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Preventing Lithium-Ion Thermal Runaway

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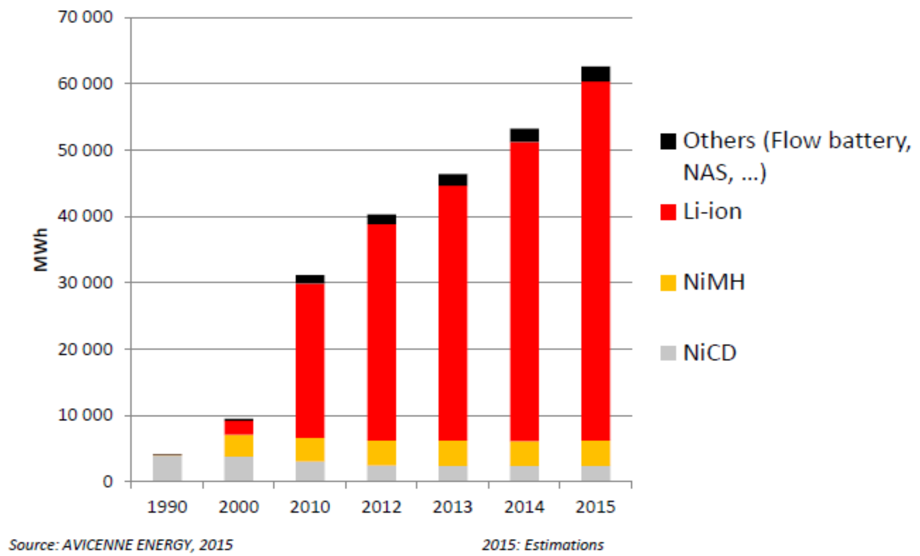
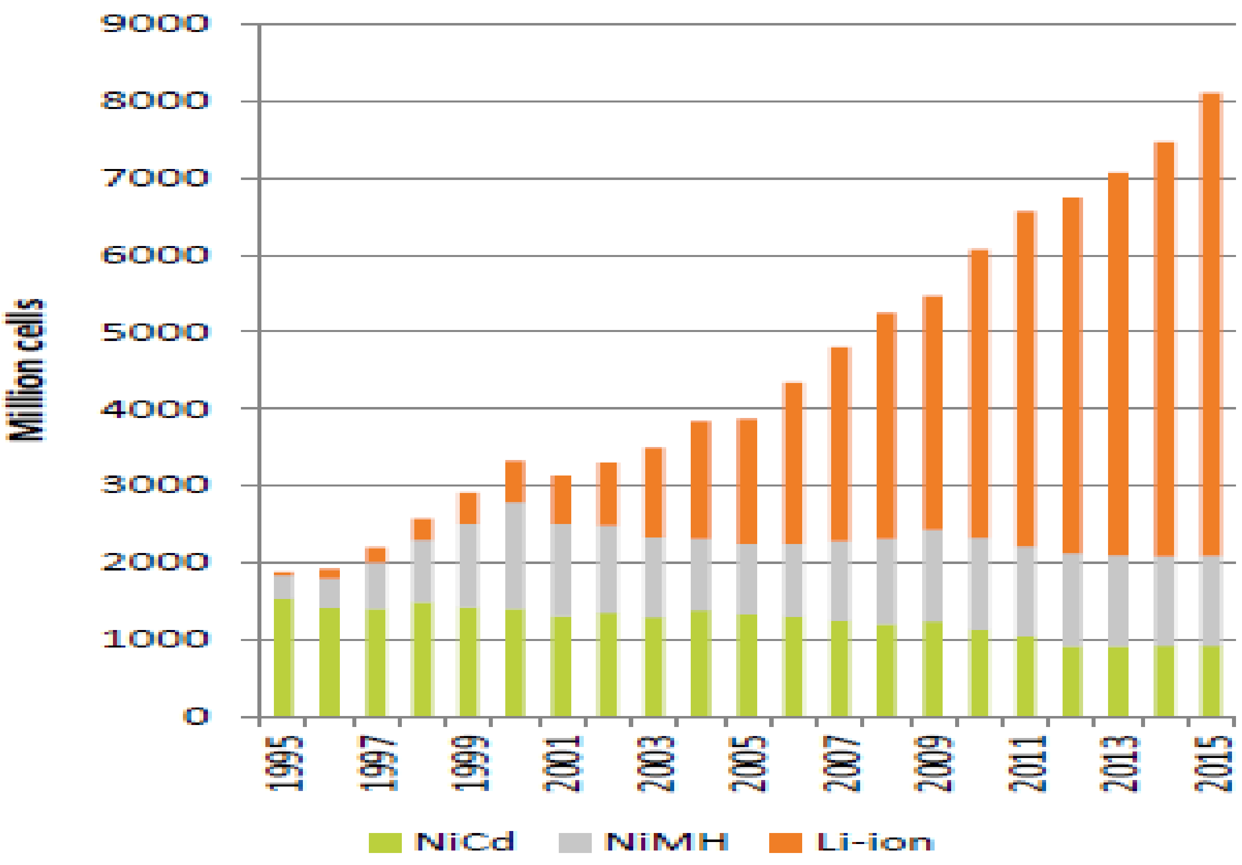
Hazard Definition

- Lithium-ion batteries are subject to a catastrophic failure mode known as thermal runaway when certain conditions create an internal short within a cell.
- Common conditions:
  - Electrical over-charge
  - Thermal over-heat
  - Manufacturing defects or impurities
  - Dendritic lithium formation
  - Mechanical damage

Hazard Definition

- Internal short failure rate is very low
  - 1:10,000,000 to 1:40,000,000 or 125 – 500 based on 2015 cell production

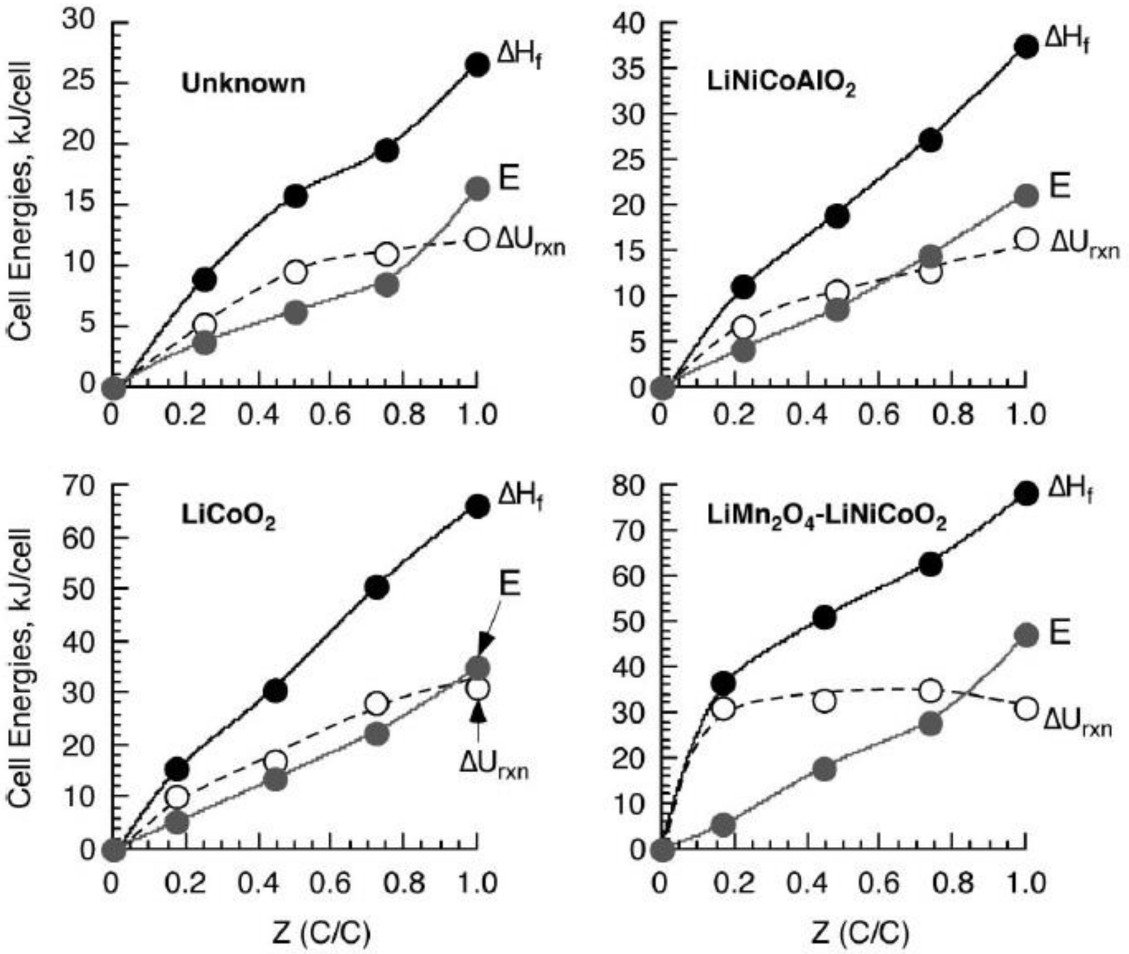




Avicenne Energy – presentation: Nice, France, October, 2015

Difference in Cell Energies Based on Cathode Material

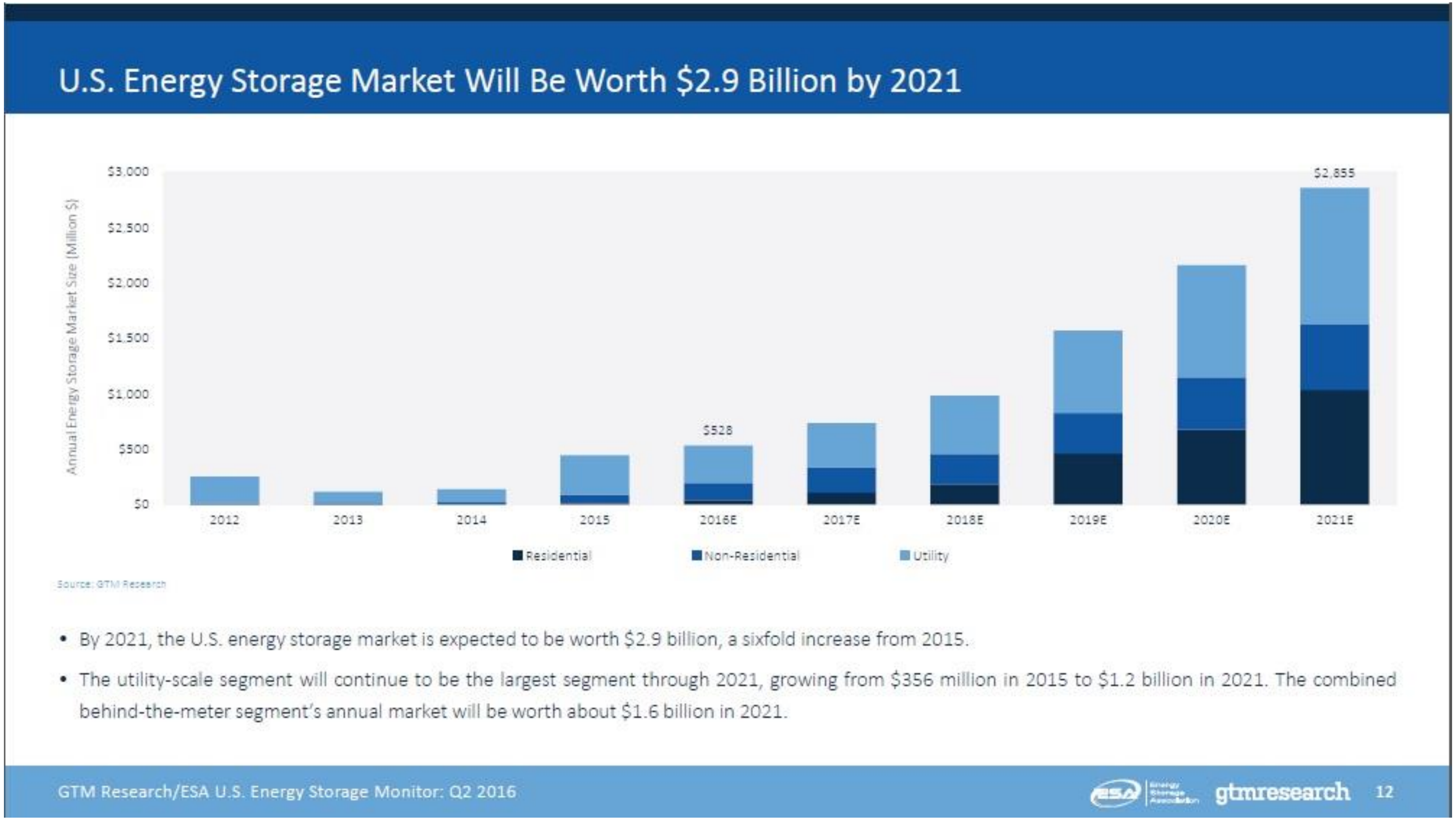
Cathode Material Directly Influences The Energy Within A Cell!!



FAA. (2016). *2015 Fire Safety Highlights.* Washington D.C.: Federal Aviation Administration.

Market Growth
Energy Storage Systems

- GTM Research is a leading market analysis & advisory firm on the transformation of the global electricity grid
- Industry in ESS alone estimated to grow from $356 million in 2015 to $1.2 billion in 2021



3M

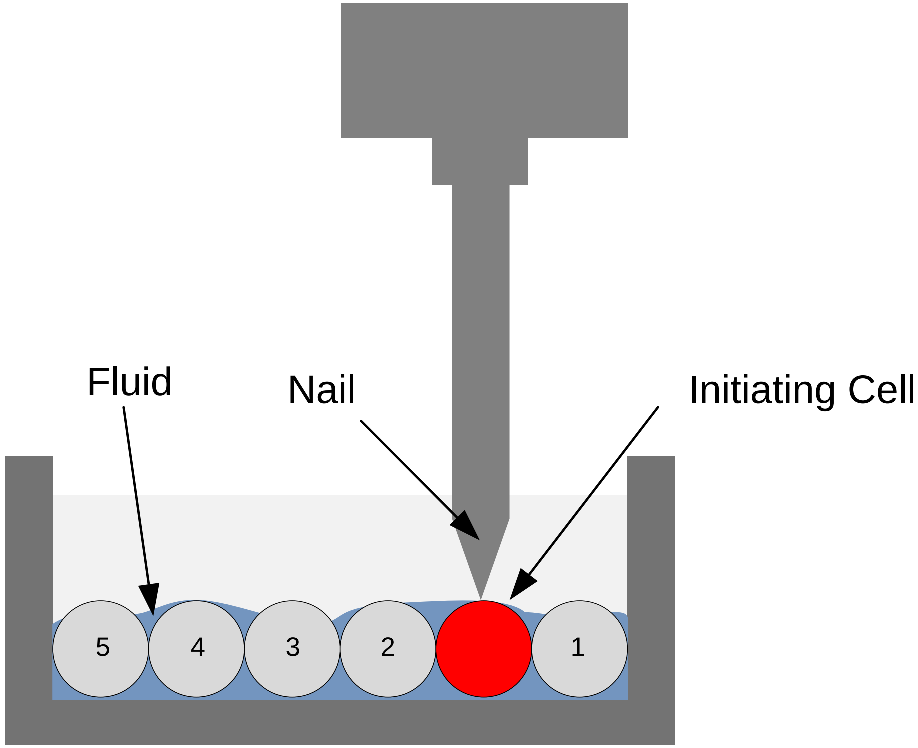
Project Scope

Use of fluorinated fluids to dissipate heat away from a Li-ion cell in thermal runaway.

- If an internal short occurs, can the exothermic thermal event be limited and escalating cell to cell failures be prevented?
- How much fluid is required to halt thermal runaway?
- Can the fluid be applied after the initial event?

Nail Puncture Test

- Linear actuator controlled by a PLC inserts a metal rod with a conical tip until it pierces the separator between the anode and cathode of the cell, causing an internal short.
- Instant thermal runaway occurs within the cell and a subsequent explosion vents high temperature materials and flammable organic solvents.
- For static immersion tests, the battery packs were secured in a stainless steel container that allowed for a variable amount of fluid to be in direct contact with the exterior surface of the lithium-ion cells.



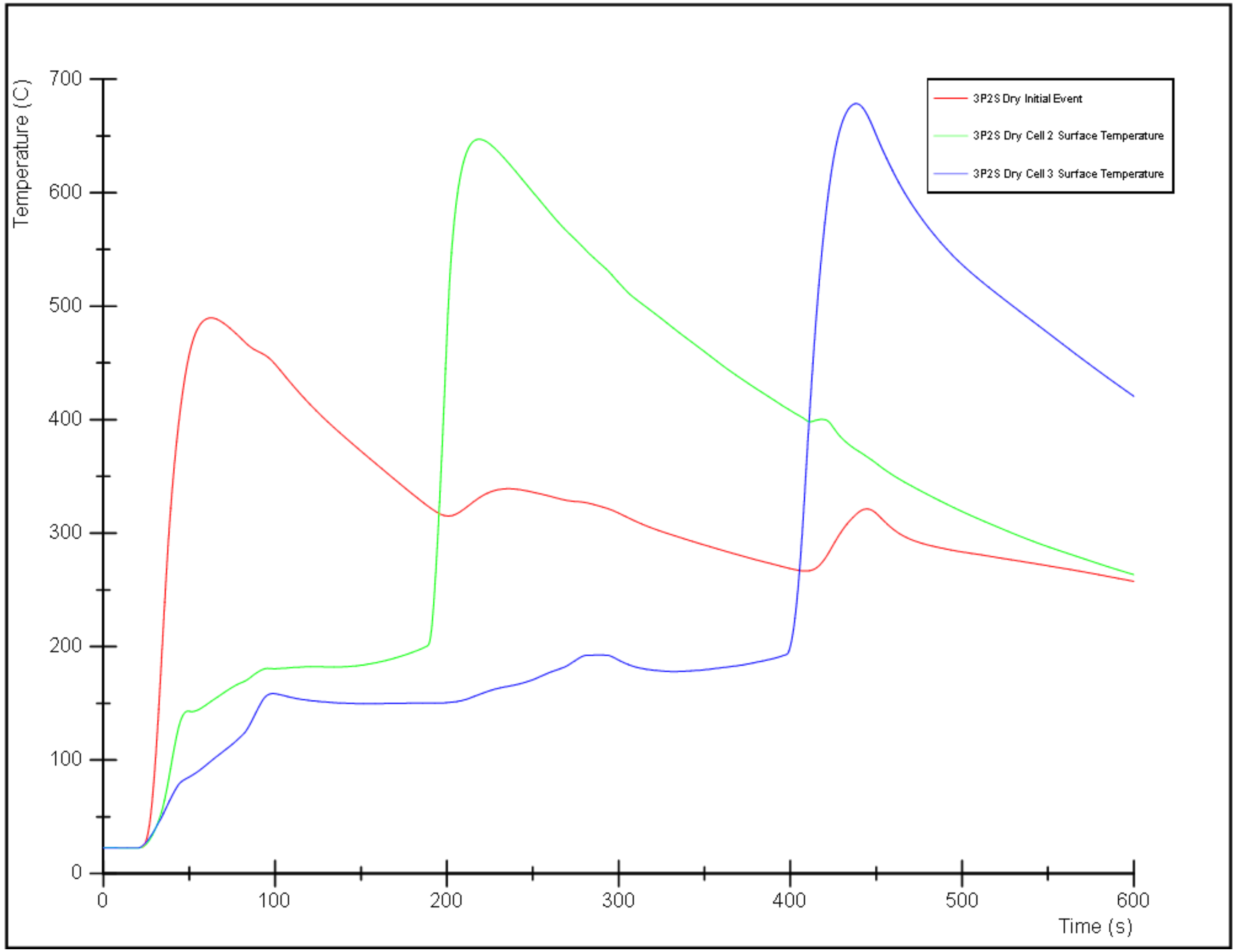
Test Cell Specification

- Testing used commercially available 2.6 amp hour 18650 cells.
- Cells had $LiCoO_2$ cathode and a graphite anode.
- The AC impedance at 1 KHz is approximately 60 mΩ.
- The cells were charged to 100% SOC using a battery cycler.
- The electrolyte solvent was dimethyl carbonate.
- 1M $LiPF_6$ in EC:EMC (3:7 by vol).

Battery Pack Test Without Protection

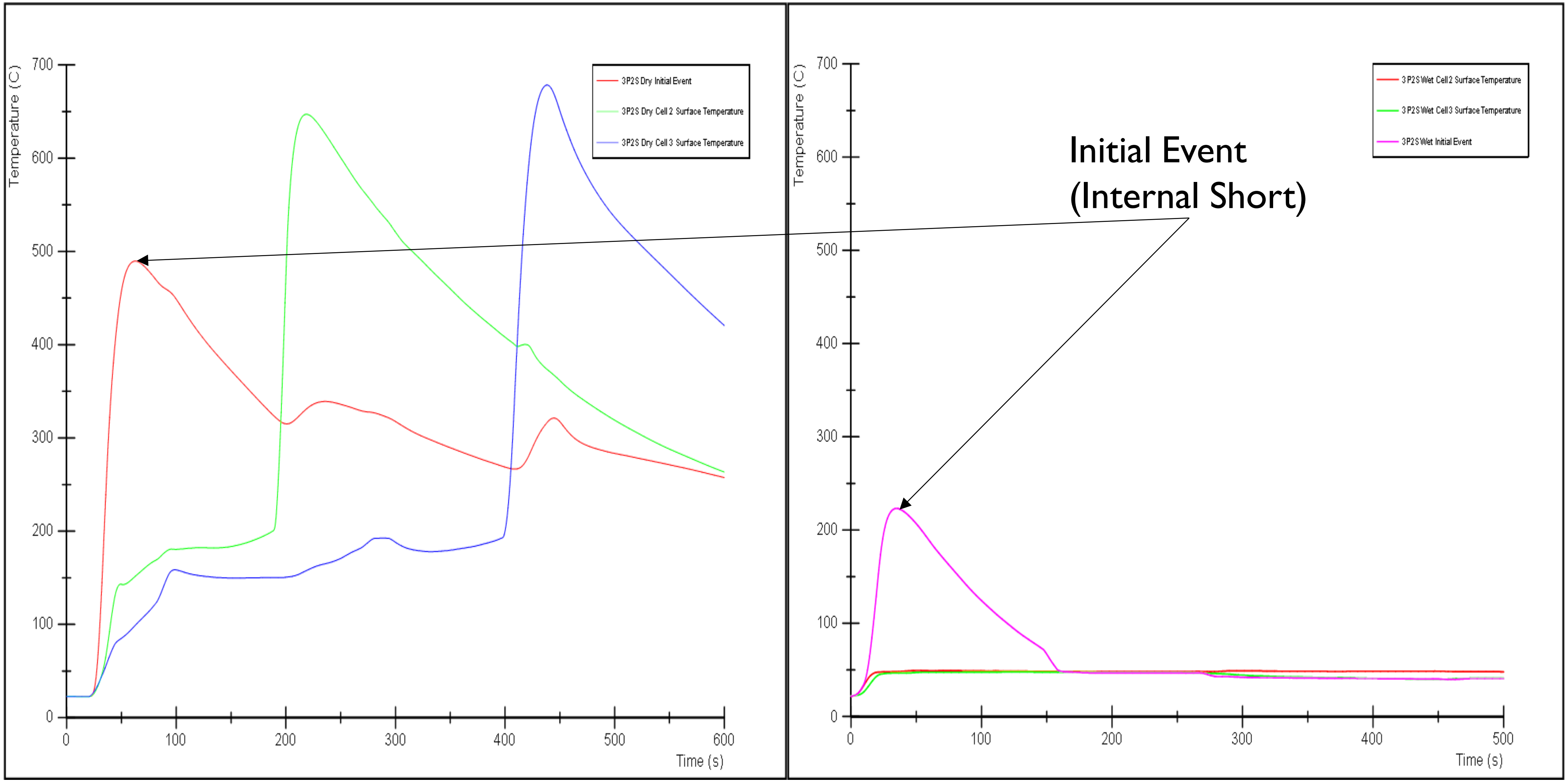
Problem Definition: Cell to Cell Thermal Runaway

Temperatures measured during cell to cell thermal runaway.



Battery Pack Test Immersed in C7 Fluorinated Ketone

Protected vs Unprotected Cells

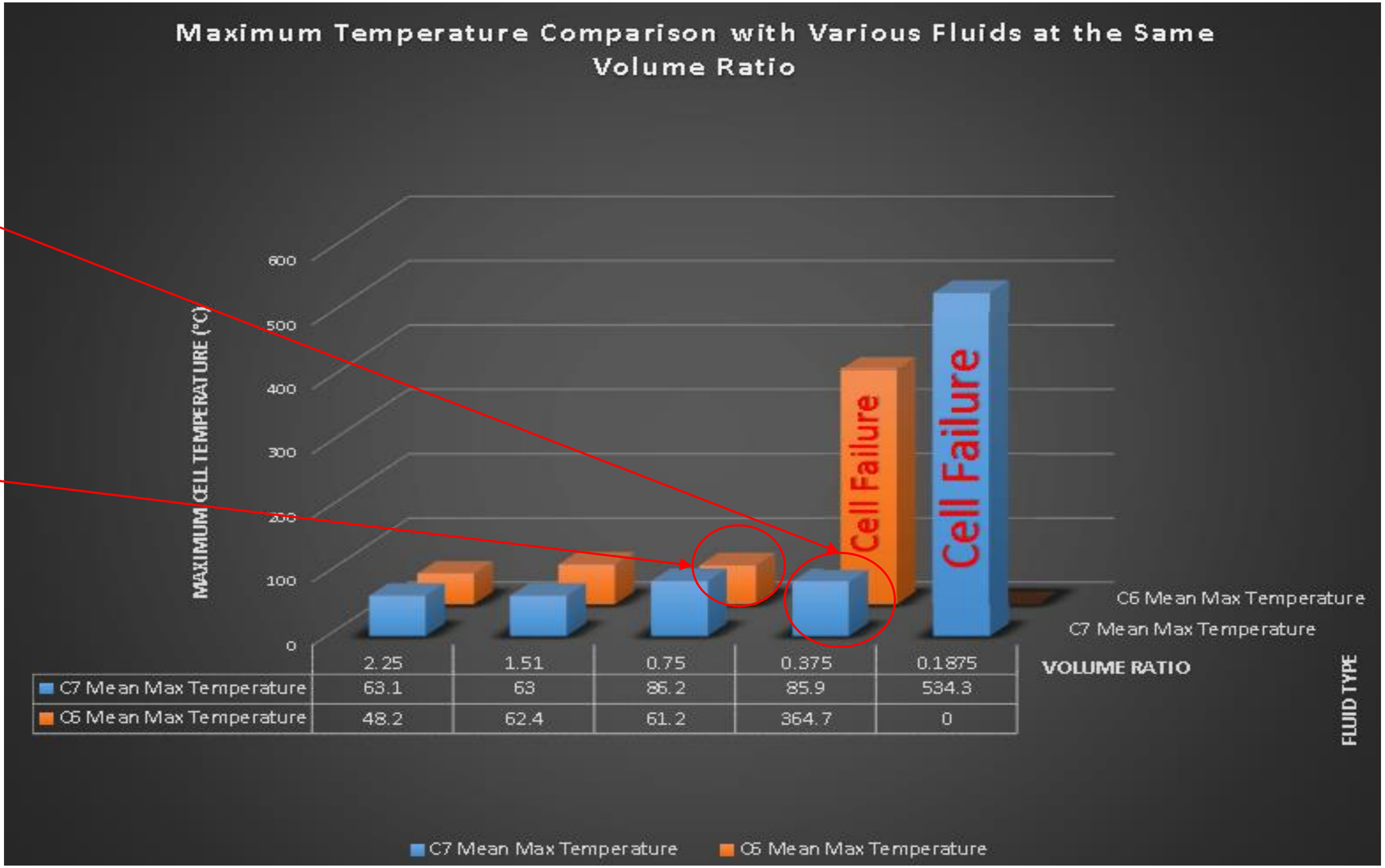


Fluid Optimization

C7 Effective at 38% of cell volume

C6 Effective at 75% of cell volume

Total immersion is not required to halt thermal runaway



	2.25	1.51	0.75	0.375	0.1875
C7 Mean Max Temperature	63.1	63	86.2	85.9	534.3
C6 Mean Max Temperature	48.2	62.4	61.2	364.7	0

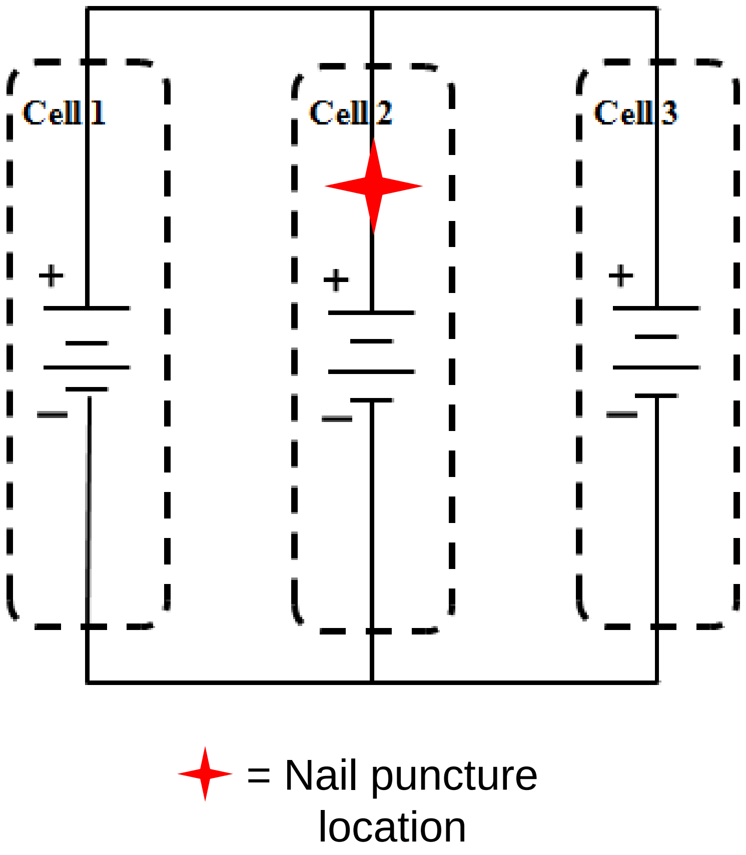
Key Findings – Performance Mechanisms

- C6 and C7 liquids work by removing a significant amount of heat from a cell undergoing thermal runaway.
  - Heat is removed from the cell, increasing the bath temperature and with localized evaporation.
- Adjacent cells are maintained at a constant temperature within the liquid bath and cell to cell thermal runaway is prevented.
- Any combustible material expelled by a cell with an internal short cannot burn in an environment where C6 or C7 liquids are present due to their flame extinguishing properties.

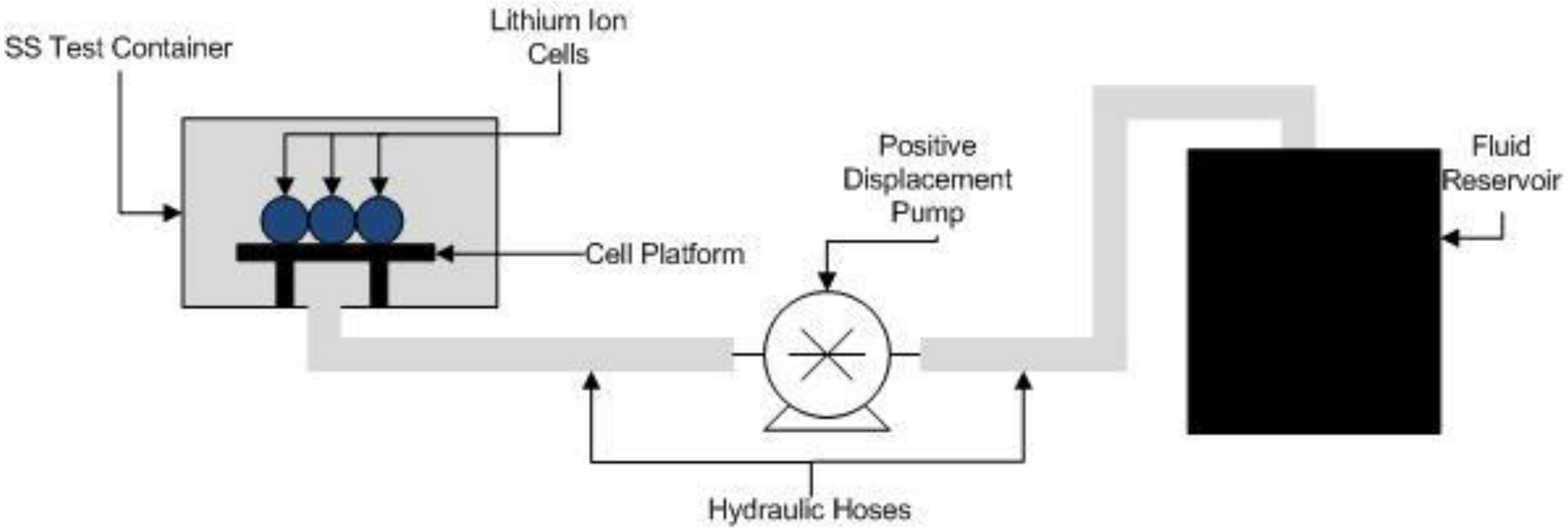
Delayed Protection

Goals:

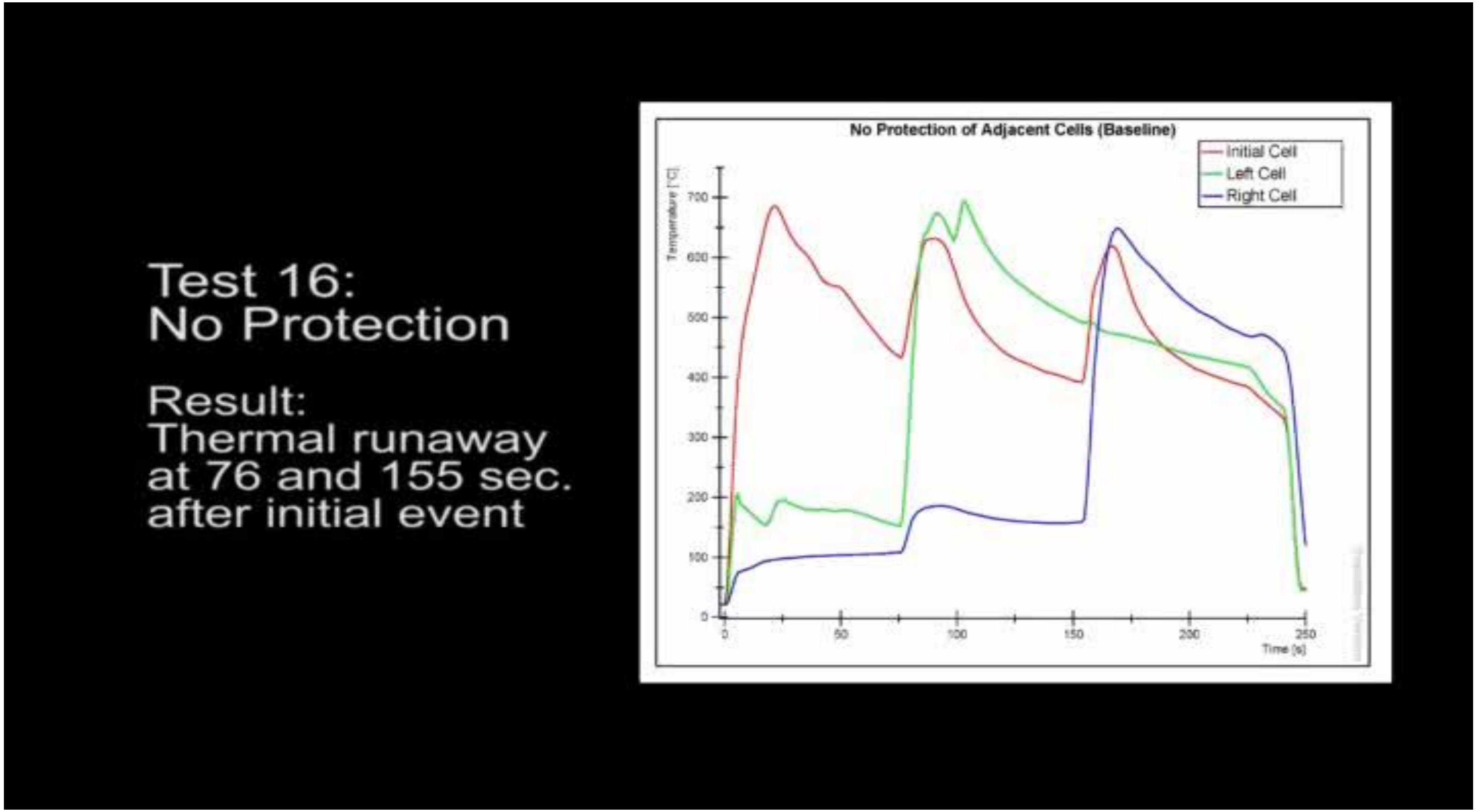
- Quantify level of protection when C6 & C7 liquid is applied after the initial event.
  - Fluid applied before first adjacent cell runaway event.
  - Fluid applied between the first and second adjacent cell runaway events.
- Determine time response required.



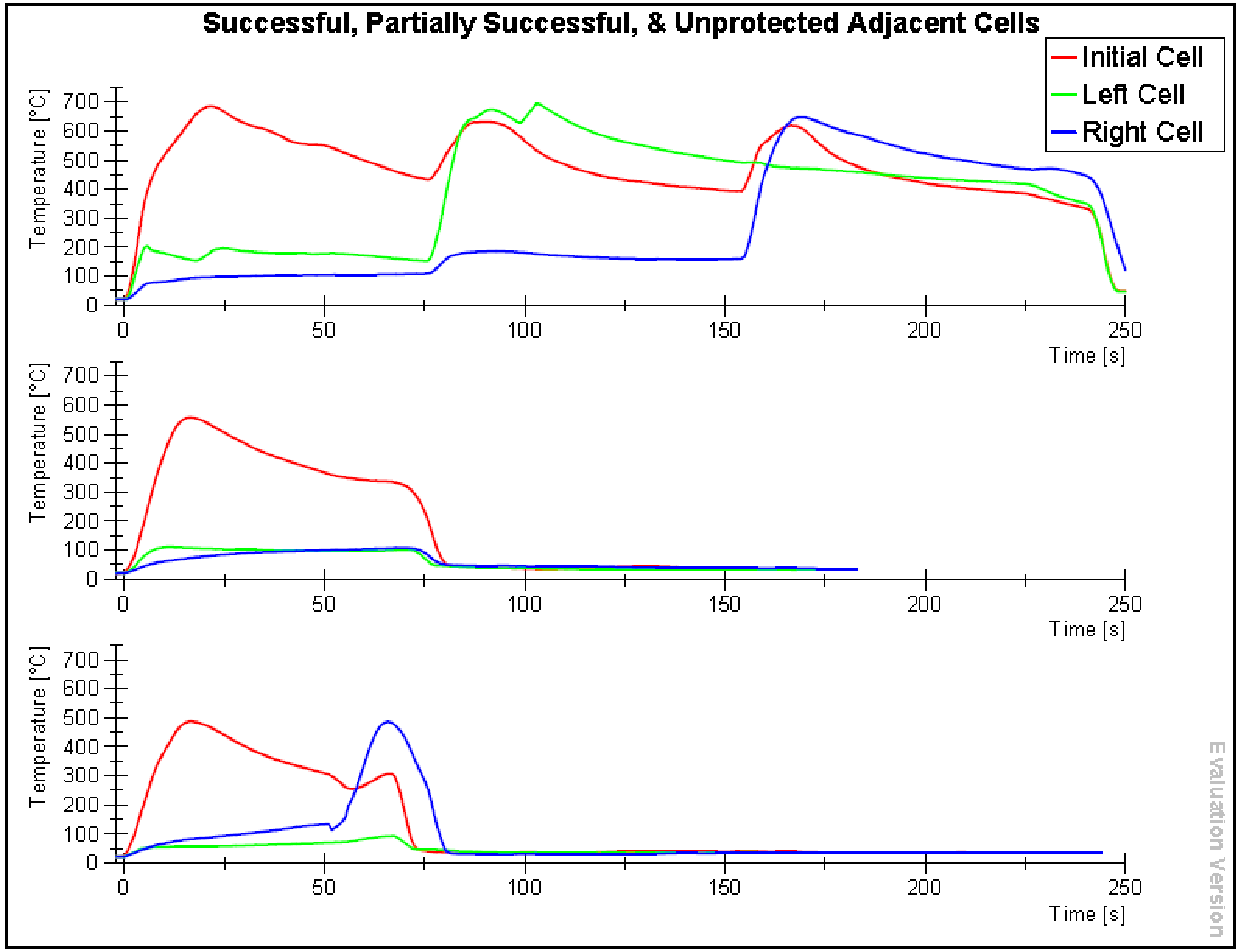
Testing Apparatus



Delayed Protection



Thermal Runaway – Delayed Protection



Key Findings

- Both C6 and C7 liquids are effective when in direct contact with cells undergoing thermal runaway.
- Cells can be in contact before, during or after thermal runaway has started.
- When immersed in fluid, the voltage across the parallel battery packs was maintained throughout the experiment.
- Time needed for adjacent cell failures to occur cannot be definitively determined.

Applications

- Energy Storage System (ESS) Protection:
  - Wind/Solar
  - Peak shaving
- Bulk air transportation on cargo planes
- Cell thermal management
- Automotive

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Questions?

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Thank You