

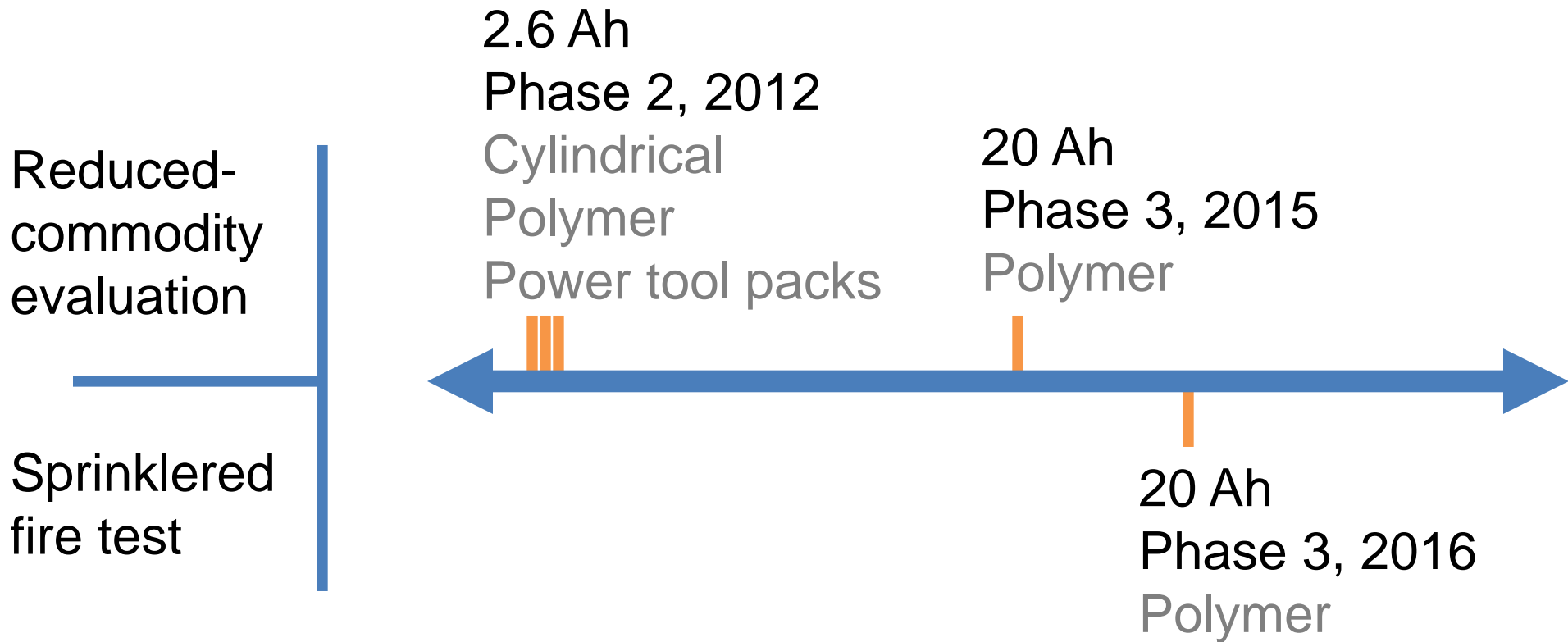


# Working Towards Protection Guidance for Warehouse Storage Li-ion Batteries

Benjamin Ditch, FM Global  
Tom Long, Exponent Inc.

SUPDET 2016, March 1 – 4, San Antonio TX

# Experimental Knowledge Timeline



# Li-Ion Battery Characterization



# Package Description



- Cardboard box: 17"x13.5"x6.5"
- Total weight: 27 lb. (including cells)
- Contents:
  - 20 battery cells
  - White polystyrene crates
  - Polyethylene bubble wraps



# Battery Cell Description



## Lithium-Ion Pouch Cell

- Dimension: 9"x6"x0.3"
- Weight: 1.1 lb
- Capacity: 20 Ah
- Voltage: 3.3 volts

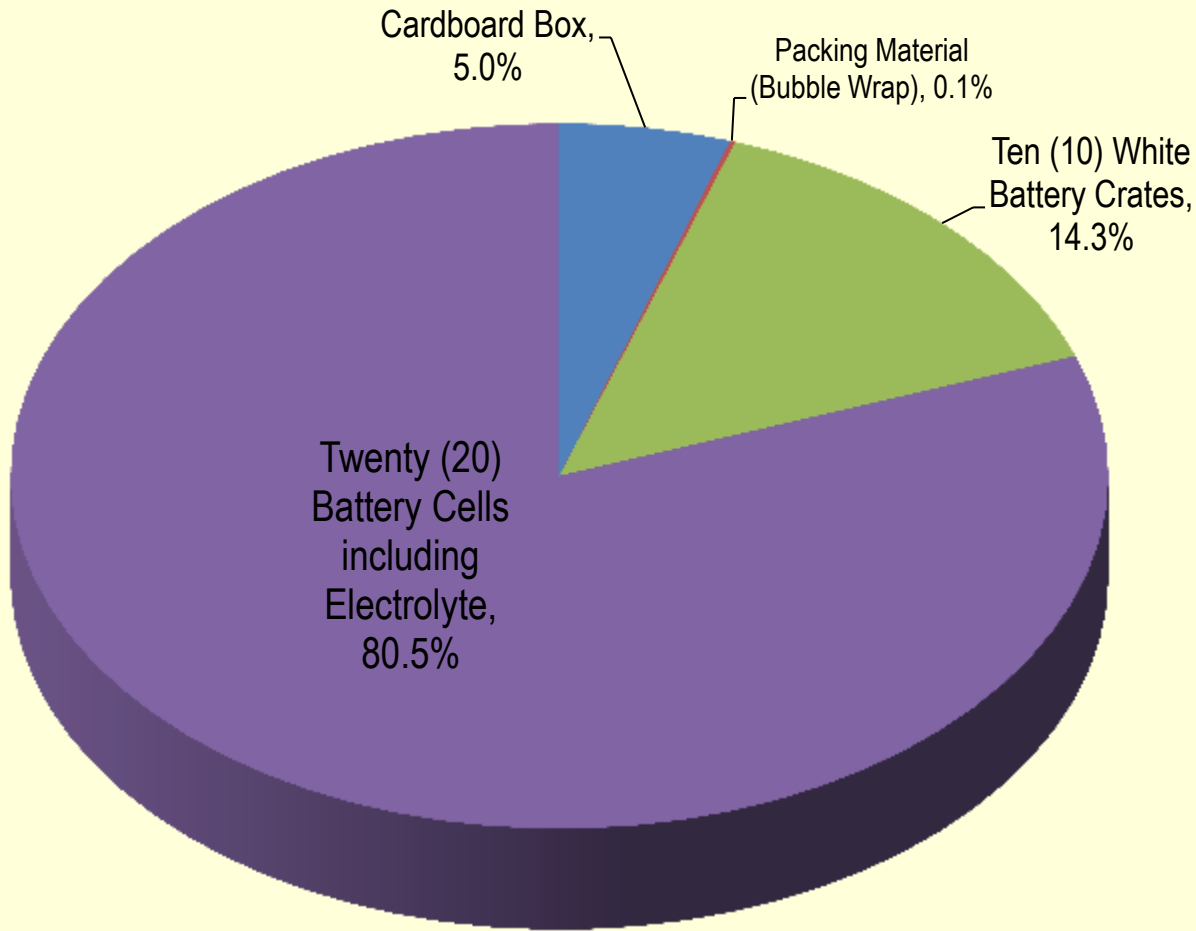


# Electrical Characterization



- Stacked Electrode Design
- Cell Chemistry: Lithium Iron Phosphate ( $\text{LiFePO}_4$ )
- As-Received SOC: 49.4%
- Electrolyte Mass: 0.083 lb

# Battery Package Mass Summary



Content per One Package	Weight
20 Battery Cells (including Electrolyte)	21.7 lb (80.5%)
10 White Battery Crates	3.9 lb (14.3%)
Cardboard	1.4 lb (5.0%)
Parking Material	0.04 lb (0.1%)
Electrolyte	1.7 lb (6.2%)
<b>Total Weight</b>	<b>27.0 lb</b>

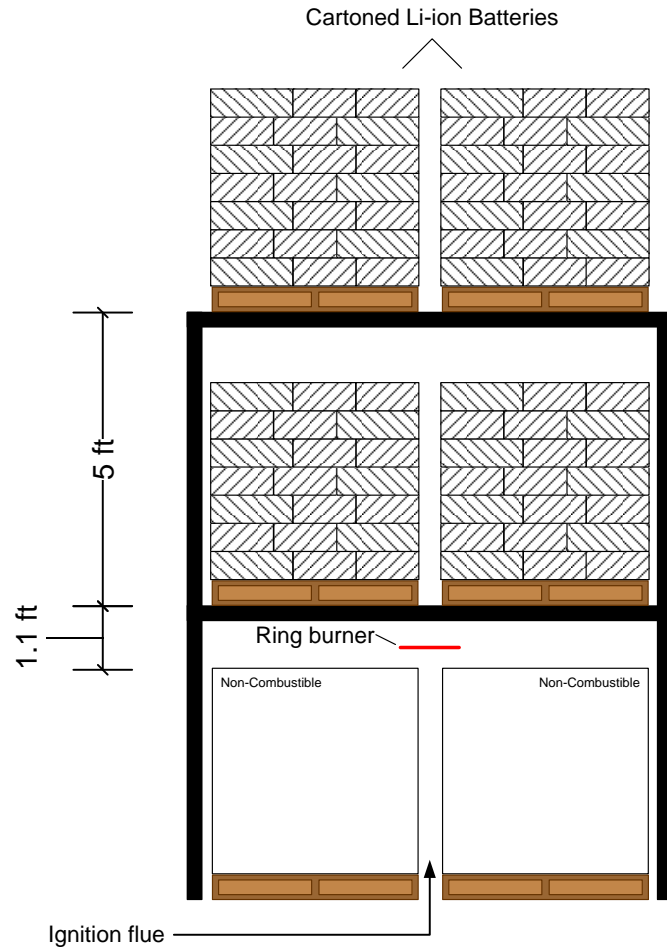
Task 1

Completed: July, 2015

# REDUCED-COMMODITY TEST



# Reduced-Commodity Test: Design



- Storage height: 15 ft
- Protection: none
  - Freeburn
- Commodity:
  - 4 full pallet loads
  - 4,480 batteries
- Ignition
  - Propane, 45 kW

# Reduced-Commodity Test



30 s



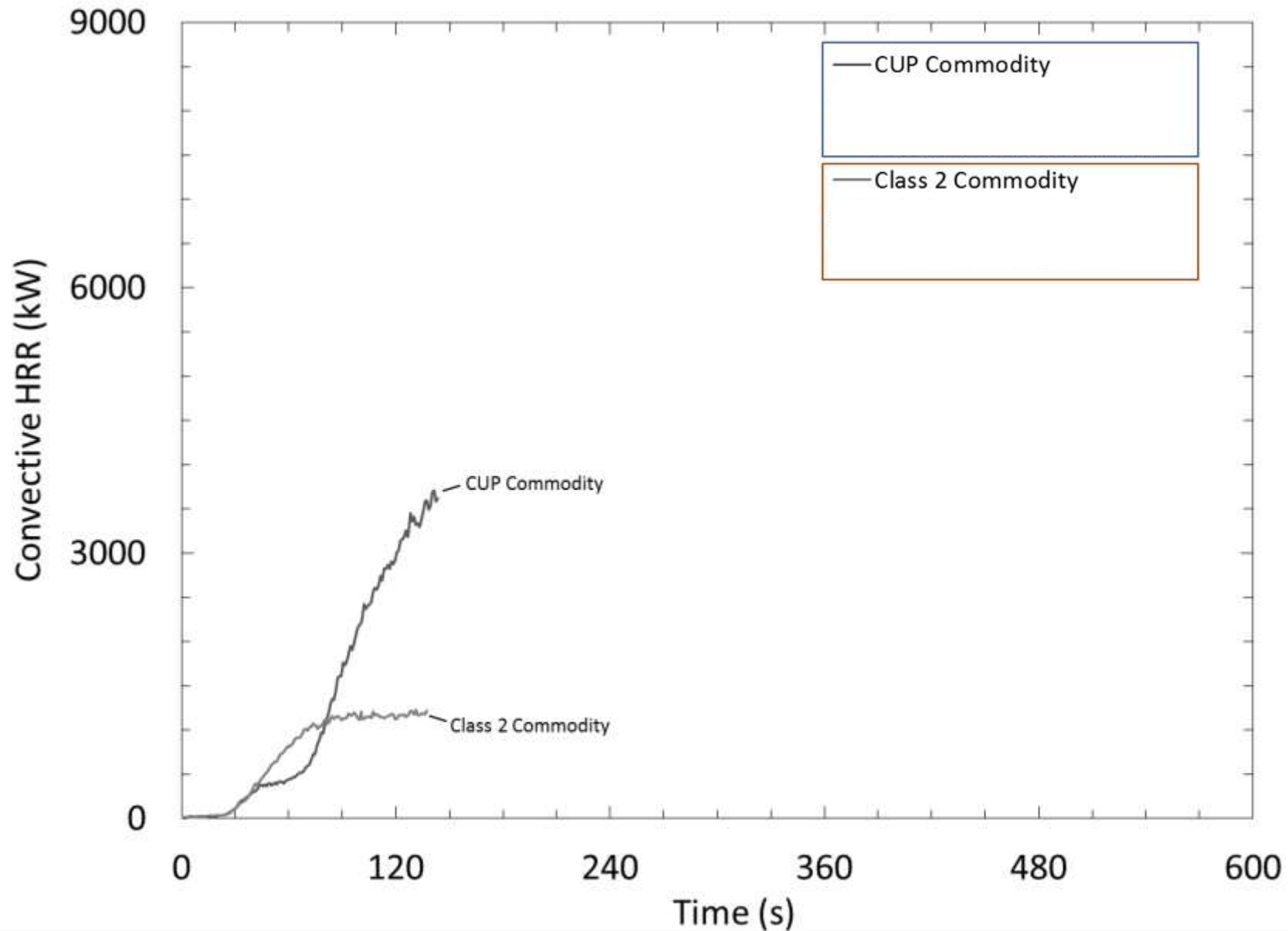
60 s



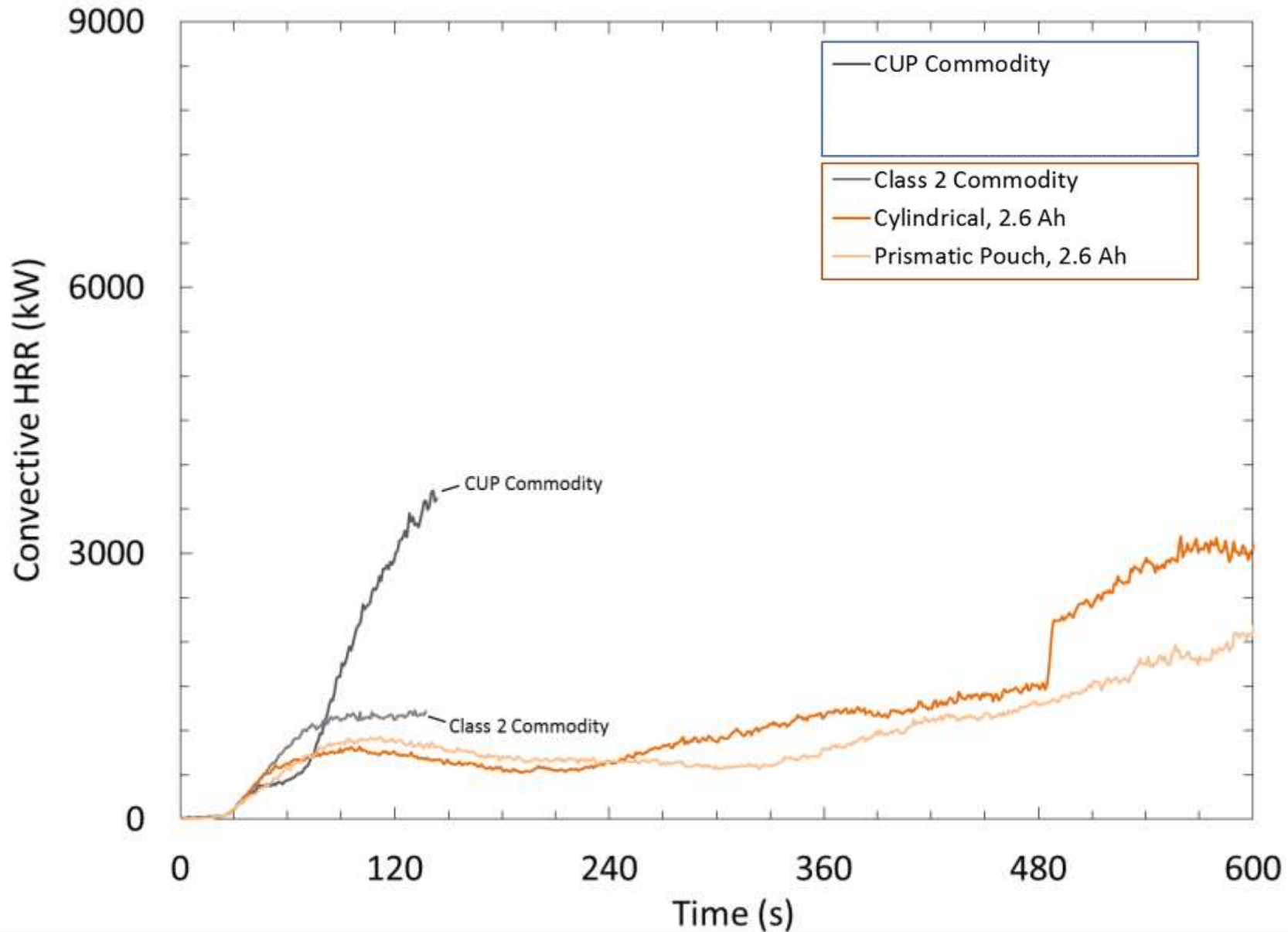
90 s



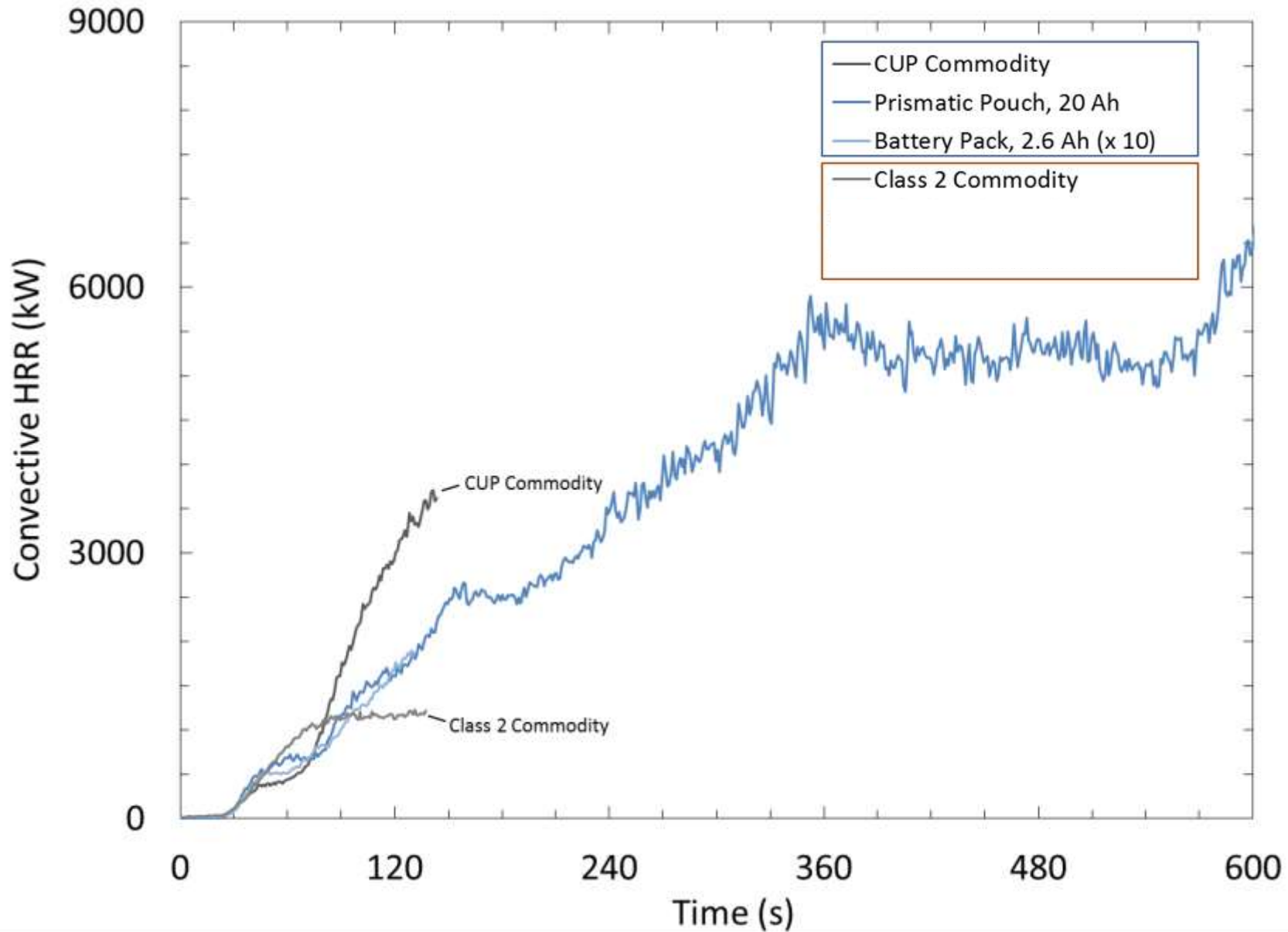
120 s



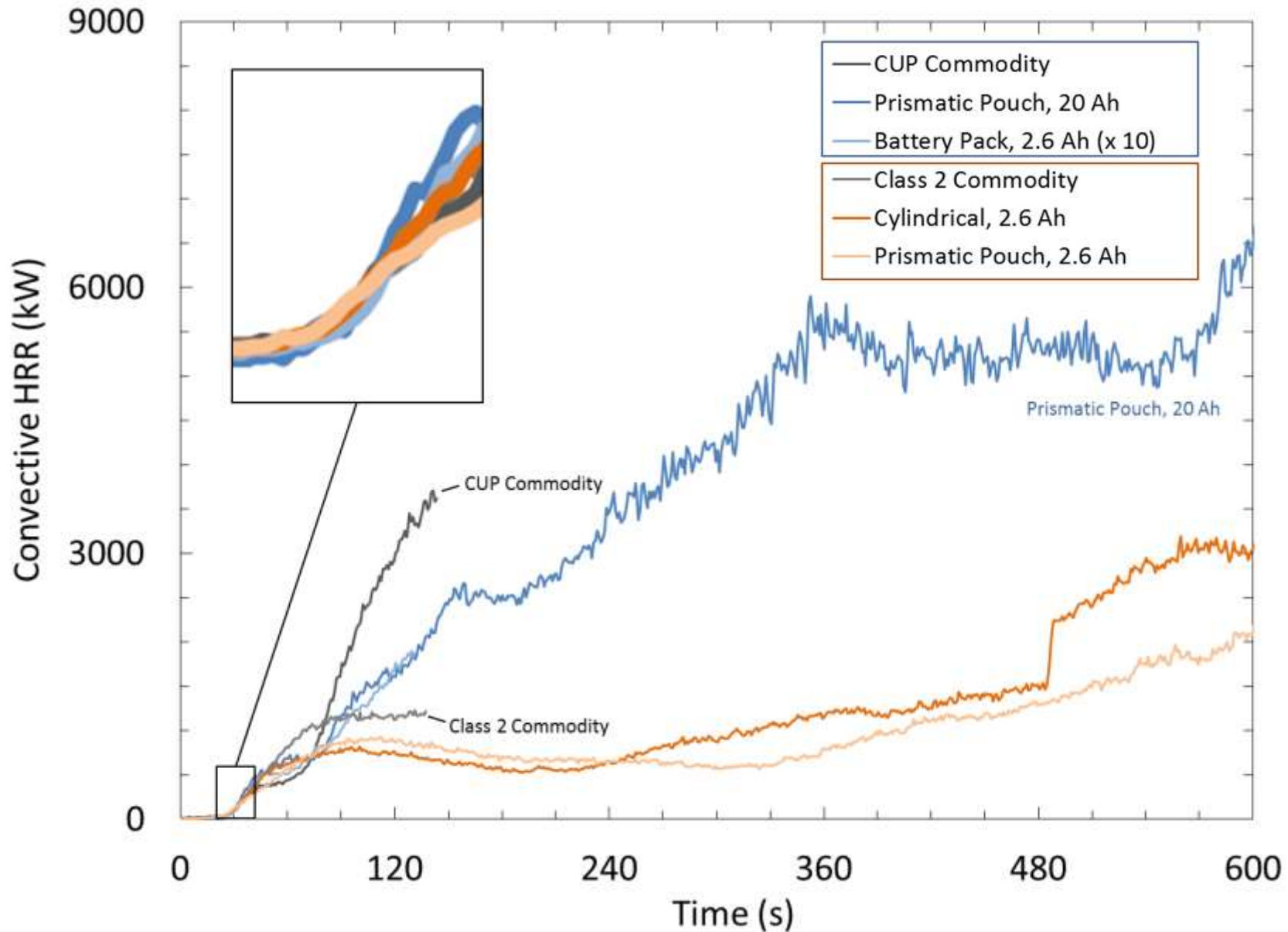
# Hazard Comparison



# Hazard Comparison



# Hazard Comparison



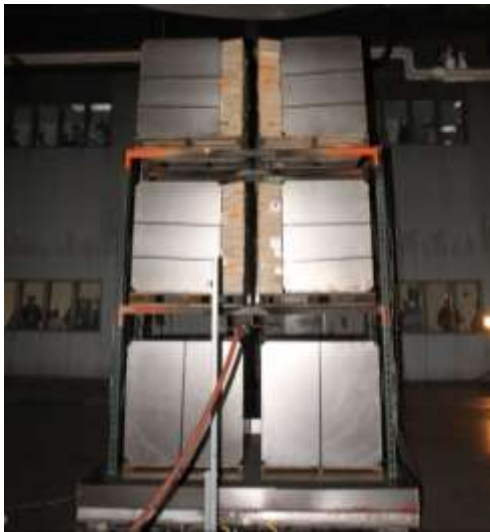


# Comparison to Previous Testing

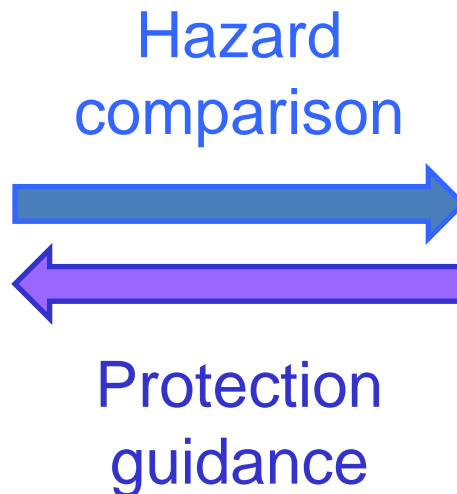
- Similar fire development
  - Initial growth dominated by cartons
  - Fire size and growth rate similar at sprinkler operation
- Time of significant battery Involvement
  - Large-format: 90 - 120 s
  - Small-format: 300 s
- ❖ Higher hazard than small format Li-ion cells

# Potential Application of Results

- Sprinkler protection option established
  - Applied to all cells with a hazard  $\leq$  cell used in sprinklered test
  - Cell hazard evaluated in reduced-commodity test



Reduced-commodity test



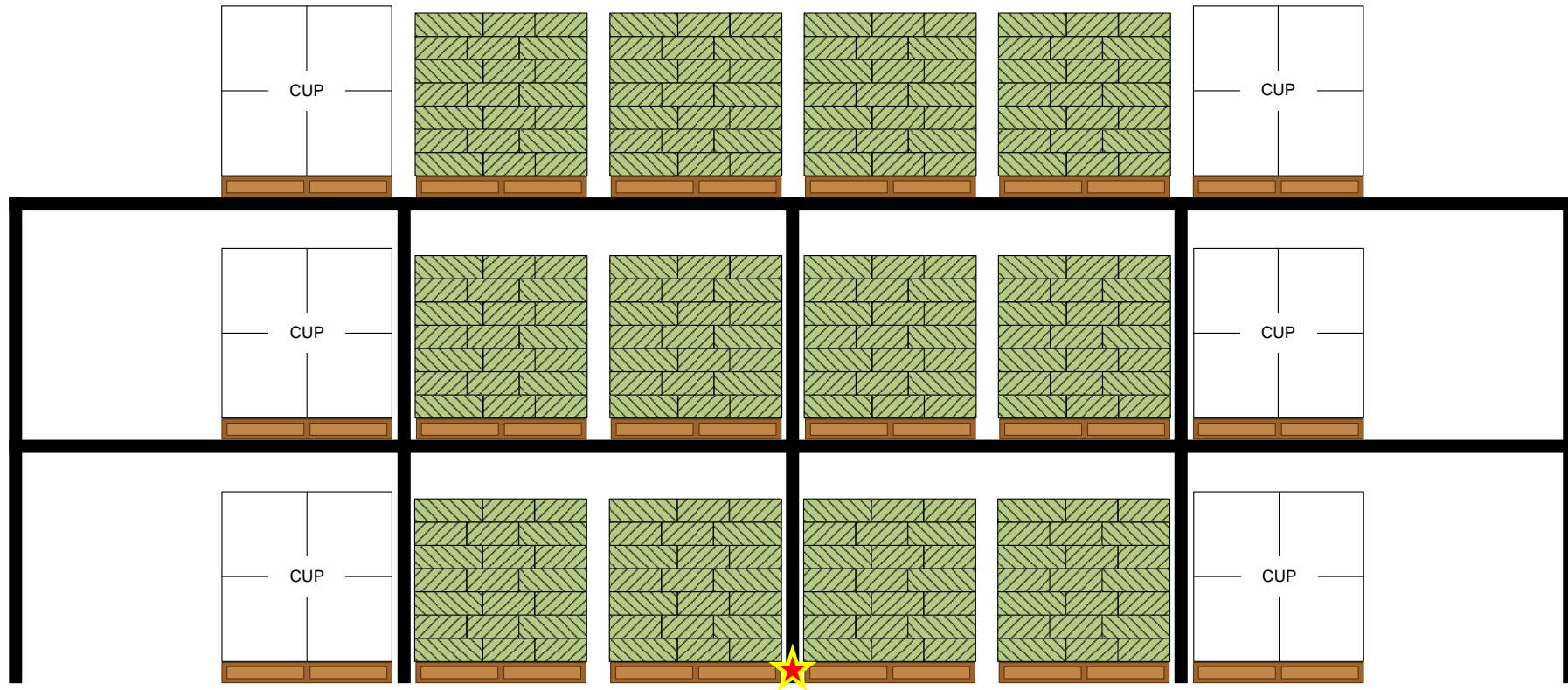
Large-scale test

Task 2

Scheduled: April, 2016

# LARGE-SCALE TEST

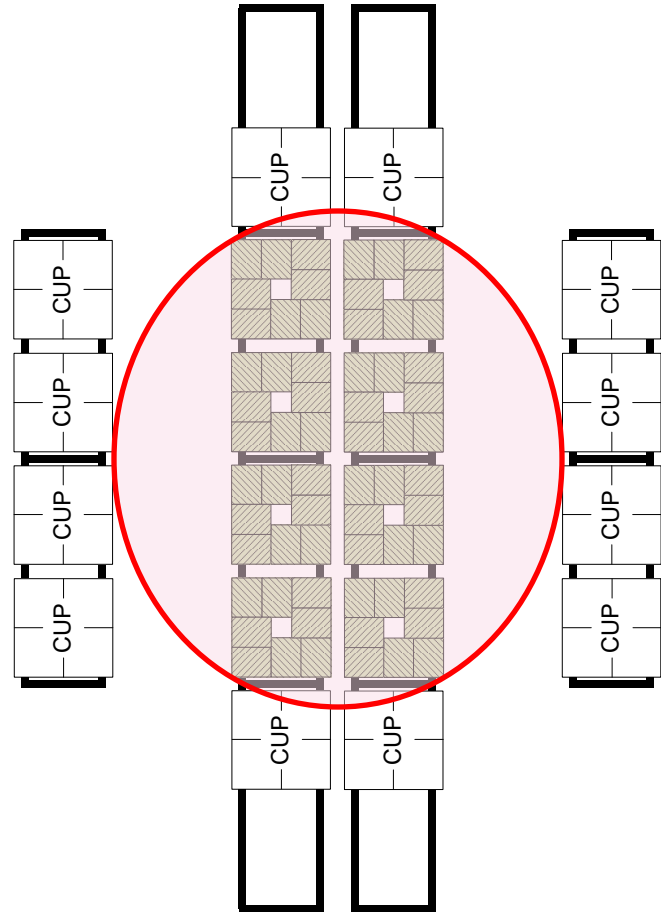
# Large-Scale Test: Schematics



# Large-Scale Test: Design

- Storage height: 15 ft (4.6 m)
- Ceiling height: 40 ft (12.2 m)
- Sprinkler: K22.4 gpm/psi<sup>1/2</sup> (320 lpm/bar<sup>1/2</sup>)
  - Response: quick-response, 165°F (74°C)
  - Density: 1.3 gpm/ft<sup>1/2</sup> (53 mm/min)
  - Spacing: 10 × 10 ft (3 × 3 m)
  - Ignition: Offset, under-1 sprinkler
- Commodity: 24 pallet loads (~27k batteries)

# Existing



vs.

# Typical

- Smaller main array
  - Reduced damage area
  - Minimize target jump
- CUP target commodity
  - No fire within carton
  - Requires early extinguishment
- ❖ Increased protection



Task 3

Completed: September 2015

# INTERNAL IGNITION TEST

# Battery-to-Battery Spread

How does thermal run away spread from battery to battery?

1) Combustion of chemical energy

- Battery rupture releases flammable electrolyte
- Burning electrolyte produces heat

Results in Fire

2) Release of electrochemical energy

- Electrical energy is converted to heat
- Heat transferred to adjacent batteries

Results in Heat

# Combustion of Chemical Energy

- How much air is needed?

- Electrolyte

- Air-to-fuel ratio: 7:1
- Mass per battery: 34 g

Required Air Per Battery	Available Air Per Carton
0.2 m <sup>3</sup>	0.01 m <sup>3</sup>

- Not enough air to burn ONE battery
- Fire must burn outside carton

# Electrochemical Heat

Propagation did not occur

- Film heaters: 650°F
- Battery at middle level
- Battery rupture @ 5 min
- 2 hour test duration
- Three batteries ruptured



Task 3

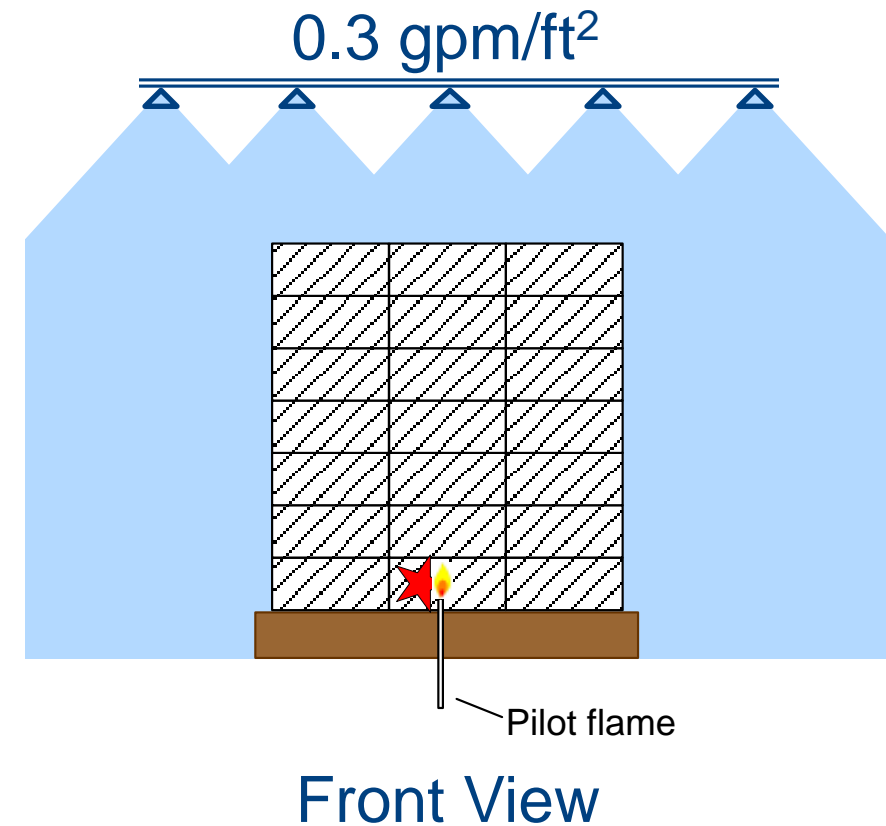
In progress: 2015/2016

# **SUPPRESSION TESTS**

# What if batteries do become involved?

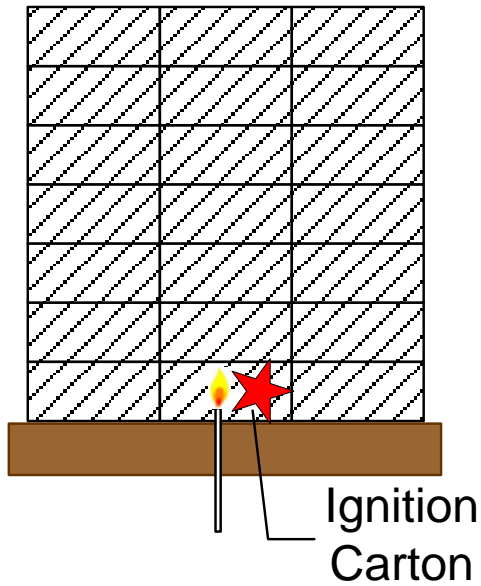
## Suppression tests

- Internal ignition
  - Pilot flame outside carton
  - Water Application Apparatus
    - Water applied when batteries are involved in fire
- 
- Allows for water application at a later stage of battery involvement than large-scale test

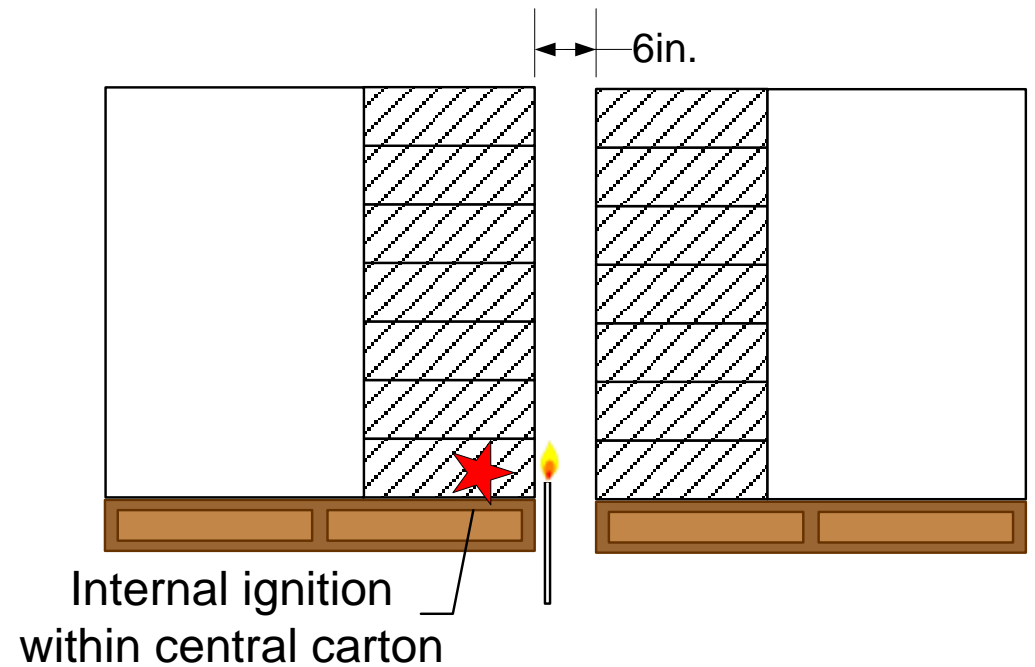




# Ignition Scenarios



Aisle Ignition



Flue Ignition

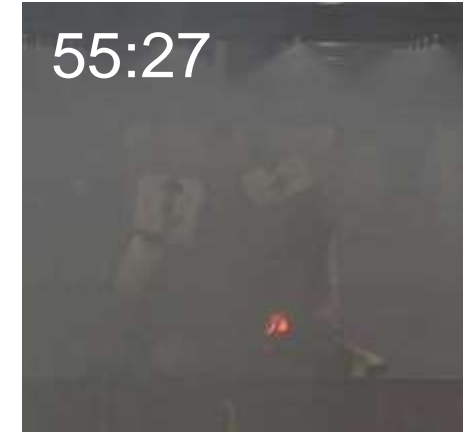
# Aisle Ignition Scenario



Pilot Ignition



Start of water application



Suppression



Flame spread

- Required external pilot ignition
- Center pallet load collapsed
- Fire extinguished
  - Water application delayed 70s
- 30% of batteries damaged



Final

# Summary

- Large-format Li-ion batteries represent higher hazard than small-format batteries
  - Thus, large-scale results with large-format batteries can be applied to small-format batteries
- Large-scale fire test scheduled for April, 2016
  - External ignition should be used for large-scale test
- Suppression test suggest sprinkler water can extinguish a developed battery fire
- Conclusion to be finalized at completion of project

# Acknowledgements

- Property Insurance Research Group
- Fire Protection Research Foundation



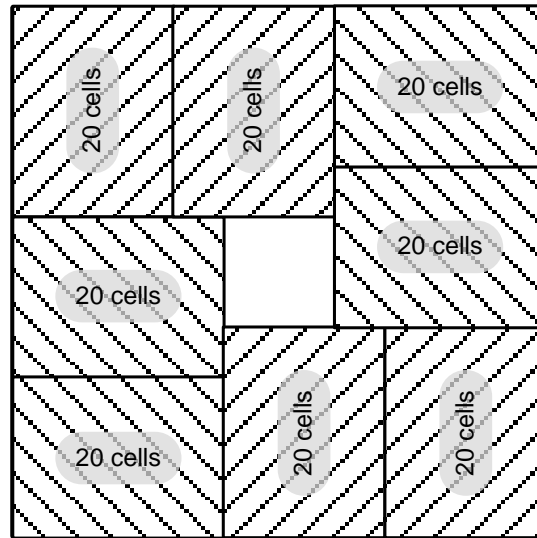
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C. Mikolajczak, M. Kahn, K. White, R. T. Long Jr., "Lithium-Ion Batteries Hazard and Use Assessment," Fire Protection Research Foundation, June, 2011

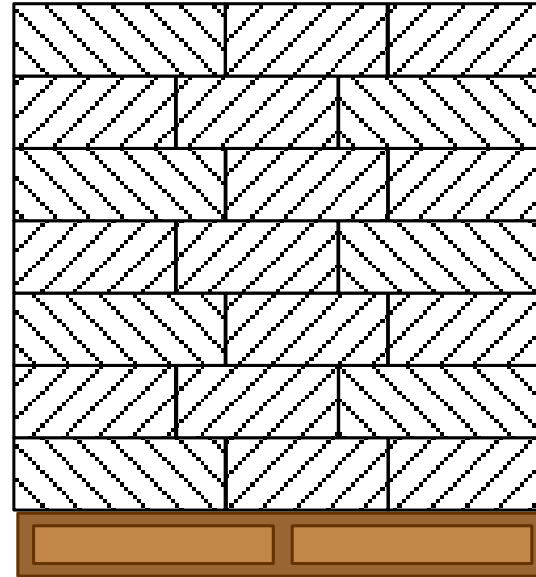
B. Ditch and J. de Vries, "Flammability Characterization of Li-ion Batteries in Bulk Storage," FM Global Technical Report, 2013

R. T. Long Jr., J. A. Sutula, M. J. Kahn, "Lithium Ion Batteries Hazard and Use Assessment Phase IIB - Flammability Characterization of Li-ion Batteries for Storage Protection," Fire Protection Research Foundation, 2013

# Pallet Design



Plan View



Front View

- Cartons as received (no repack)
- Pallet loads require restacking (42 in. × 42 in.)

# Current Battery Hazard Knowledge

- Use and Hazard Assessment (Phase 1)
- Reduced-commodity test (Phase 2)
  - 2.6 Ah cells (cylindrical, polymer, packs) and standard cartoned commodities
  - Comparison of hazard up to 1<sup>st</sup> sprinkler operation
  - Cylindrical and polymer cells similar
  - Power packs equivalent to CUP
  - Applicable to cartoned warehouse storage
- No protection options directly from battery tests

# QR Sprinkler, 10 ft (3 m) Clearance

Commodity	Link Operation Time (s)	$Q_{be}$ (kW)	Fire Growth Rate (kW/s)
Li-ion, 20 Ah Prismatic Pouch	37	335	33
Li-ion, 2.6 Ah small-format	43	270	20
Class 2	59	209	15
CUP	43	232	16

- Sprinkler: RTI = 50 ft<sup>1/2</sup>s<sup>1/2</sup>, 165°F  
(28 m<sup>1/2</sup>s<sup>1/2</sup>), (74°C)