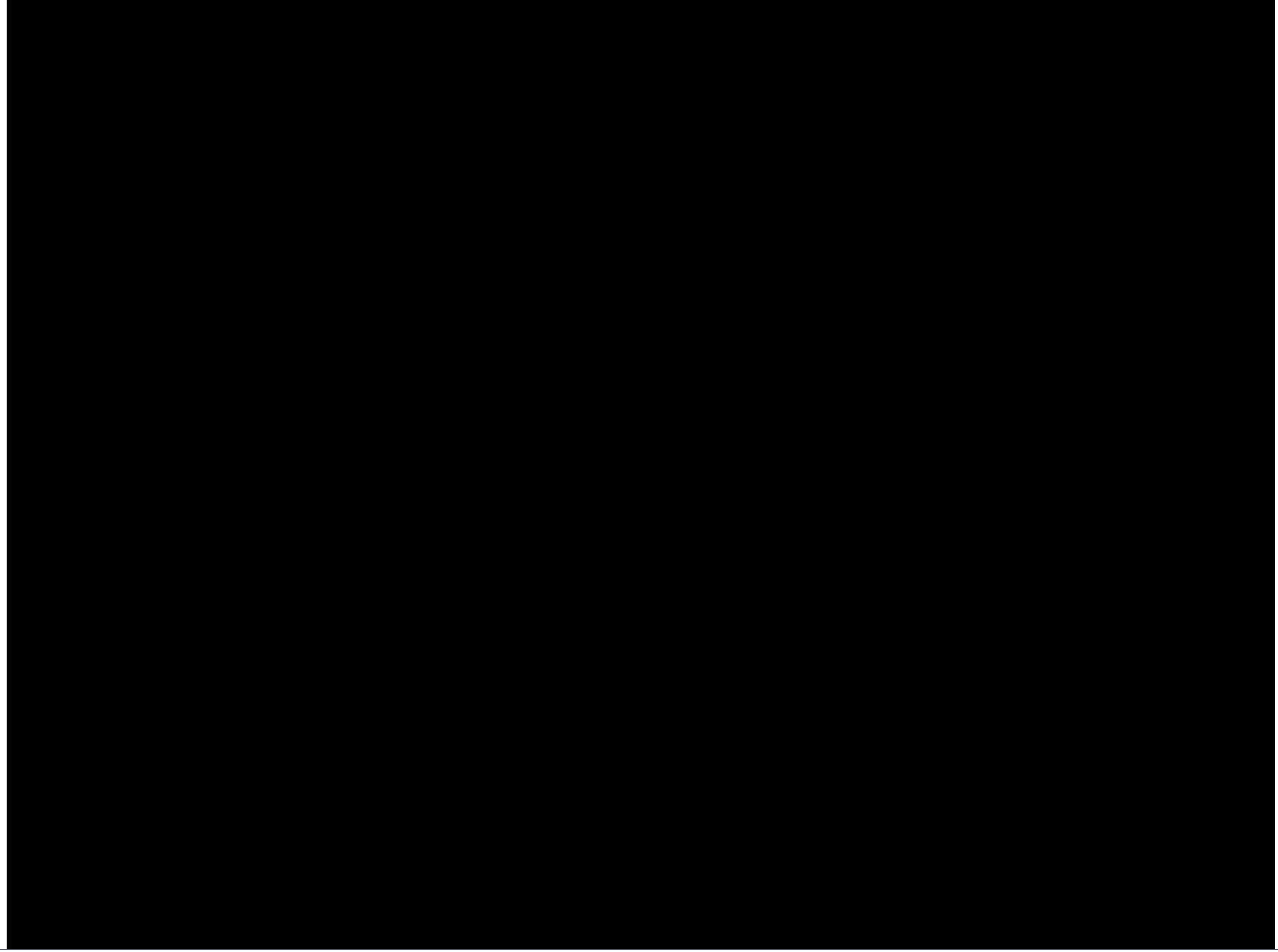
* Cylindrical Battery Size Notation: First two digits are cell diameter in mm, and the next three digits are cell height in mm

Battery Cell Testing

Fire Exposure Test Description

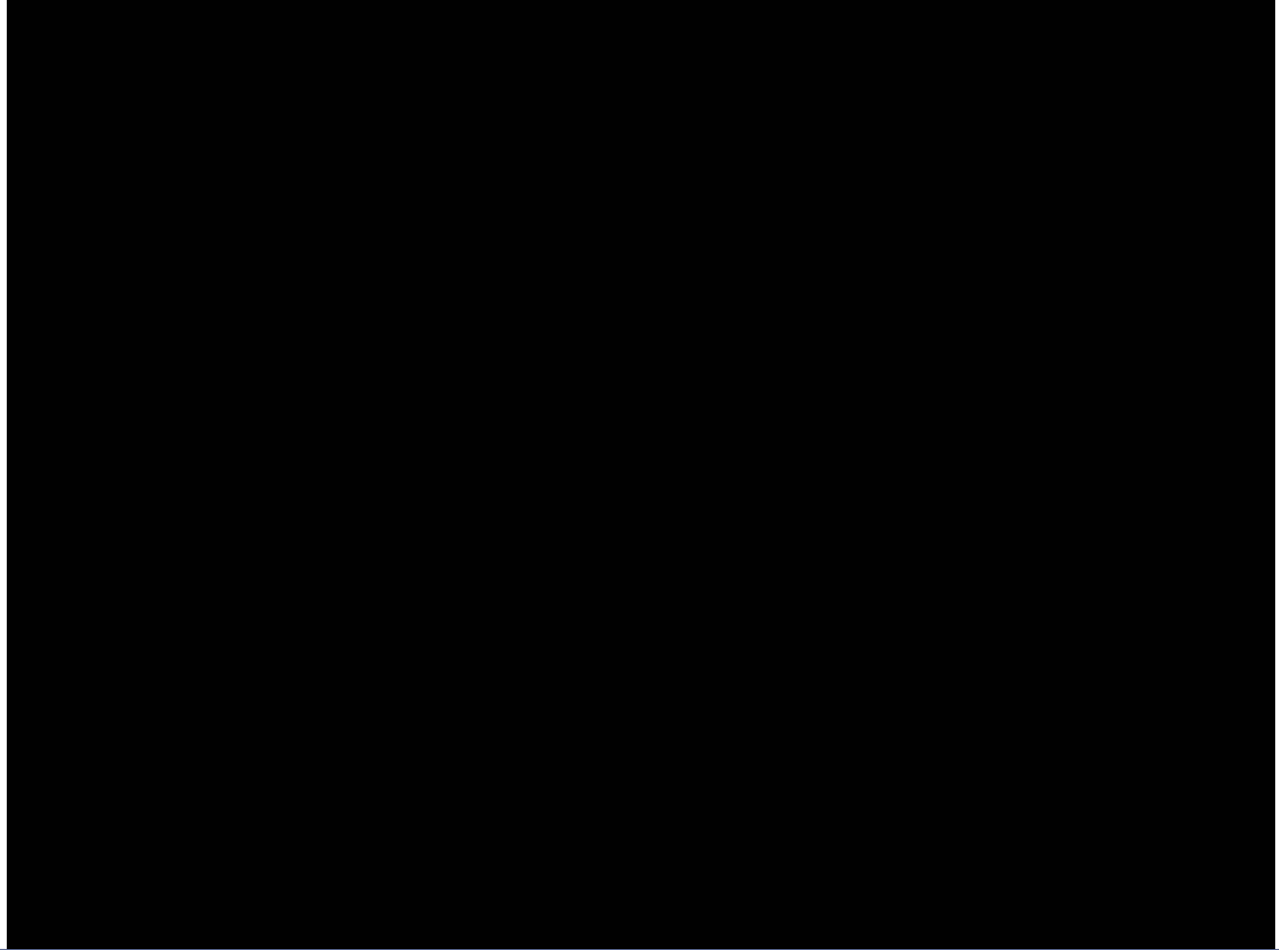
Battery cell(s) with a 100% state of charge (SOC) will be suspended 4″ above a 5.25″ fire pan located within a 64 ft^3 test chamber. 50 ml of 1-propanol will be loaded into the fire pan and ignited with a propane torch. Behavior of the battery cell will be monitored and recorded. Four type-K thermocouples will monitor the temperature change within the test cell and a calorimeter will measure heat flux produced by the source fire and battery ignition/failure.





Video Example of Venting Reactions During Single Cell Fire Exposure Tests

Results from Single Cell Fire Exposure Tests



Video Example of Venting Reactions During Multiple Cell (8 Cells Packaged Tightly Together) Fire Exposure Tests

Results from Multiple Cell Fire Exposure Tests

Battery Cell Testing

Fire Exposure Test Results

	Single Cell				Four Cells			
	Appr. Time to First Event (min)	Peak Temp (F)	Appr. Time to Reach Peak Temp	Appr. Time to Fire Out (min)	Appr. Time to First Event (min)	Peak Temp (F)	Appr. Time to Reach Peak Temp	Appr. Time to Fire Out (min)
Cell Type #1	1.00	450	1.25	4.00	0.75	560	1.50	4.5
Cell Type #2	1.00	605	1.50	3.25	2.00	700	2.00	4.5
Cell Type #3	0.75	780	0.75	2.75	0.75	900	1.00	1.75

	Eight Cells			
	Appr. Time to First Event (min)	Peak Temp (F)	Appr. Time to Reach Peak Temp	Appr. Time to Fire Out (min)
Cell Type #1	1.00	545	2.00	5.25
Cell Type #2	2.50	580	2.50	3.25
Cell Type #3	0.75	750	1.00	2.25

Battery Cell Testing

External Short Circuit Test Description

Battery cell(s) will be packaged in a tight configuration and placed within a 64 ft^3 chamber. A wire connected to the positive and negative terminals of one of these cells will force a short circuit within that cell. The test article will be monitored for any reaction that may take place and if this reaction affects or causes a failure in adjacent battery cells. Temperature within the test chamber and external battery cell temperature will be monitored with four type-K thermocouples. A calorimeter will measure heat flux produced by any reaction, fire or explosion that takes place.

Battery Cell Testing

External Short Circuit Test Results

- Battery cell type 1:
  - No ignition or venting event occurred
  - Peak temperature of battery cell not available

- Battery cell type 2:
  - No ignition or venting event occurred
  - Peak temperature of battery cell - 200°F

- Battery cell type 3:
  - No ignition or venting event occurred
  - Peak temperature of battery cell - 110°F

Battery Cell Testing

Pressure Pulse Test Description

Battery cell(s) will be suspended 4″ above a 5.25″ fire pan located within a 10 m^3 sealed test chamber. 50 ml of 1-propanol will be loaded into the fire pan and ignited with a propane torch. Behavior of the battery cells will be monitored and recorded. Temperature and pressure readings within the pressure vessel will be monitored and recorded.

Battery Cell Testing

Pressure Pulse Test Results

	Single Cell			Four Cells		
	Peak Pressure Rise (psi)	Appr. Time to Reach Peak Press. (min)	Peak Temp (F)	Peak Pressure Rise (psi)	Appr. Time to Reach Peak Press. (min)	Peak Temp (F)
Cell Type #1	0.70	3	420	1.10	5	470
Cell Type #2	1.40	4	500	1.50	4.5	585
Cell Type #3	2.15	1.75	770	4.10	2	1065

	Eight Cells		
	Peak Pressure Rise (psi)	Appr. Time to Reach Peak Press. (min)	Peak Temp (F)
Cell Type #1	1.35	6.5	480
Cell Type #2	1.10	5	515
Cell Type #3	5.30	3.5	N/A

Battery Cell Testing

Autoignition Test Description

The purpose of these tests is to determine the risk of a cell reaching thermal run away due to a smoldering suppressed fire. The battery cells will be suspended in the center of a 1 ft^3 insulated test chamber. An external acetylene torch fitted with a rosebud nozzle will be used as the heat source. Temperature within the test chamber will be monitored and behavior of the battery cells will be monitored and recorded.

Battery Cell Testing

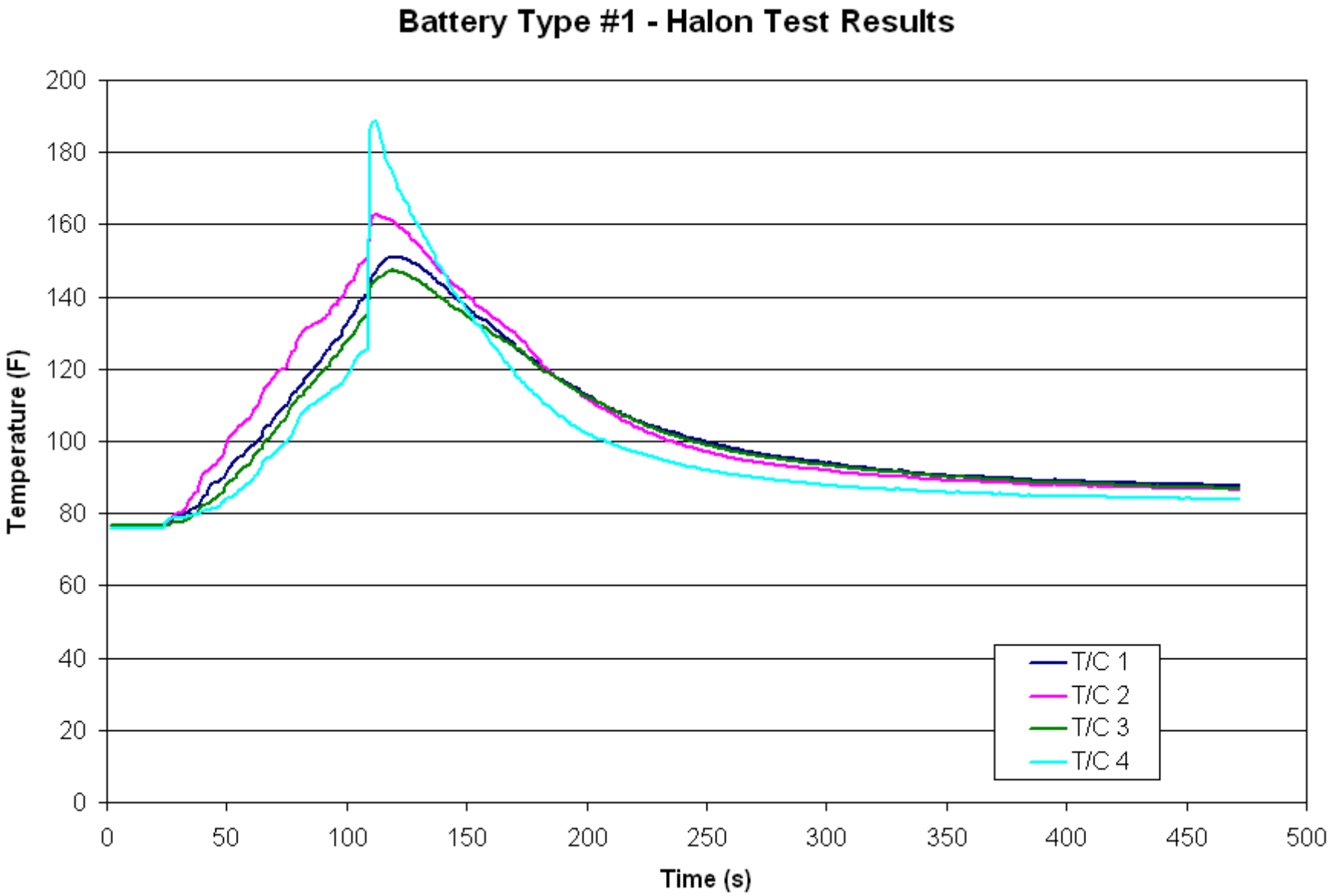
Autoignition Test Results

	Trial 1		Trial 2	
	Ignition Temp (F)	Peak Temp (F)	Ignition Temp (F)	Peak Temp (F)
Cell Type #1	440	572	490	649
Cell Type #2	480	664	527	639
Cell Type #3	340	741	330	788

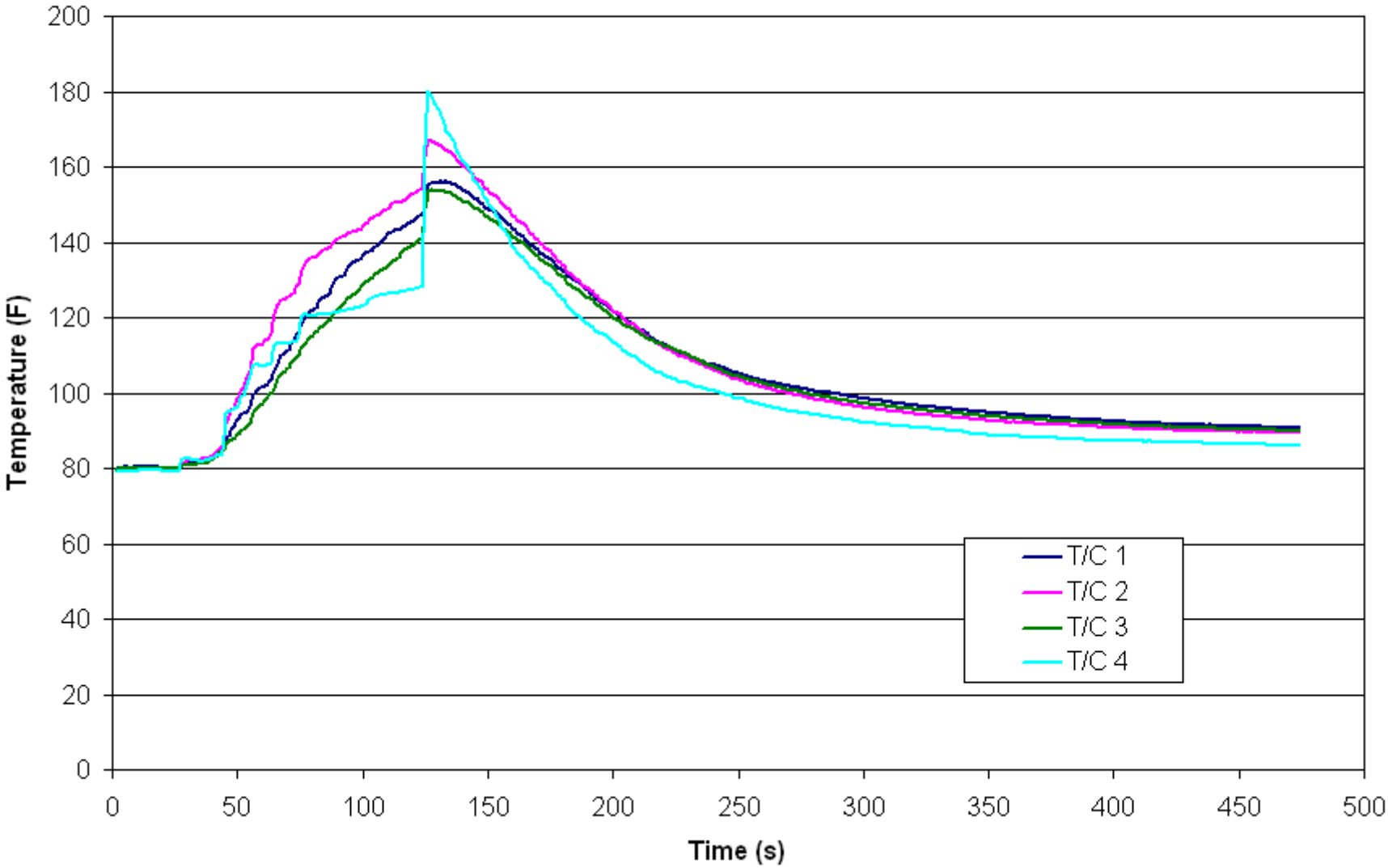
Battery Cell Testing

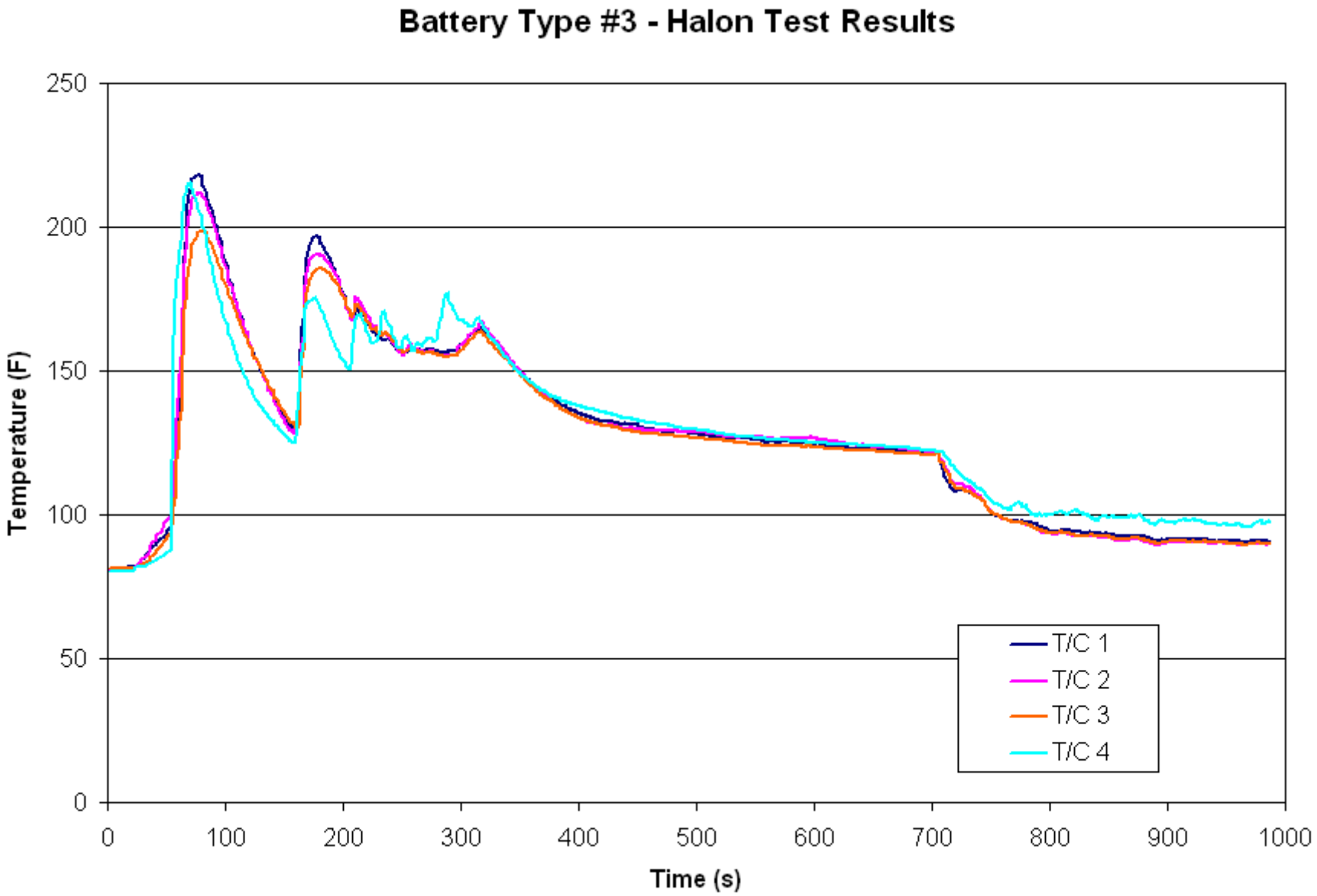
Halon 1211 Handheld Suppression Test Description

Tests will be conducted to evaluate the effectiveness of a typical handheld fire extinguisher in suppressing a fire involving Li-ion battery cells. Tests will be conducted in a similar manner to the Fire Exposure Tests. Once the failure of the battery cells has occurred, the contents of the handheld extinguisher will be discharged. Behavior of the battery cells will be monitored and recorded. Four type-K thermocouples will monitor the temperature change within the test cell and a calorimeter will measure heat flux produced by the source fire and battery ignition/failure.


Battery Type #1 - Halon Test Results
Temperature (F)
200
180
160
140
120
100
80
60
40
20
0
0
50
100
150
200
250
300
350
400
450
500
Time (s)
T/C 1
T/C 2
T/C 3
T/C 4

Battery Type #2 - Halon Test Results




Battery Type #3 - Halon Test Results
250
200
150
100
50
0
Temperature (F)
0
100
200
300
400
500
600
700
800
900
1000
Time (s)
T/C 1
T/C 2
T/C 3
T/C 4

Summary

- Cylindrical Li-Ion and Li-Po battery cells can react violently when exposed to an external fire.
- During Single Cell tests for battery type 2, vents failed to open, resulting in an explosion of the battery cell.
- Li-Po battery cells greatly fueled the existing fire as the full amount of electrolyte is exposed at once to the fire source.
- Li-Po battery cells resulted in significantly higher temperature and pressure increases compared to the cylindrical cells.
  - It must be remembered however that the Li-Po cells had a significantly higher energy density and power capacity (8Ah/cell as compared to 1.2 and 2.3Ah/cell).

Summary (cont.)

- Short circuiting of cells did not result in any thermal runaway events

- Halon 1211 successfully extinguished fires involving all three battery types, however several re-ignition events were observed while attempting to suppress the Li-Po battery fire.