The Effect of Thermal Management Material on Thermal Runaway Propagation

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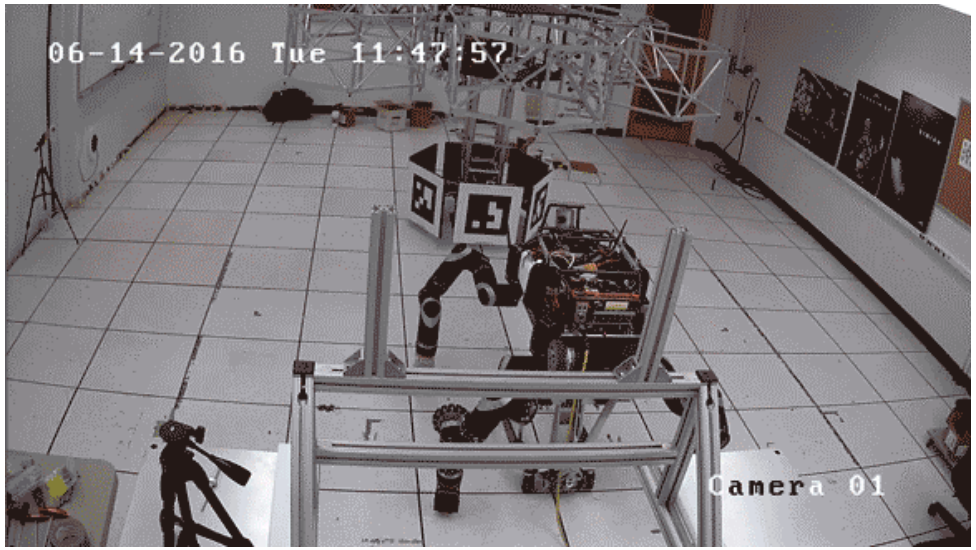
Lithium-Ion Battery Fires

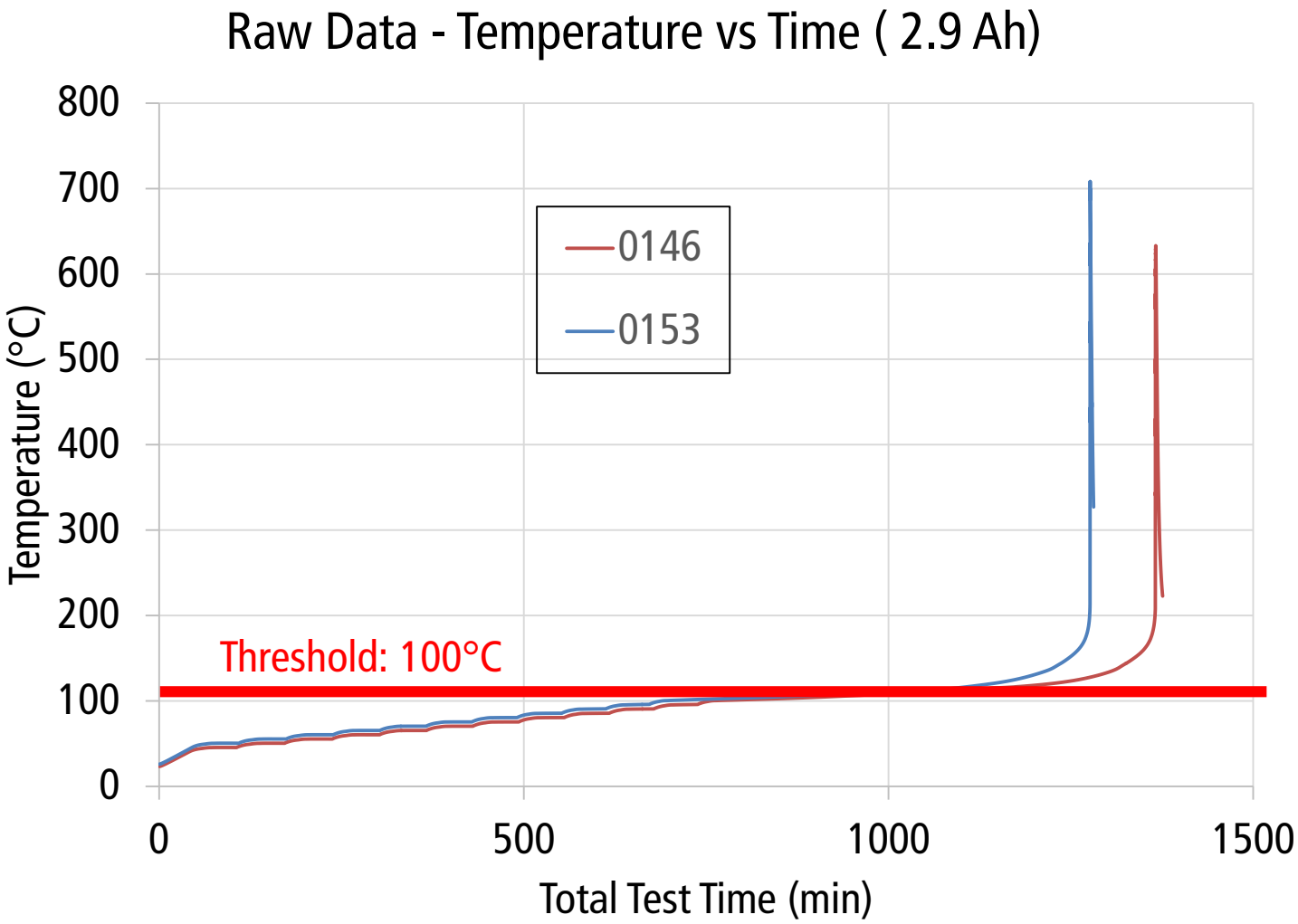


Lithium-Ion Battery Fires

- Lithium ion battery fires serious threat
  - Hoverboards
  - Galaxy Note 7
- Safety concern for aerospace companies
  - Dreamliner grounded due to battery fire
  - Jet propulsion laboratory prototype robot destroyed by 98 cell explosion
- Must engineer lithium ion packs assuming one cell will short
  - Boeing with the best BMS and fusing still had a failed cell cause a catastrophic fire

Thermal Runaway, Cell Level

- Thermal runaway: Cell chemistry reacts rapidly generating heat
- Accelerating Rate Calorimetry
  - See what temperature cell enters TR
  - Depends on cell and state of charge
  - 90°C to 120°C



Thermal Runaway Propagation: Heat transfer

Success Criteria: Adjacent cell temperature T_c < 100°C

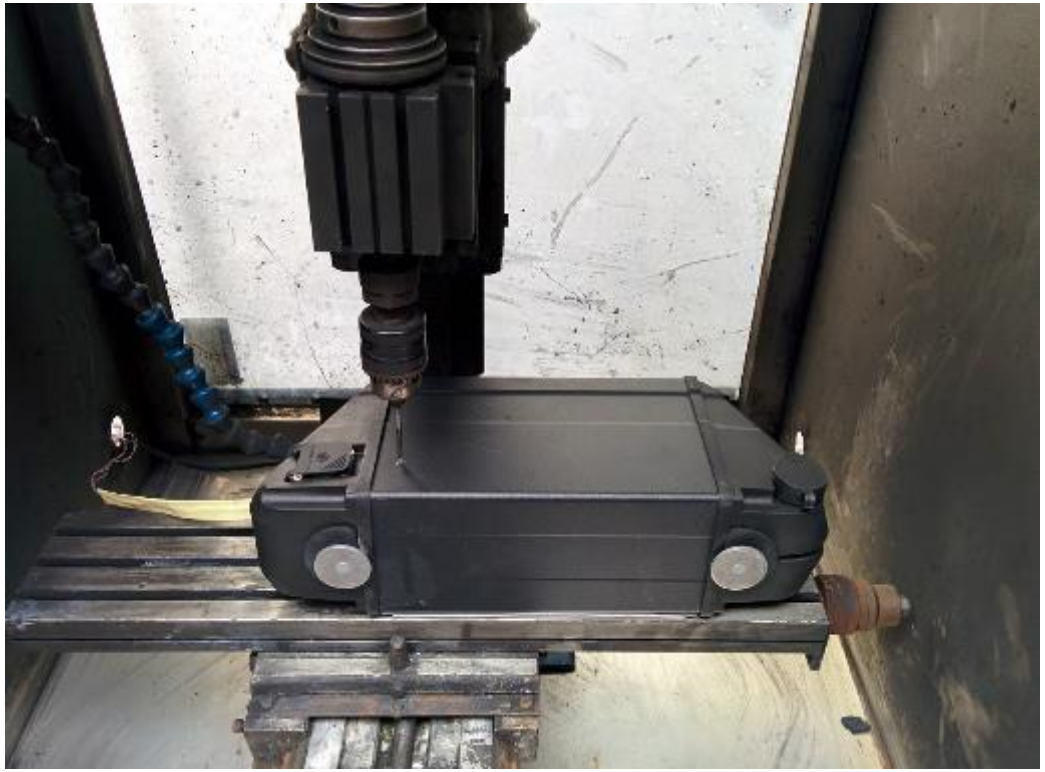
- Q: Cell heat generation from TR
  - Cell energy
  - Parallel welds
  - Combustion
- Conduction to adjacent cells
  - Pack material thermal diffusivity
  - Cladding thickness
  - Contact resistance
- Convection to surroundings

- Thermal diffusivity a function of temperature in phase change materials

$$T_c \approx D = \frac{k}{\rho C_p(T)}$$

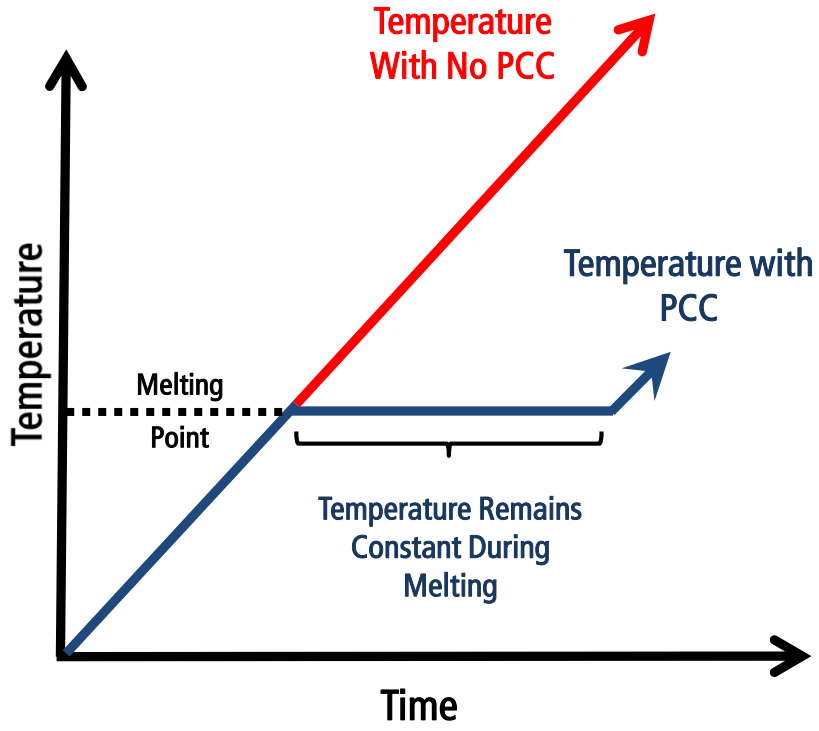
Research Overview

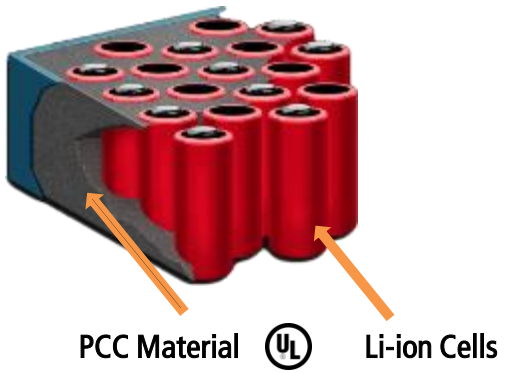
- Evaluate what cell packaging materials can prevent the propagation of thermal runaway in a small pack of 18650 style cells.
  - Air
  - Graphite
  - Wax
  - Graphite and Wax (PCC)
- Evaluate the importance of battery configuration and weld strength on thermal runaway propagation
- Nail penetration test



Battery Pack Materials Evaluated

- Phase Change Composite (PCC)
  - 20 wt.% graphite
  - 80 wt.% wax
  - Wax micro-encapsulated
  - Melts at 55°C
  - ½ Latent heat of ice
- Graphite only (90% porous)
- Wax (100%)
- Air

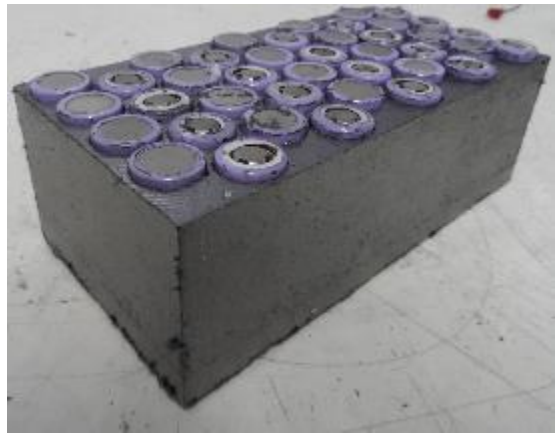




Different Material Properties

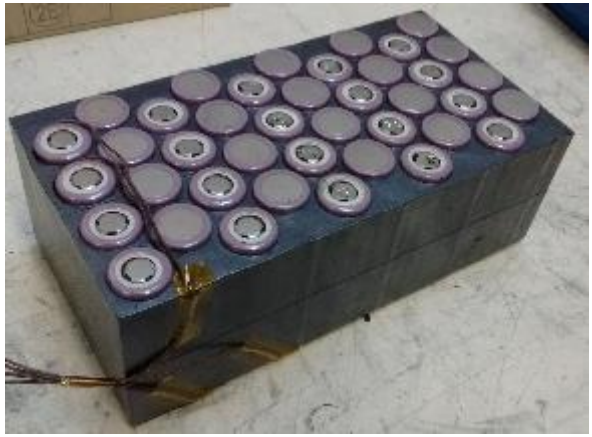
Air

Graphite Only



Wax Only

PCC



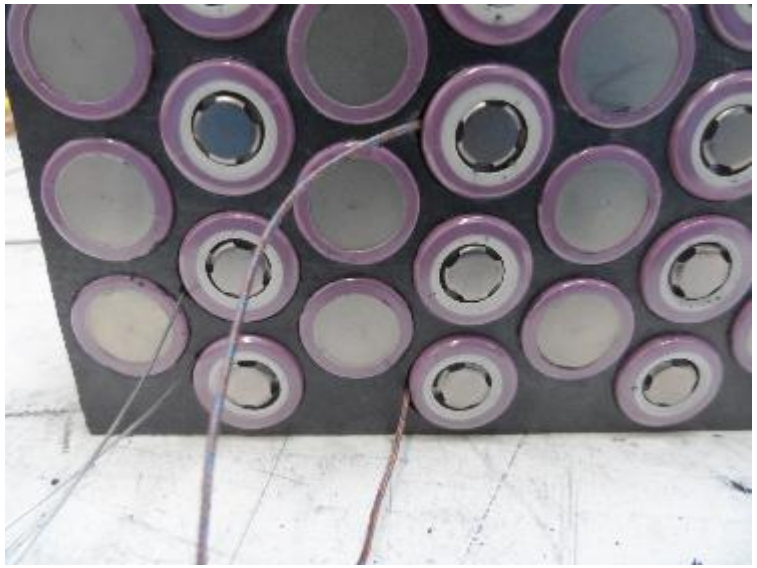
	Air	Graphite Only	Wax Only	PCC
Conductivity (W/m-K)	0.024	13.77 (in-plane)	0.15	17.21 (in-plane)
Density (kg/m^3)	1.23	200	775	935
Specific Heat (J/kg-K)	1005	725	2384	1837
Latent Heat (J/g)	N/A	N/A	211	153
Diffusivity (mm^2/s)	19.42	94.96	0.08	10.02

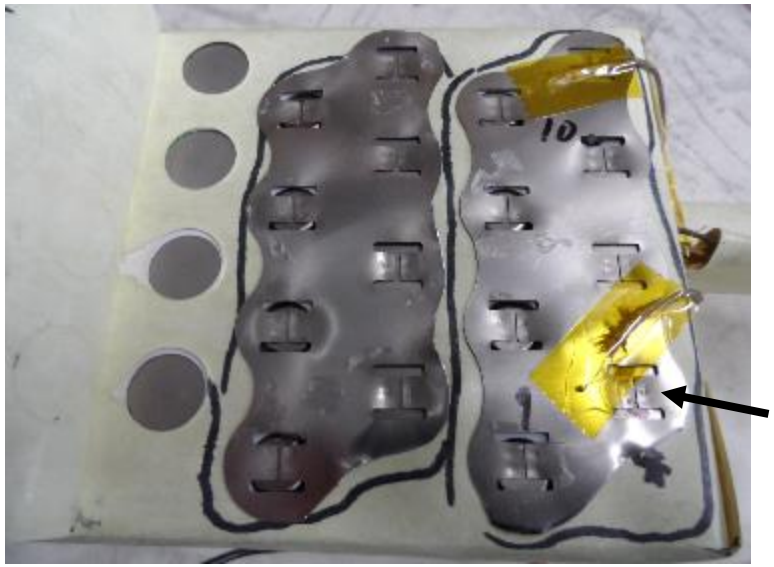
Battery Pack Specifications

Pack specifications	
Specification	Value
Configuration	10s4p
Energy (Wh)	413
Voltage, nominal (V)	36.2
Mass (kg)	2.75
Specific Energy (Wh kg^{-1})	150
Dimensions (cm)	32 x 9 x 13
Casing	Aluminum & plastic

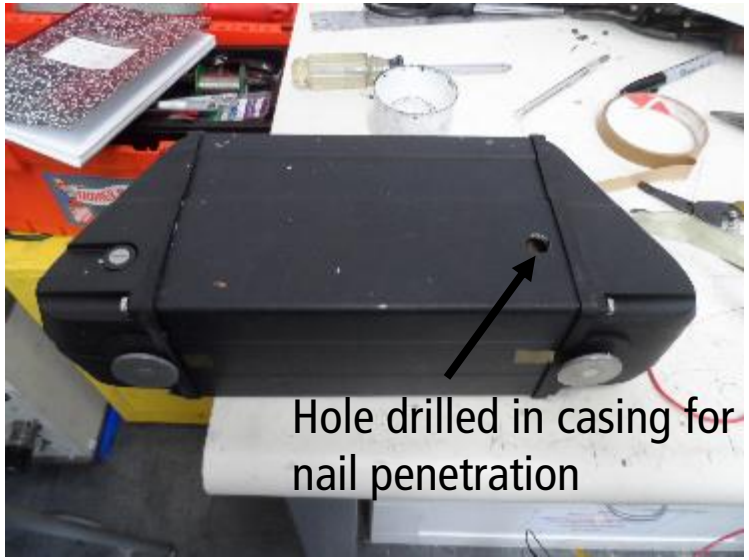
Cell specifications	
Specification	Value
Form Factor	18650
Capacity, nominal (Ah)	2.85
Voltage, nominal (V)	3.62
Specific Energy (Wh kg^{-1})	224
Energy Density (Wh L^{-1})	603
Chemistry	Graphite anode, NCA cathode

Pack Build Procedure





6 welds on trigger cell (normally 4)



Hole drilled in casing for nail penetration

Air Pack TRP Video

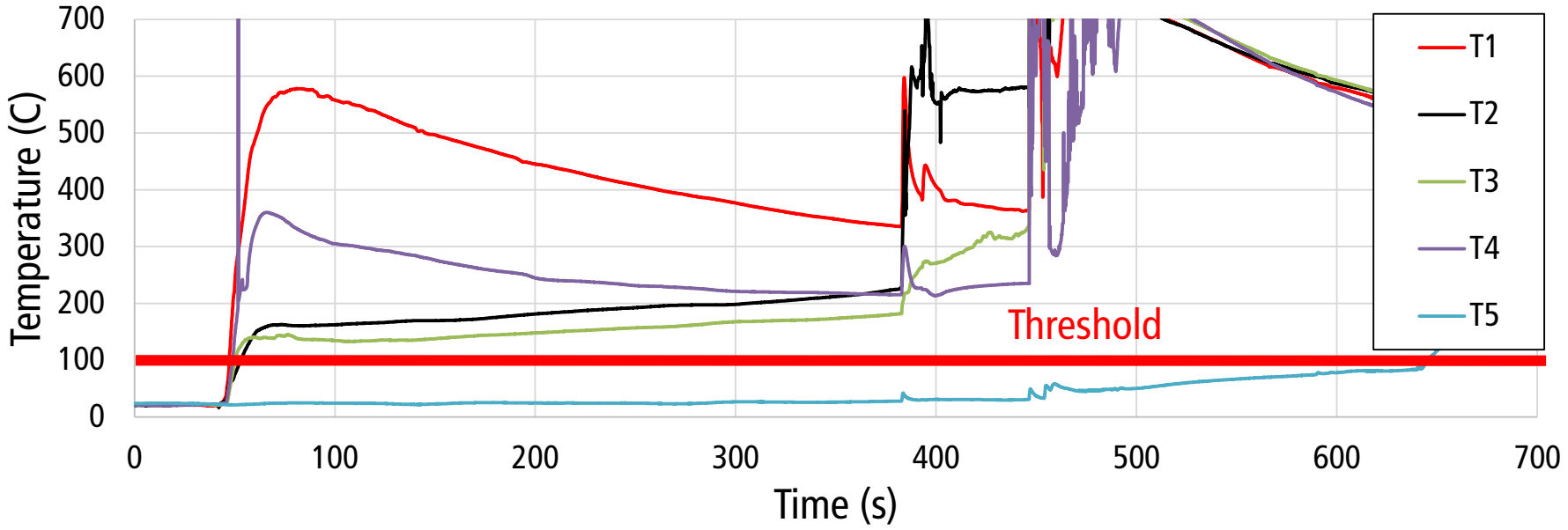
- https://youtu.be/vmUpbou8VtA

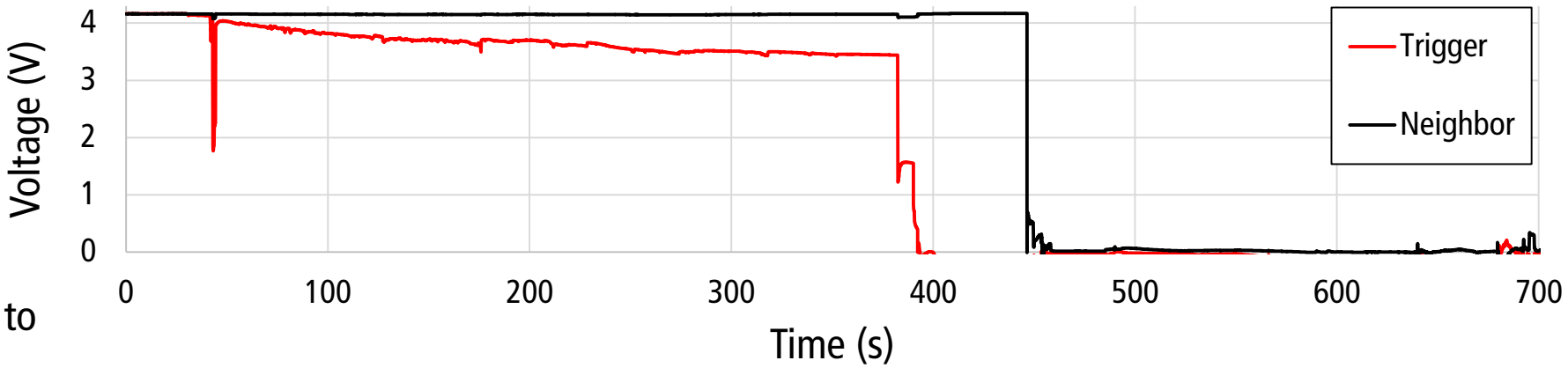
Air Pack: Thermal Runaway Propagation

Trigger String

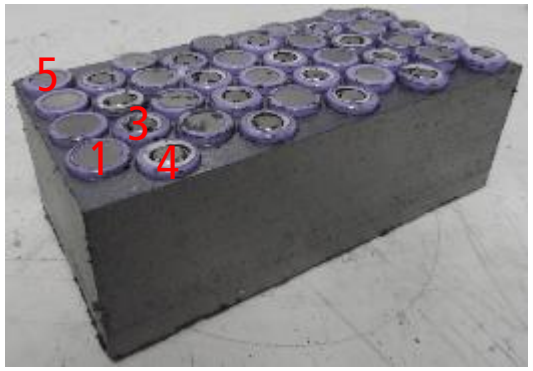
Neighbor String

- TRP occurred slowly due to air low thermal conductivity and low ability to store heat



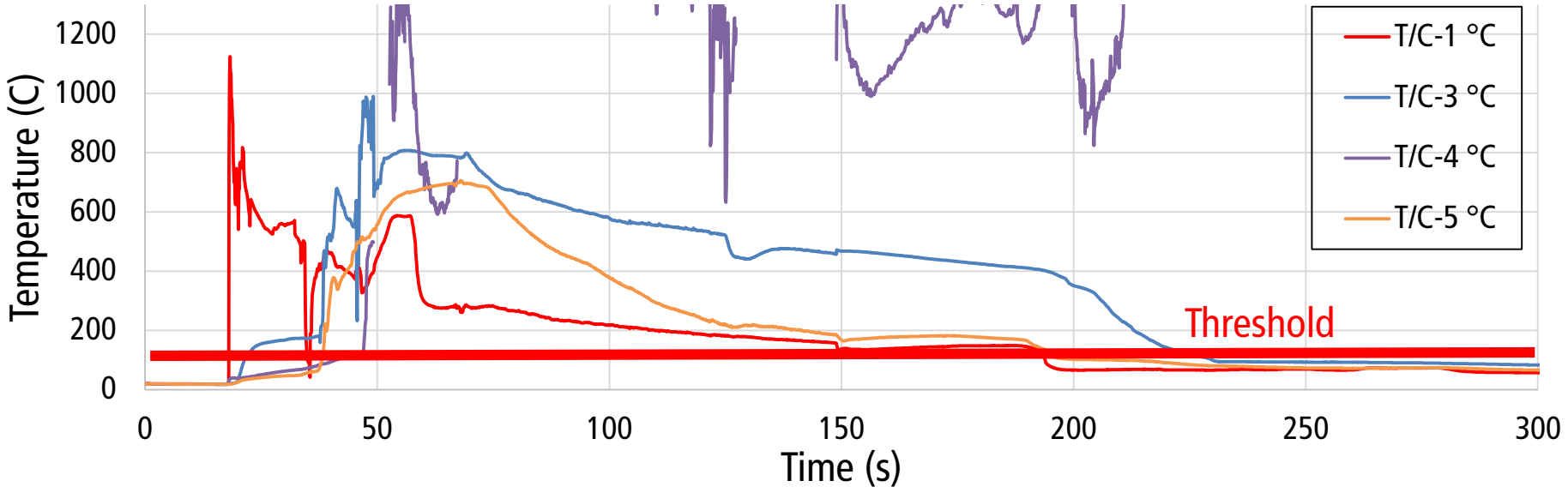


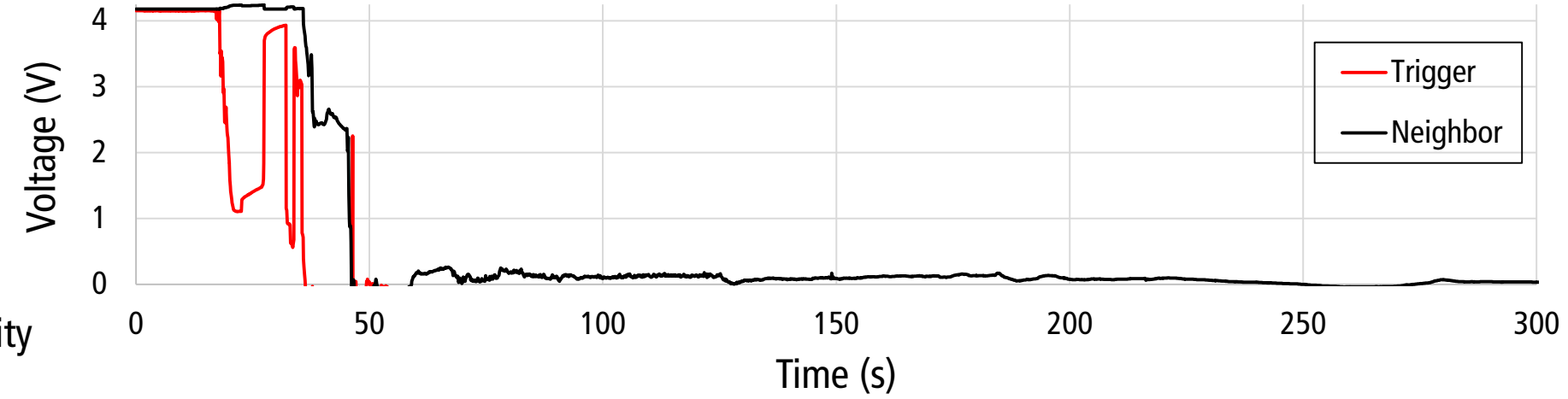
Graphite Only: Thermal Runaway Propagation



Trigger String

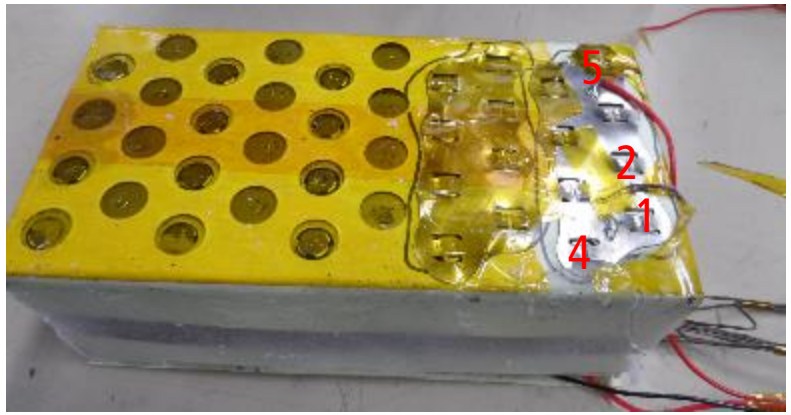
Neighbor String





- TRP occurred quickly due to high thermal conductivity and low ability to store heat

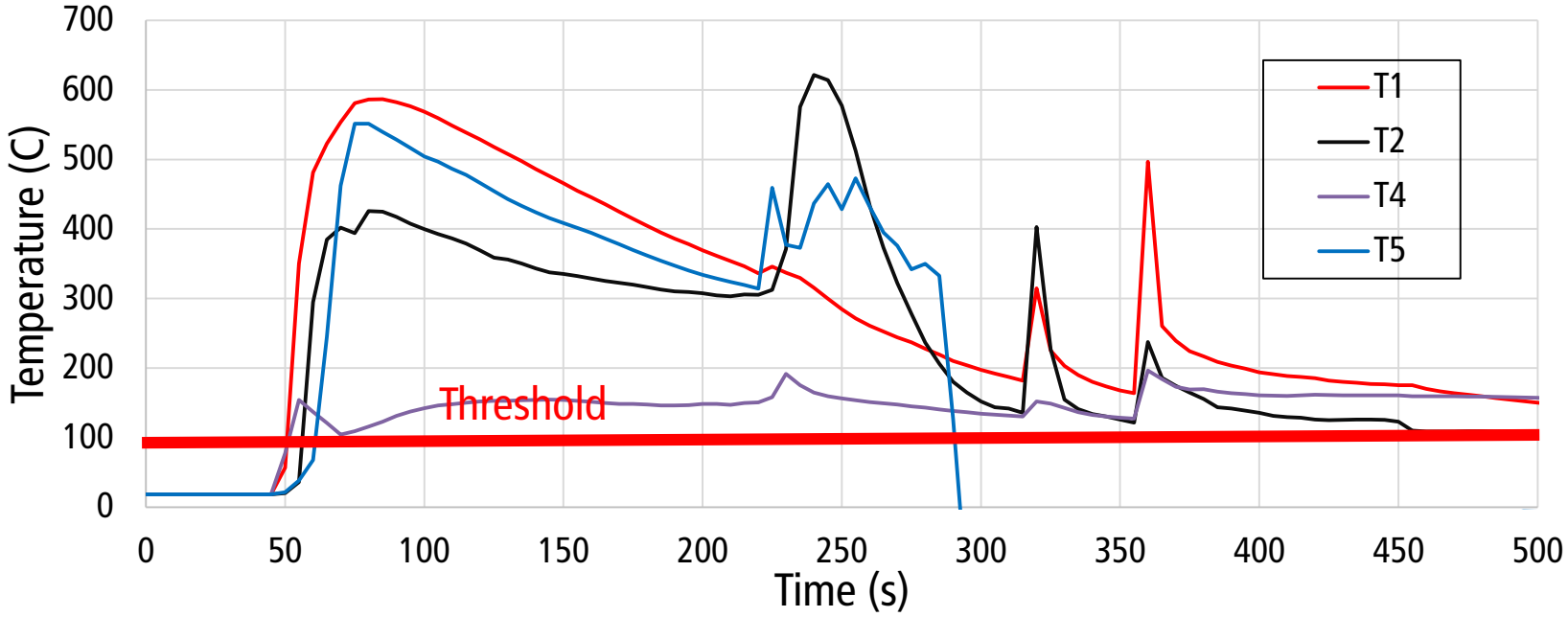
Wax Only: Thermal Runaway Propagation

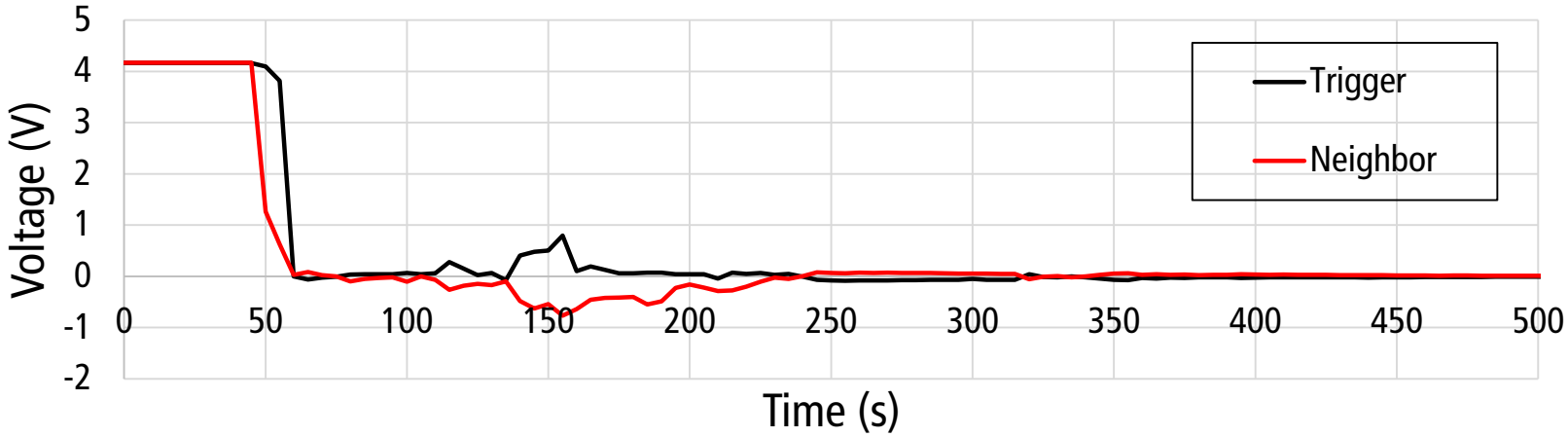


Trigger String

Neighbor String

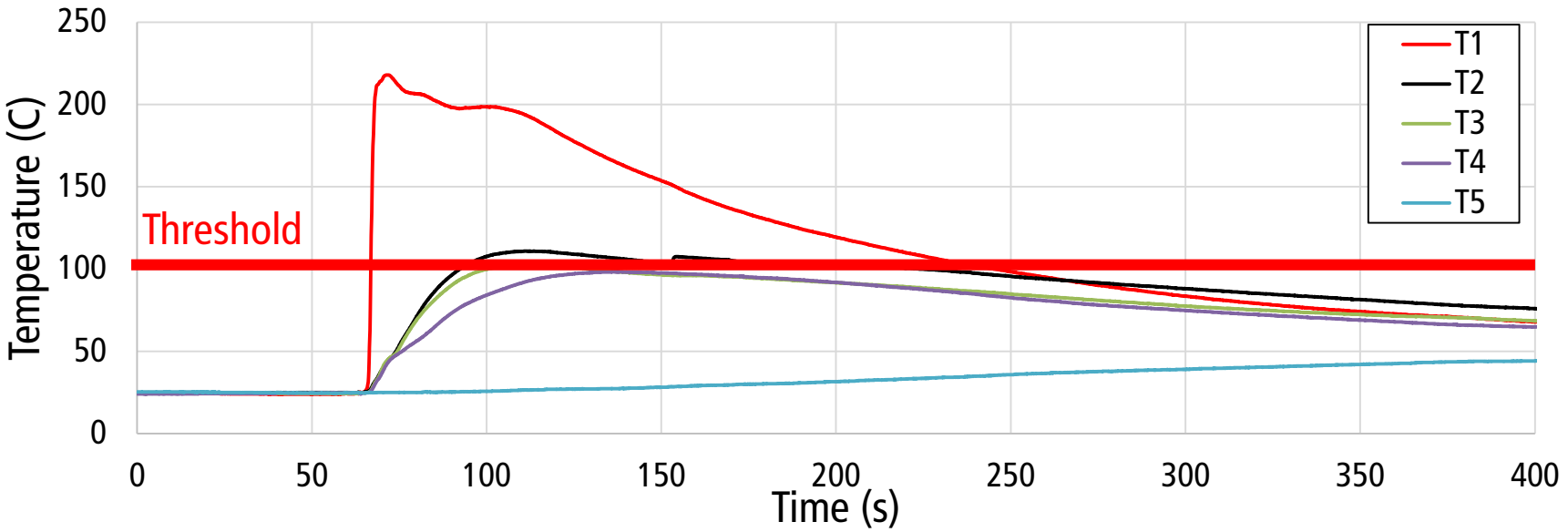
- TRP occurred quickly due to liquid wax flow and wax combustion

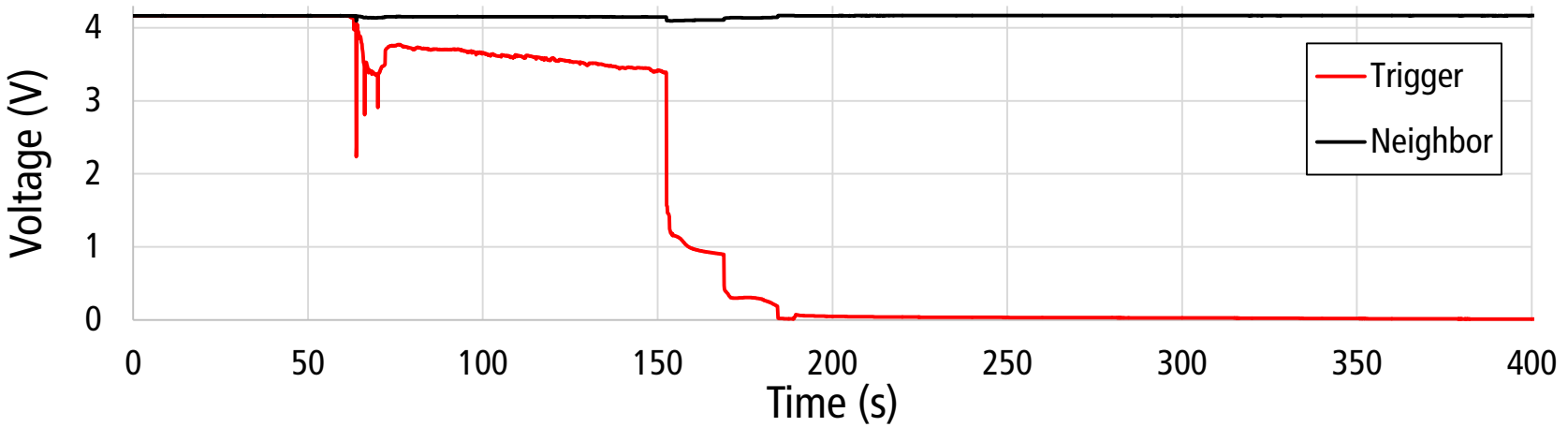




Phase Change Composite (PCC): Avoided Thermal Runaway Propagation

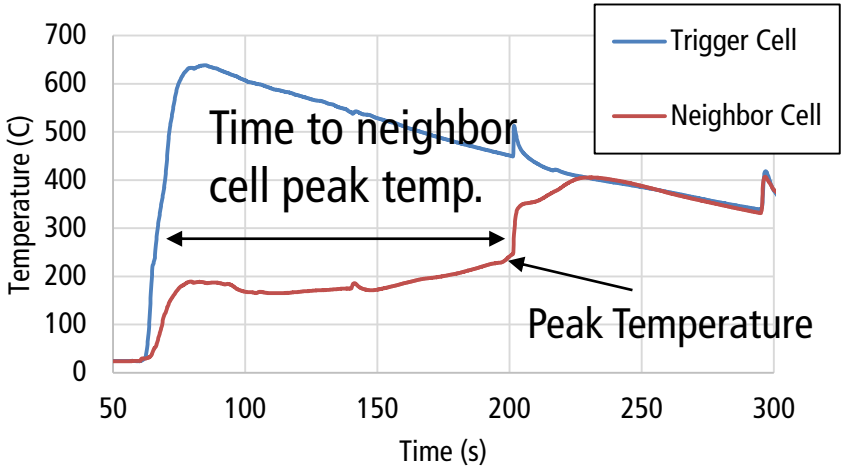
Trigger String
Neighbor String



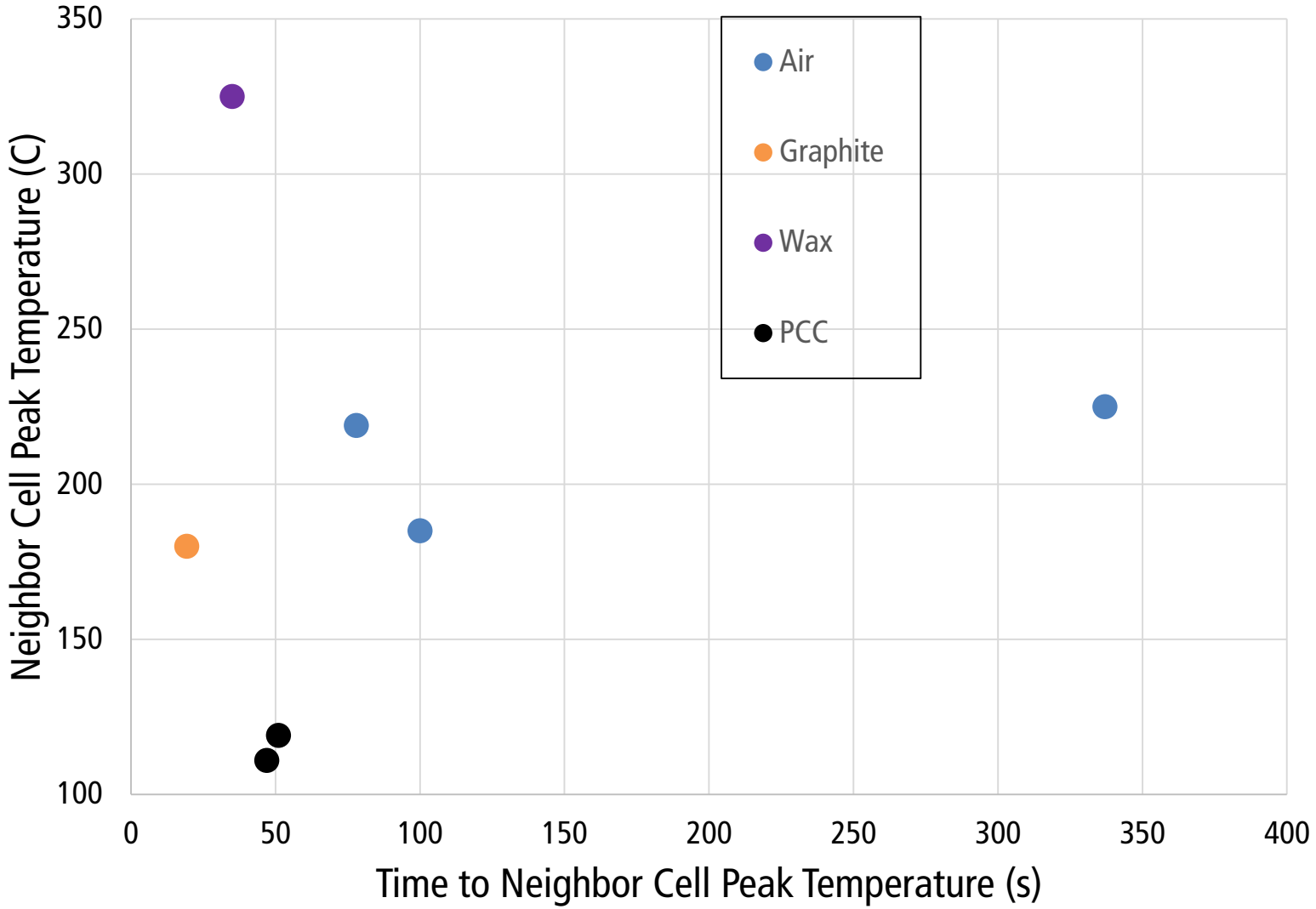


- TRP was prevented due to phase change absorbing thermal runaway energy

Comparison Between Packs



Pack Material	Thermal Runaway Propagation?
Air	Fail
Graphite	Fail
Wax	Fail
PCC	Pass



Autopsy

No Thermal Runaway Propagation

Thermal Runaway Propagation

*Pack was sprayed with water after second cell propagated in packs that propagated

Nickel separation during cell venting

Nickel Cladding can separate from venting cell isolating electrical energy available for thermal runway propagation

Not 100% reliable separation. Cells can vent outside of side casing

Ongoing Research with PCC

Cell Energy	Pack Configuration	Thermal Runaway Propagation
2.9 Ah	10s4p	Pass
3.2 Ah	10s4p	Pass
3.5 Ah	10s4p	Fail
3.5 Ah	10s0p	Pass

Conclusions and Future Work

- PCC (graphite and wax) reliably prevented TRP in 2.9 Ah, 10s4p packs
- Packs need to be engineered for TRP on a case by case basis
  - Cell energy (2.9, 3.2, 3.5 Ah…)
  - Material thermal properties
  - Parallel configuration and cladding separation
- Future tests will investigate different cell energies and graphite densities for AllCell Battery Products: http://www.allcelltech.com/

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