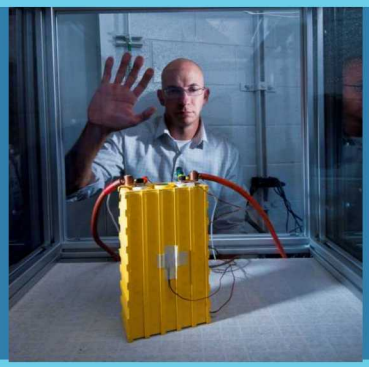
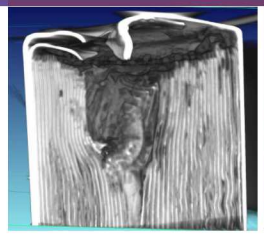
SAND2019-14610C

Understanding the factors impacting battery failure propagation and its mitigation





PRESENTED BY

Loraine Torres-Castro

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Outline

- **Introduction**
  - ✓Battery Abuse Testing Laboratory (BATLab) Capabilities
  - ✓Motivation
  - ✓Objective
- Methodology
- Results & Discussion
  - ✓Baseline Failure Propagation
  - ✓Passive Thermal Management
    - ✓Single module battery packs
    - ✓Multi-module packs
- Summary
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Capabilities and Infrastructure: Battery Abuse Testing Laboratory (BATLab)

Comprehensive abuse testing platforms for safety and reliability of cells, batteries and systems from mWh to kWh.

Mechanical abuse

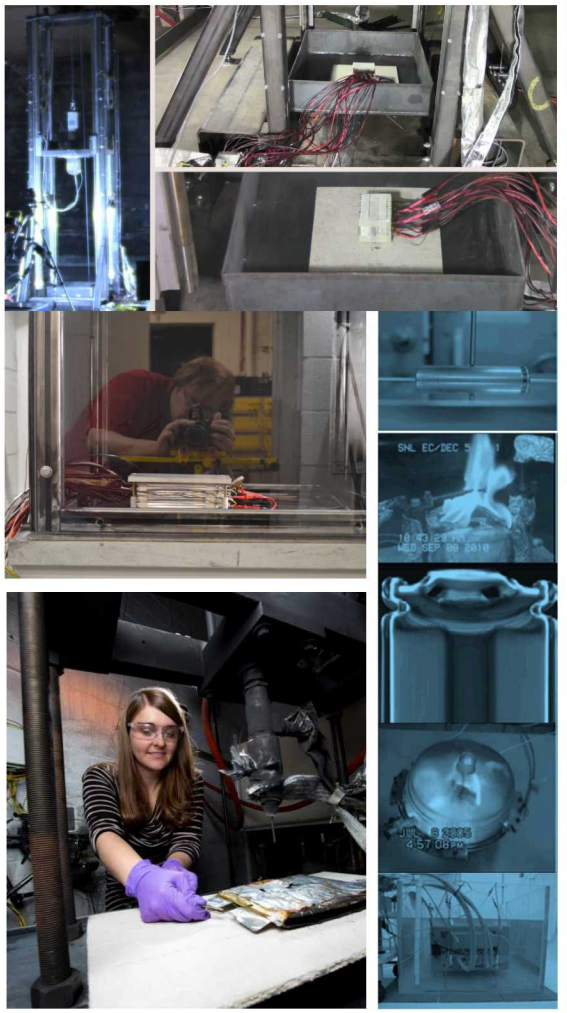
- **Penetration** (max. force 25 klbs, max speed 10 mm/s)
- Crush (max. force 100 klbs, max speed 2 mm/s)
- Impact (max. height 8”8’, max. drop weight 700 lbs)
- Immersion

Thermal abuse

- Over temperature (250 ˚C, 5 ˚C/min)
- Flammability measurements (250 ˚C, 5 ˚C/min)
- Calorimetry (405 ˚C, 5 ˚C/min)

Electrical abuse

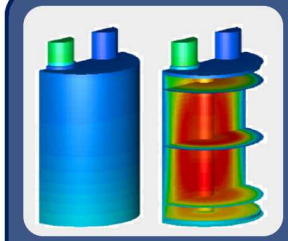
- Overcharge (max. current 300 A)
- Overdischarge (max. current 300 A)
- Short Circuit (max. current 2500 A)



Science and Diagnostics of Battery Failure

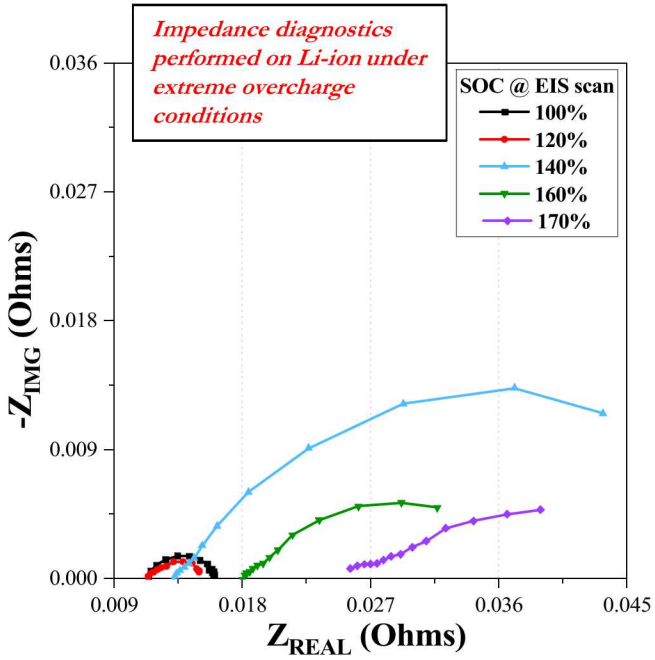
Materials R&D
- Non-flammable electrolytes
- Electrolyte salts
- Coated active materials
- Thermally stable materials
- Battery failure post mortem materials analysis

Testing
- Diagnostics during battery failure (pictured right)
- Gas analysis
- Battery calorimetry
- Electrical, thermal, mechanical abuse testing
- Failure propagation testing on batteries/systems
- Large scale thermal and fire testing (TTC)



Simulations and Modeling
- Multi-scale models for understanding thermal runaway
- Validating failure propagation models
- Fire Simulations to predict the size, scope, and consequences of battery fires

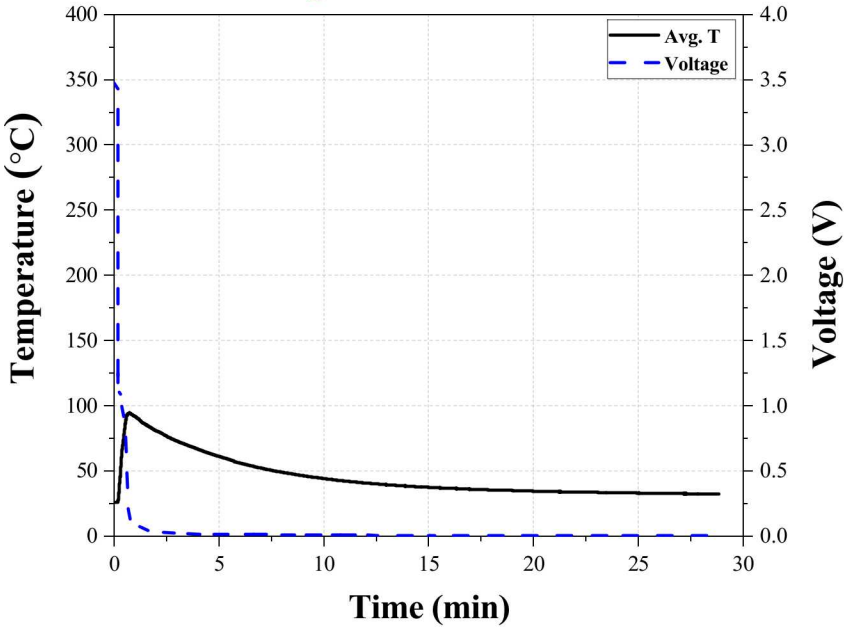
Procedure Development and Stakeholder Interface
- USABC Abuse Testing Manual (SAND 2005 3123)
- OE Energy Storage Safety Roadmap
- R&D programs to inform best practices, and policies.
- Hosted International Battery Safety Workshops and Energy Storage Safety Workshop



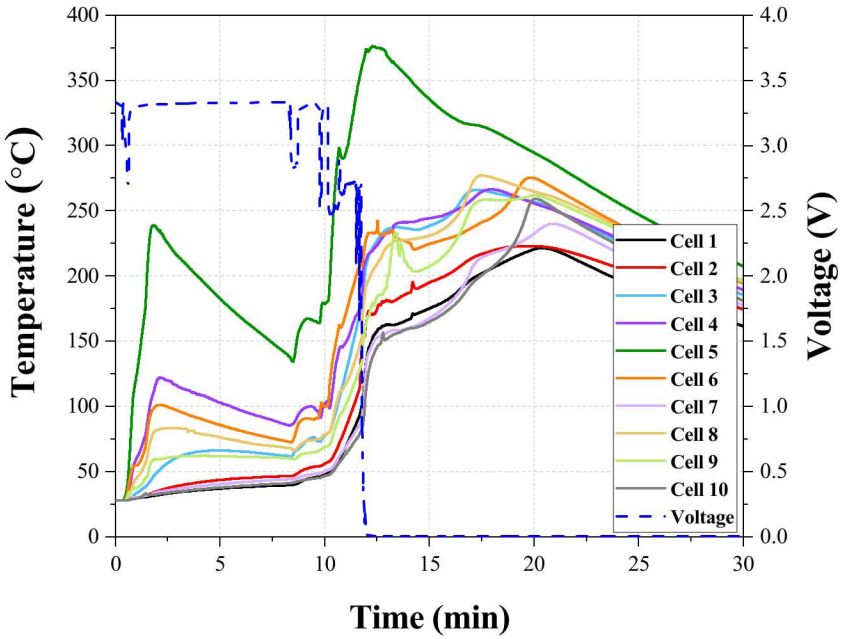
- Sandia is uniquely positioned to study the entire life cycle of a technology.
- Diagnostic tests can be performed under extreme failure conditions to understand the *how* and *why* of battery failure.

Motivation for Propagation Testing

Single Cell Failure



How do these behaviors impact a larger, more complex system?



Consumer Cells (0.5-5 Ah) → Large Format Cells (10-200 Ah) → Batteries (1-50 kWh) → Vehicle system

Objective

Understand the extent of propagation with inclusion of passive thermal management in the from of spacers (aluminum and copper) between (i)pouch cells in a 5 cells pack, and (ii) between modules of a 3s3p configuration battery pack.

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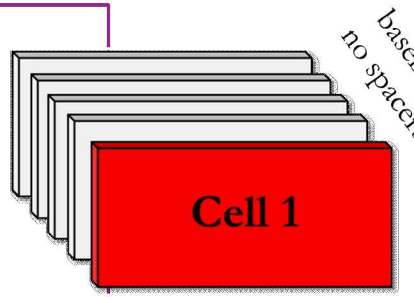
Methodology and Approach

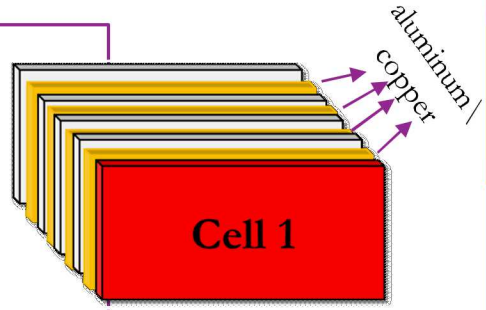
Part I: Baseline failure propagation

- COTS LCO 3 Ah pouch cells
- 5 cells closely pack together
- Failure initiated by a mechanical nail penetration along longitudinal axis of outer cell (cell 1)



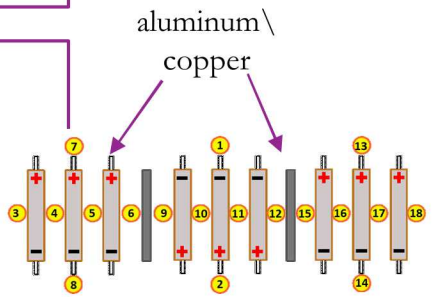
Part II: Passive thermal management between cells

- COTS NMC 3 Ah pouch cells
- 5 cells closely pack together
- Aluminum or copper spacers between cells (1/8 in, 1/16 in, 1/32 in)
- Failure initiated by a mechanical nail penetration along longitudinal axis of outer cell (cell 1)



Part III: Passive thermal management between modules

- COTS $LiCO_2$ 5 Ah pouch cells
- Packs electrically connected in 3s3p configuration
- Failure initiated by a mechanical nail penetration along longitudinal axis of the middle cell in the middle module



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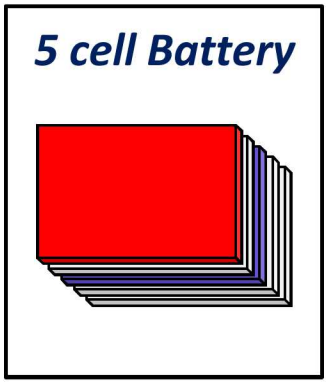
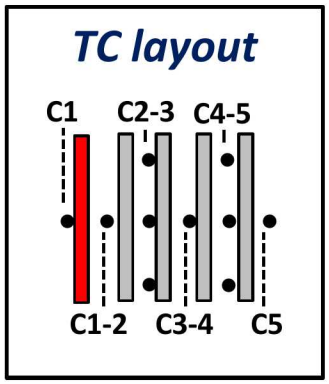
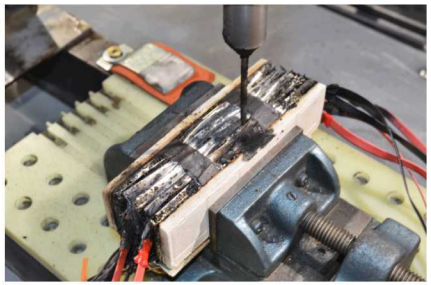
Baseline Failure Propagation

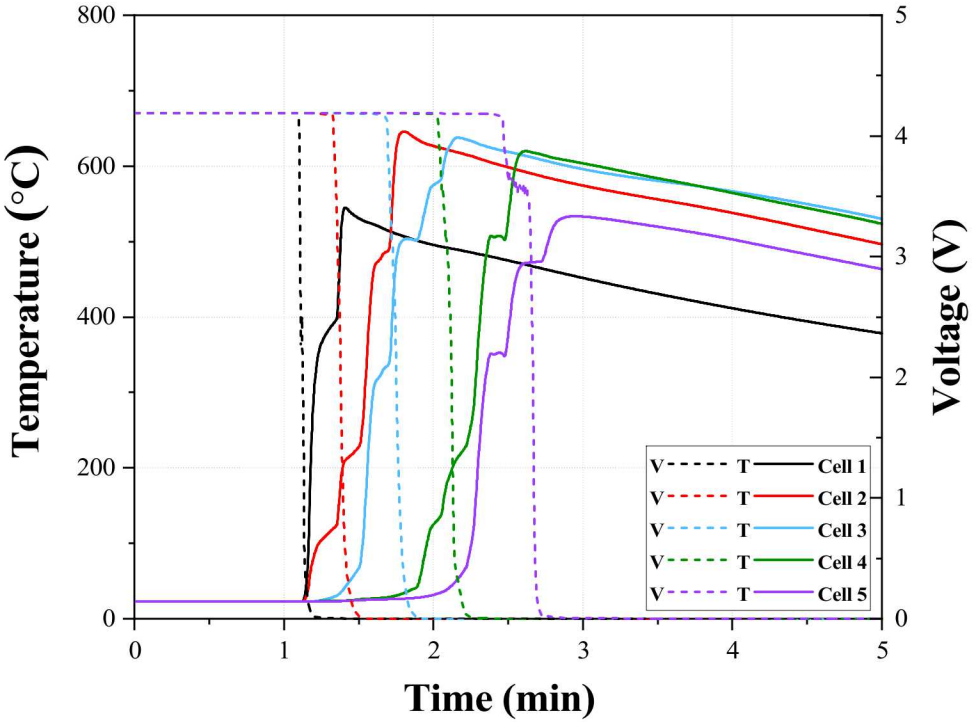
Failure initiated by mechanical insult to edge cell of a COTS LCO pack at 100% SOC (3Ah cells)







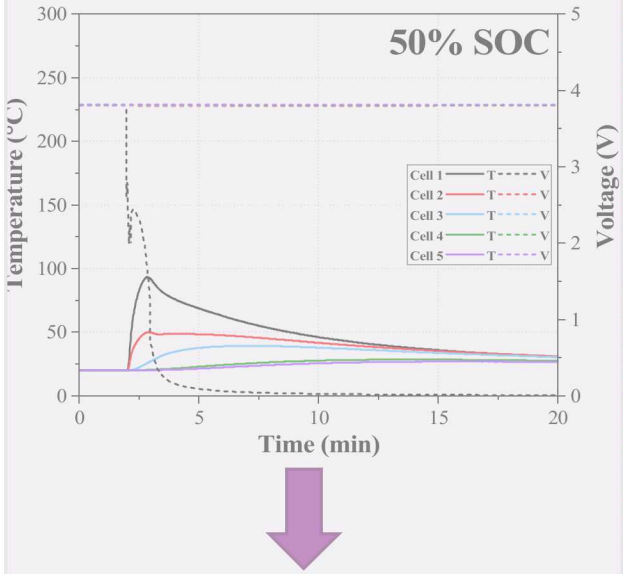
- Successful initiation at Cell #1
- Propagation to adjacent cells
- Cascading failure to entire battery over 82 s



Observed complete propagation when cells are close packed with no thermal management

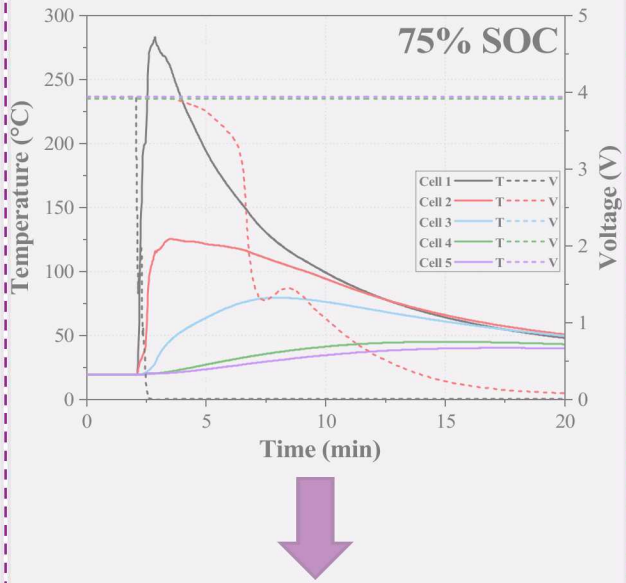
Failure Propagation and Cell Failure at Reduced States of Charge

Failure initiated by mechanical insult to edge cell of COTS LCO packs (3Ah cells)



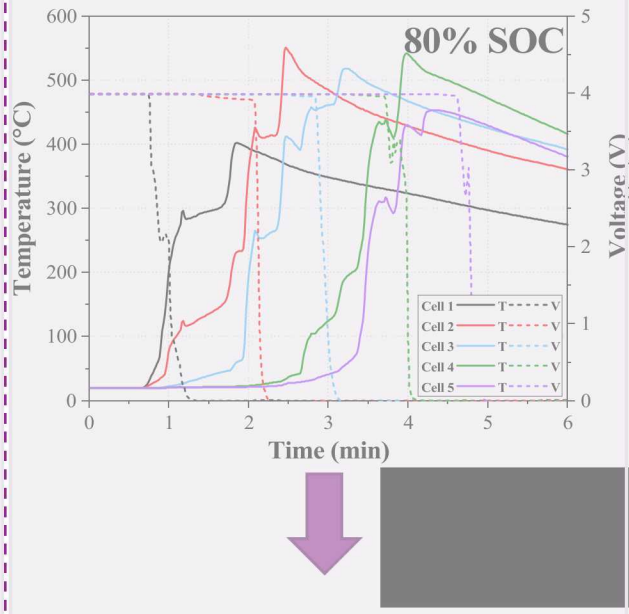
50% SOC

- No cell to cell propagation.
- Thermal runaway of initial cell failure was minimal.



75% SOC

- Limited propagation.
- Damage was observed for Cell 2 but no high thermal runaway events seen for cell 3 to 5.



80% SOC

- Full failure propagation.
- Compared to baseline test, peak temperatures were marginally lower (550 ˚C vs 620 ˚C)
- Cascading failure to entire battery over ~240 s.

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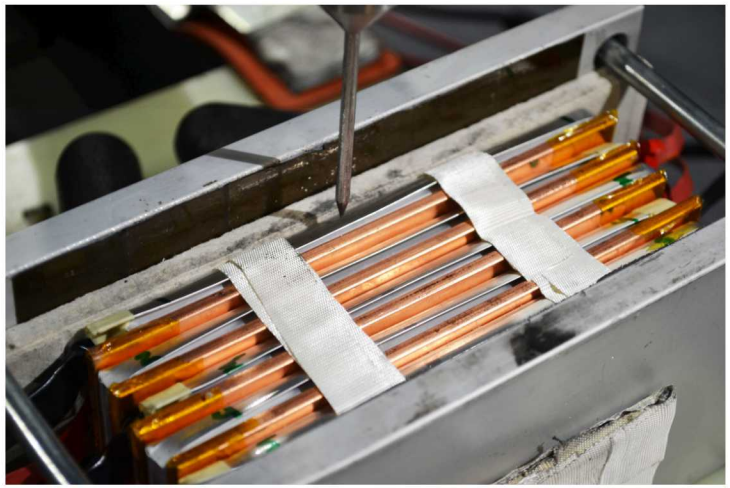
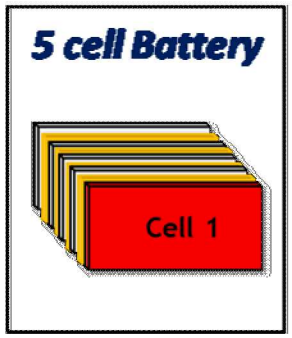
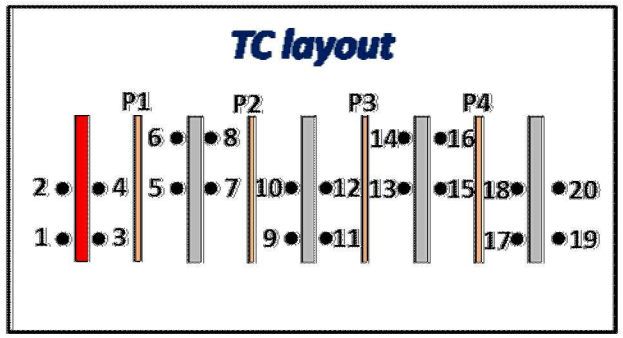
Failure Propagation Testing: Inclusion of Thermal Management



The focus of this section is to understand the extent of propagation with the inclusion of thermal management in the form of heat sinks between pouch cells.

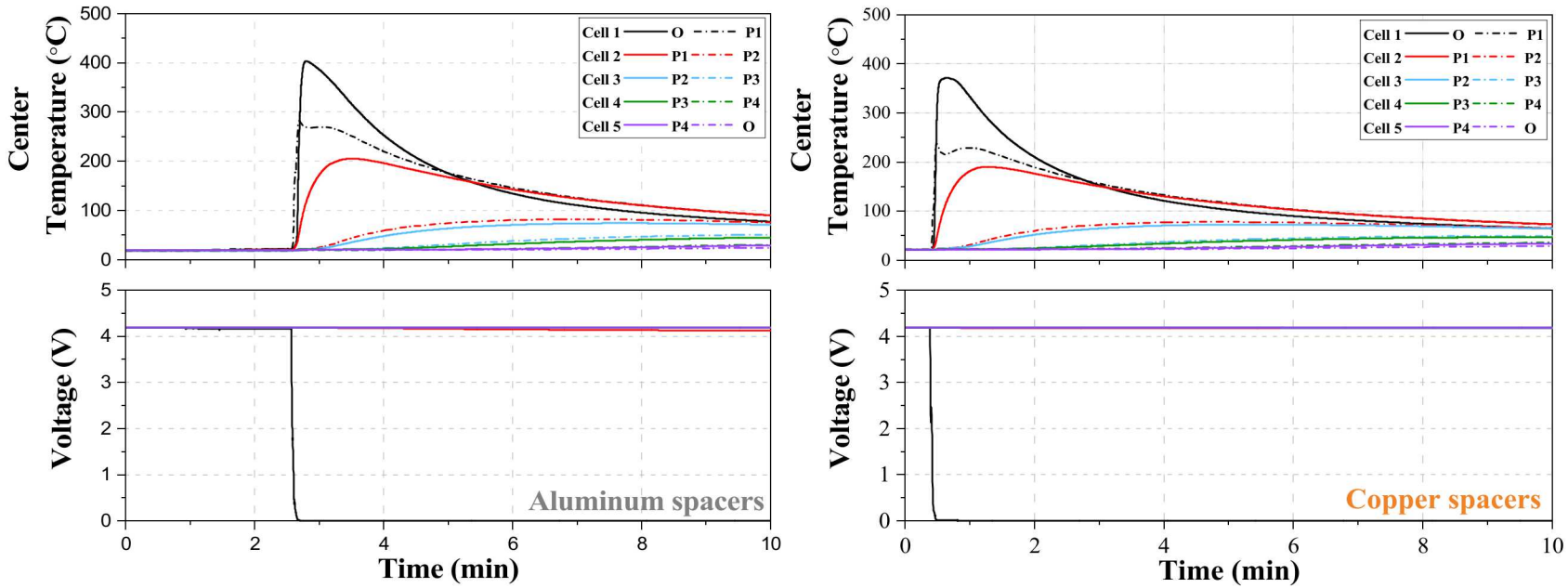
- **Aluminum plates**
  - 1/8 inch
  - 1/16 inch
  - 1/32 inch
- **Copper plates**
  - 1/8 inch
  - 1/16 inch
  - 1/32 inch

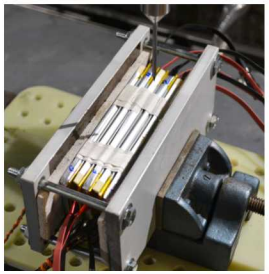


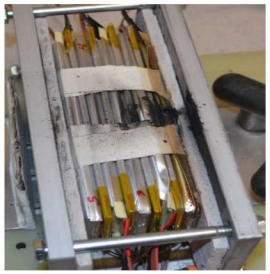


Thermal Management: 1/8 inch barrier

Failure initiated by mechanical insult to edge cell of COTS LCO packs



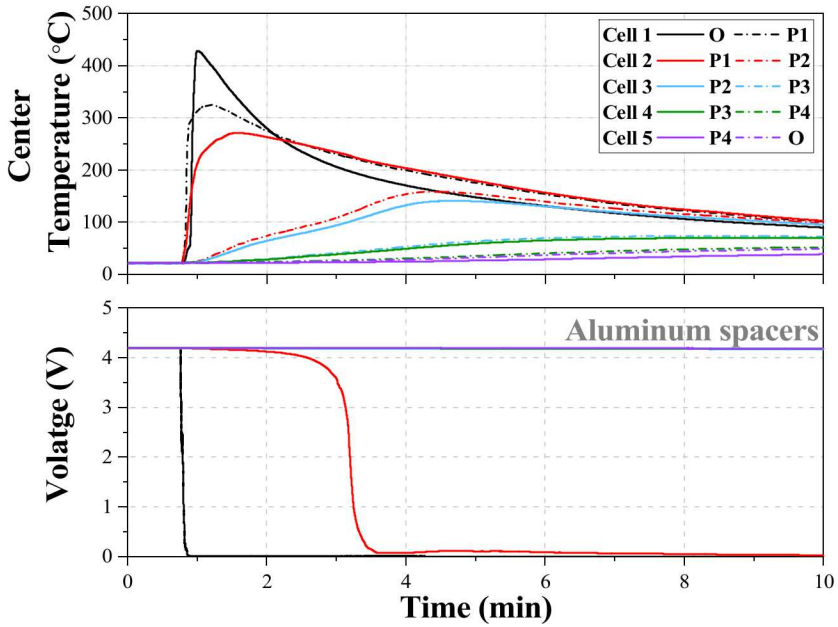


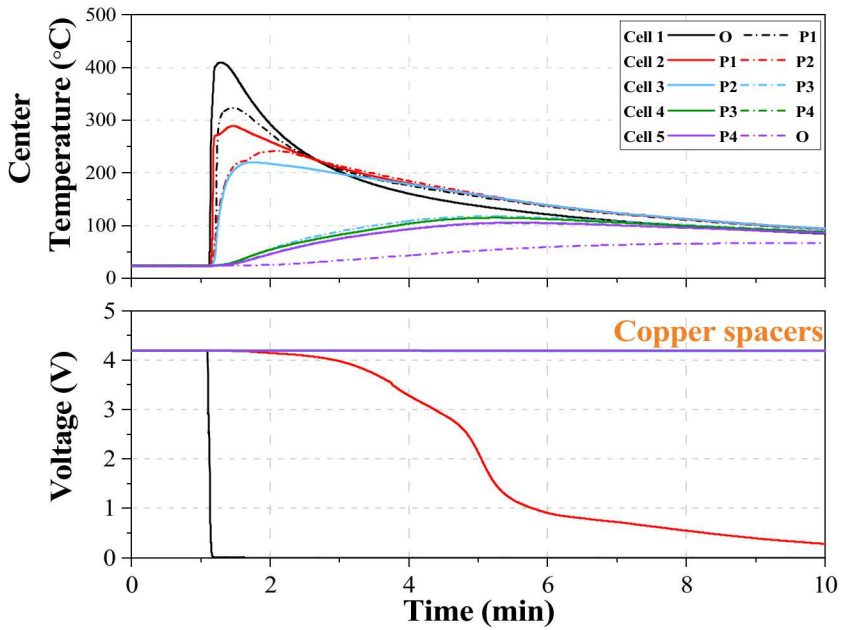


- Successful initiation of Cell #1 for all the different tests.
- Failure of cell 1 in both cases were consistent and peak temperatures reached ~400 °C.
- No propagation was realized while using 1/8 inch aluminum or copper spacer.
- Energetic thermal runaway was not observed beyond the initial failed cell in either case.

Thermal Management: 1/16 inch barrier

Failure initiated by mechanical insult to edge cell of COTS LCO packs

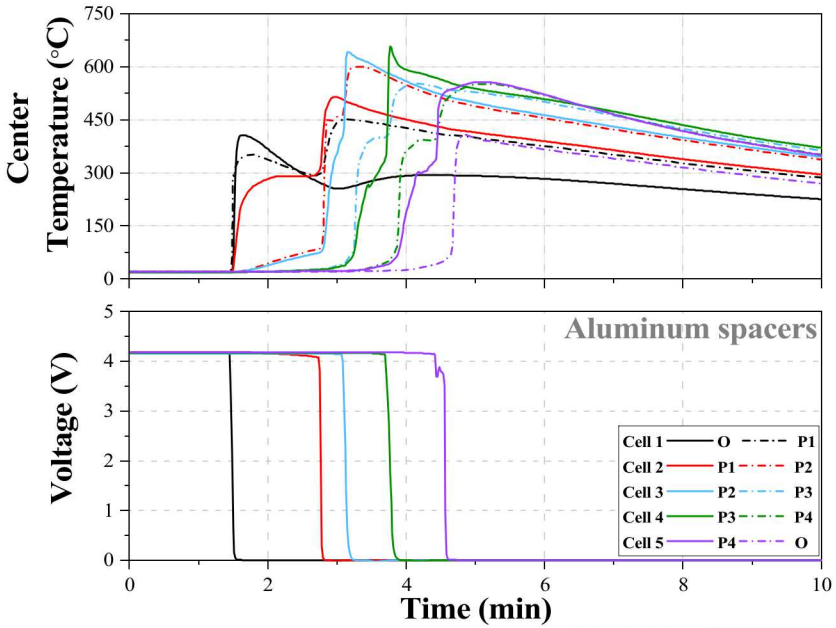


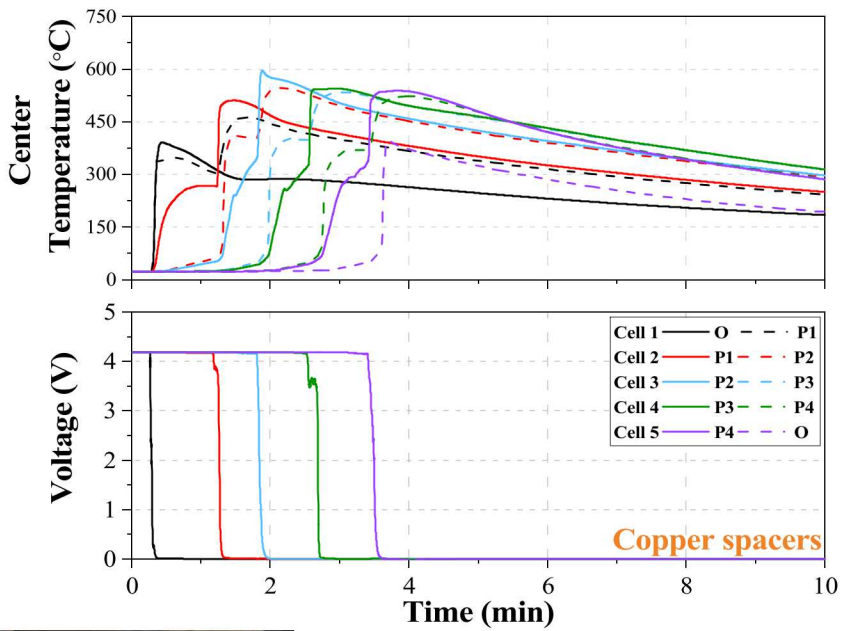


- Successful initiation of Cell #1 for all the different tests.
  - Limited propagation (from cell 1 to 2).
- For both cases, cell 2 reached ~300 °C and eventually lost voltage.

Thermal Management: 1/32 inch barrier

Failure initiated by mechanical insult to edge cell of COTS LCO packs





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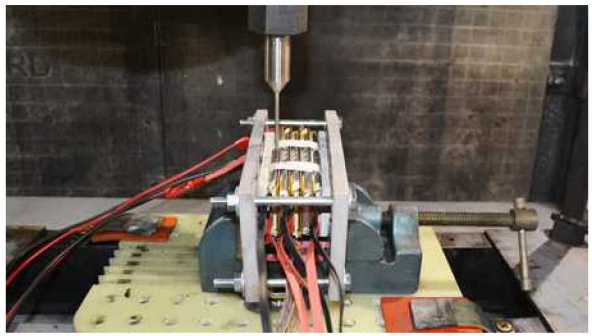

- Successful initiation of Cell #1 for all the different tests.
- Pulsing propagation behavior observed over the next several minutes.
- Entire pack consumed ~4 minutes after initial failure.

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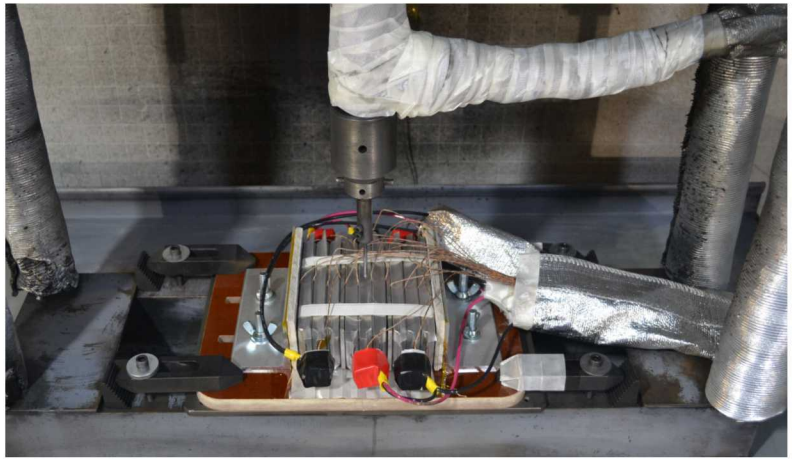
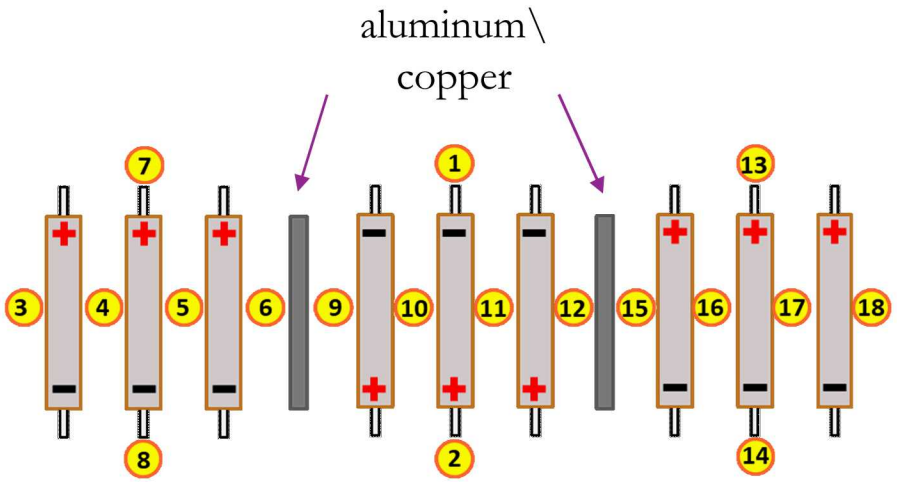
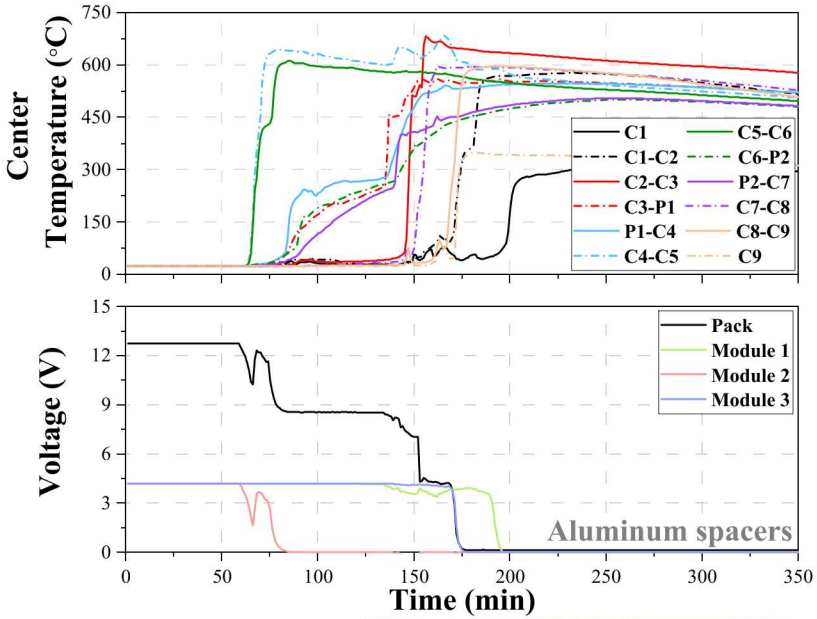


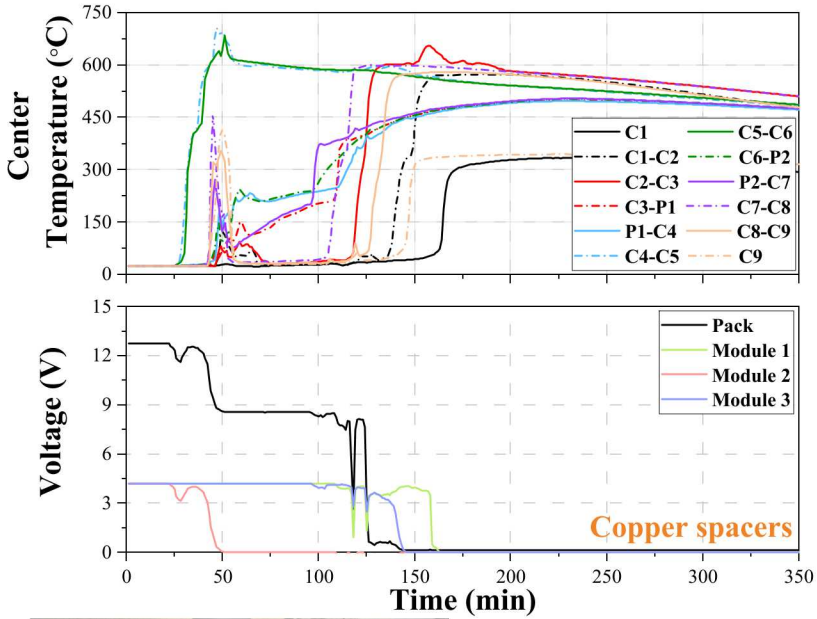
The focus of this section is to understand the extent of propagation with the inclusion of thermal management in the form of heat sinks between modules of a battery with a 3s3p configuration.



- **Aluminum plates**
  - 1/8 inch
  - 1/16 inch
- **Copper plates**
  - 1/8 inch
  - 1/16 inch

Thermal Management within modules: 1/8 inch barrier





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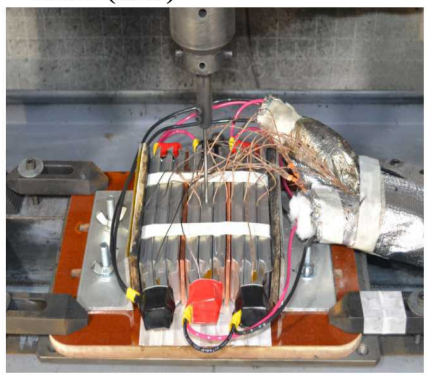
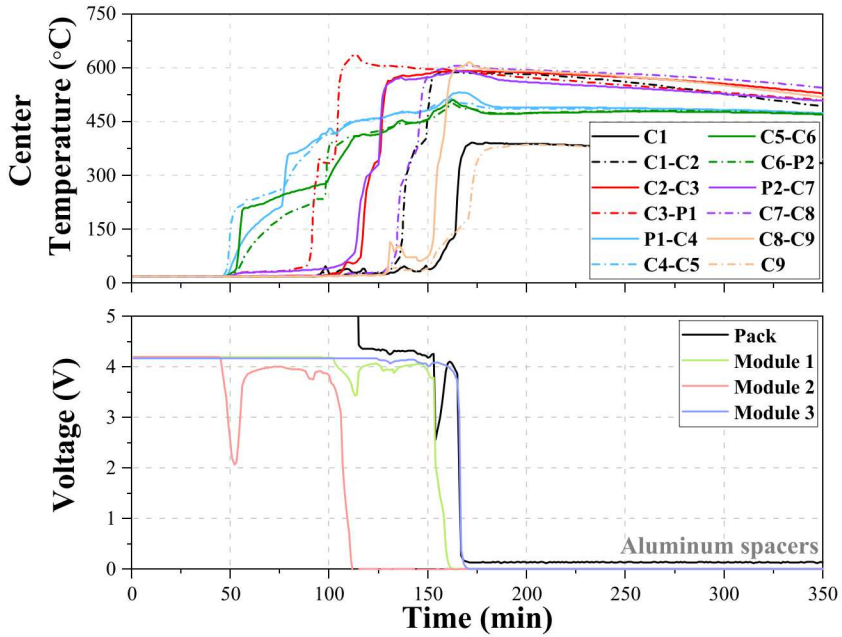
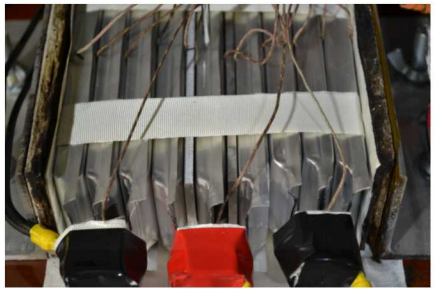


- Successful initiation of Cell #5 in module 2 for all the different tests.
- In both cases, cells within the target 1S3P module were rapidly consumed.
- Outer modules did not initiate thermal runaway until ~120 seconds after initial failure.

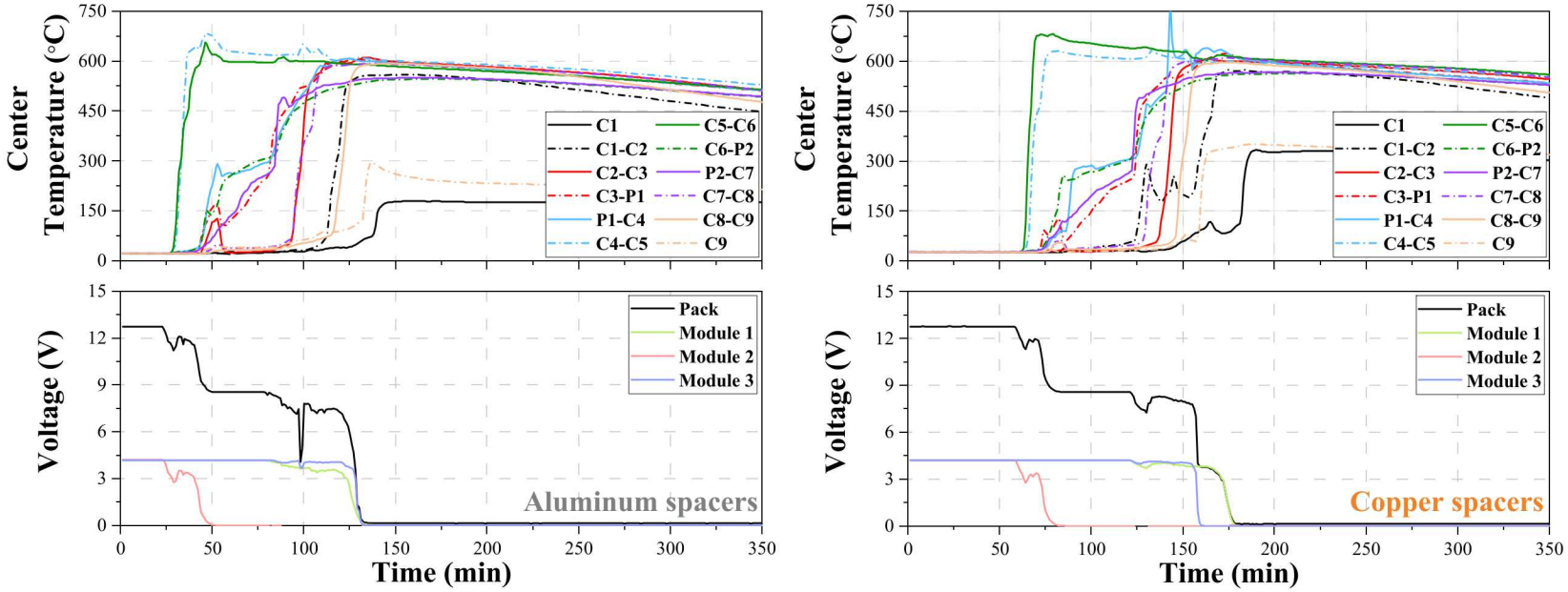
Thermal Management adjacent to the failed cell: 1/8 inch barrier





- Successful initiation of Cell #5 in module 2.
- The metallic barriers failed to mitigate the heat transfer to neighboring cells, and the target 1S3P module was rapidly consumed.

Thermal Management within modules: 1/16 inch barrier



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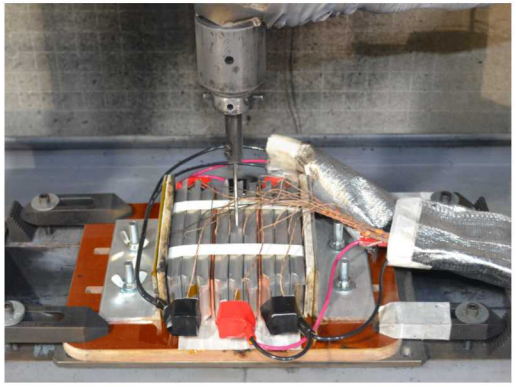

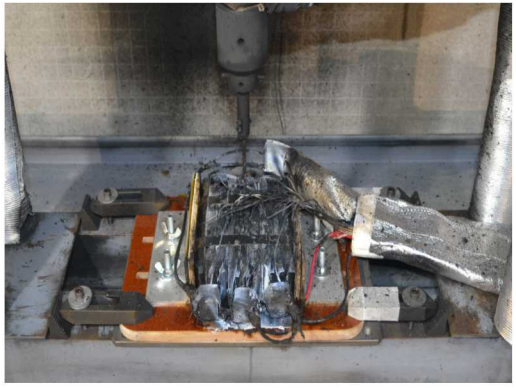

- Successful initiation of Cell #5 in module 2 for all the different tests.
- In both cases, initial failure immediately consumes cells within the central 1S3P module.
- Outer modules show signs of failure ~20 seconds after initial initiation.

Summary

- A cell may exhibit dramatically different failure response when in a string, module or pack than during single cell abuse testing.
- Limiting the SOC can have a meaningful impact in propagating failure, however this comes at a significant cost to total energy storage.
- Propagation can be mitigated through system engineering, however the results can be unpredictable. Further, electrical design will play a role in susceptibility to failure testing.
- Failure testing of large, complex systems is fairly resource intensive. Model based design presents a potential remedy to this, allowing us to infer a large amount of information from a relatively small number of tests.

Acknowledgements

DOT/NHTSA

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SNL

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Sandia National Laboratories