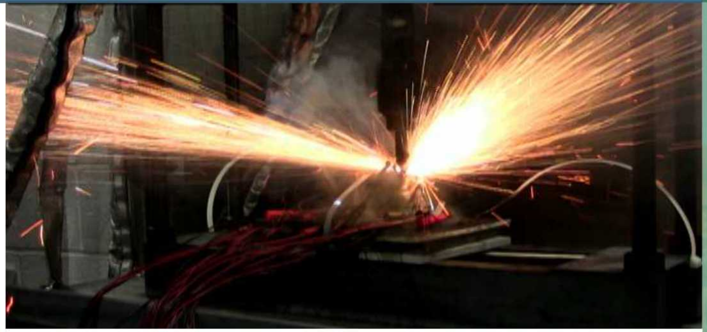
SAND2020-9539C

Mitigation of Failure Propagation Through Active Cooling: A Model-Based Experimental Design



PRESENTED BY

Loraine Torres-Castro

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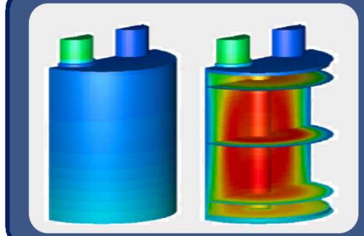
SAND2019-11198 C

Project Overview

Science and diagnostics of battery failure

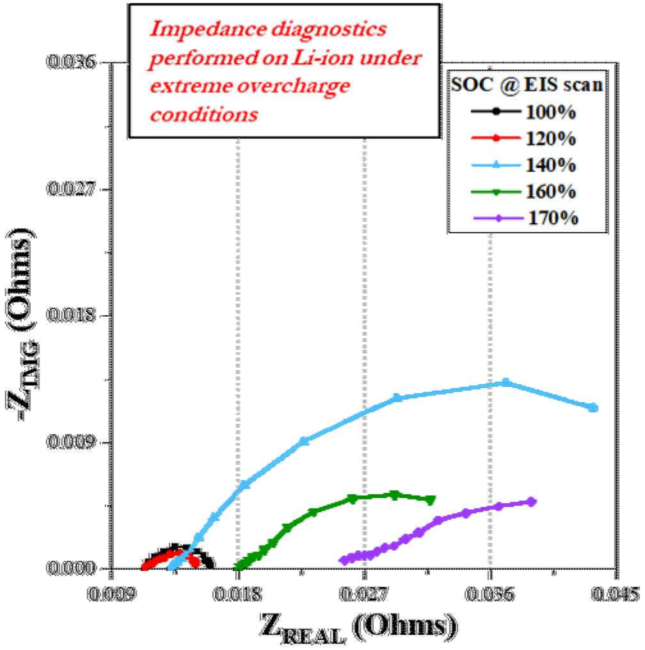
Materials R&D
- Non-flammable electrolytes
- Electrolyte salts
- Coated active materials
- Thermally stable materials

Testing
- Electrical, thermal, mechanical abuse testing
- Battery calorimetry
- Large scale thermal and fire testing (TTC)
- Failure propagation testing on batteries/systems
- Degradation and diagnostics during and post battery failure



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

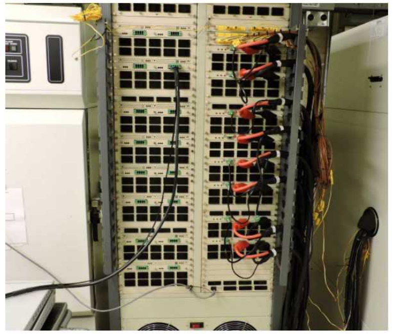
Procedure Development and Stakeholder Interface
- USABC Abuse Testing Manual (SAND 2005 3123)
- OE Energy Storage Safety Roadmap
- R&D programs with NHTSA/DOT to inform best practices, policies, and requirements



- Sandia is uniquely positioned to study the entire life cycle of a technology.
- New technologies present new risks. A high rigor environment at Sandia allows those risks to be adequately managed.

Project Team

Sandia Battery Test Facilities



Yuliya Preger
Armando Fresquez
Reed Wittman

Sandia Battery Abuse Testing Laboratory

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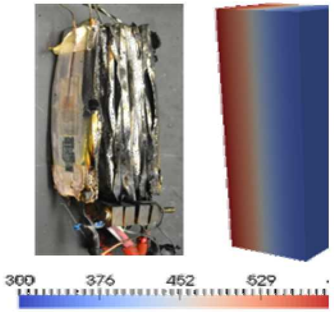
Chris Grosso
Lucas Gray
Jill Langendorf

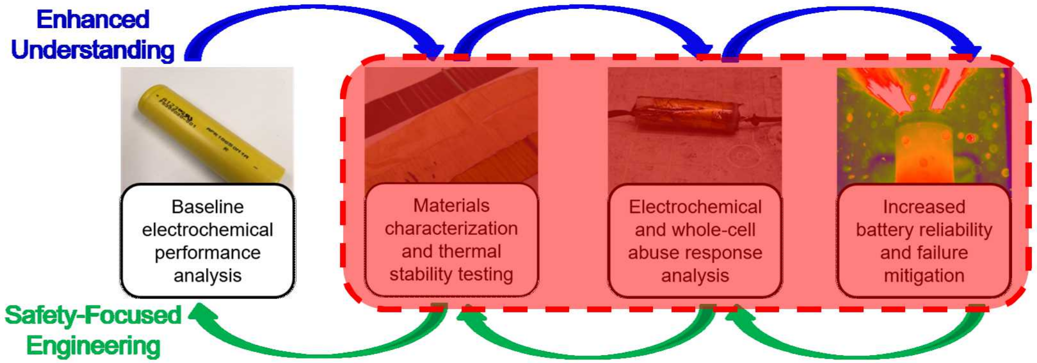
Sandia Fire Sciences



- John Hewson
- Randy Shurtz
- Andrew Kurzawski

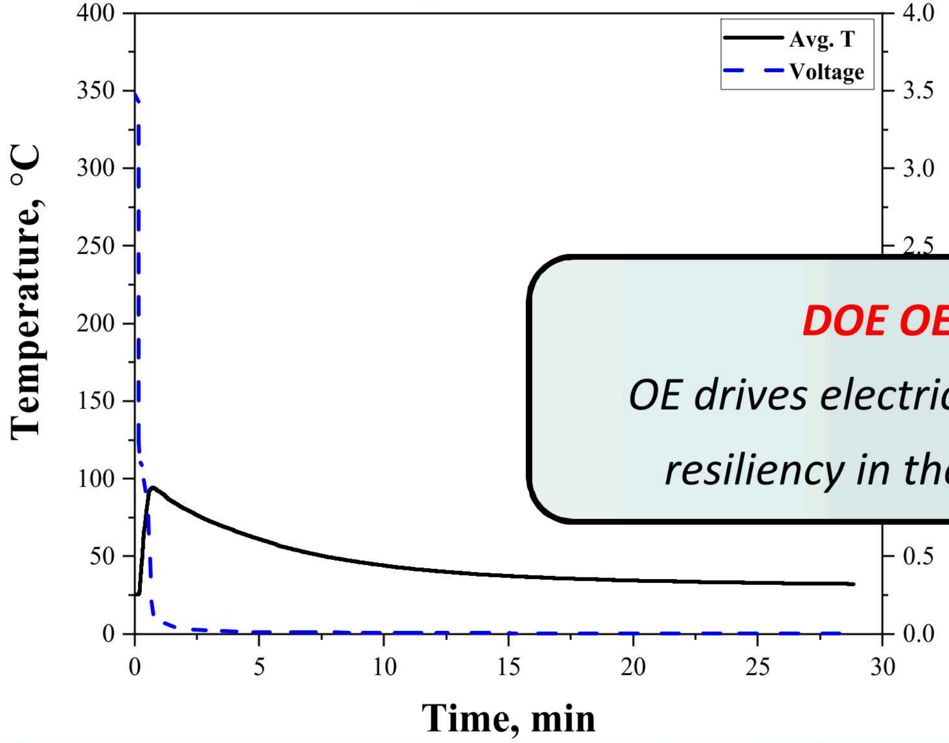
Center for Integrated Nanotechnologies

Sergei Ivanov

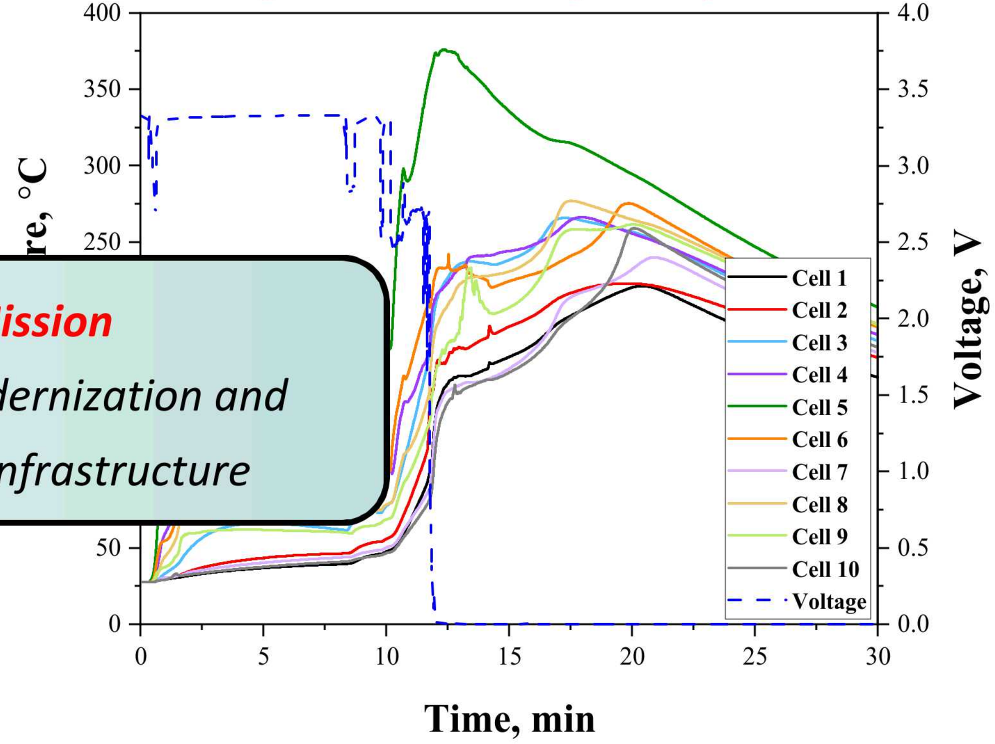


Motivation for Propagation Testing

Single Cell Failure



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



DOE OE's Core Mission

OE drives electric grid modernization and resiliency in the energy infrastructure

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

Objective

Reduce the risk of failure propagation with active cooling following a model-based experimental design

Project Objectives

Objective #1 – Modeling

Investigate the effect of active cooling on heat transfer and provide a model-based experimental design

Objective #2 – Experimental

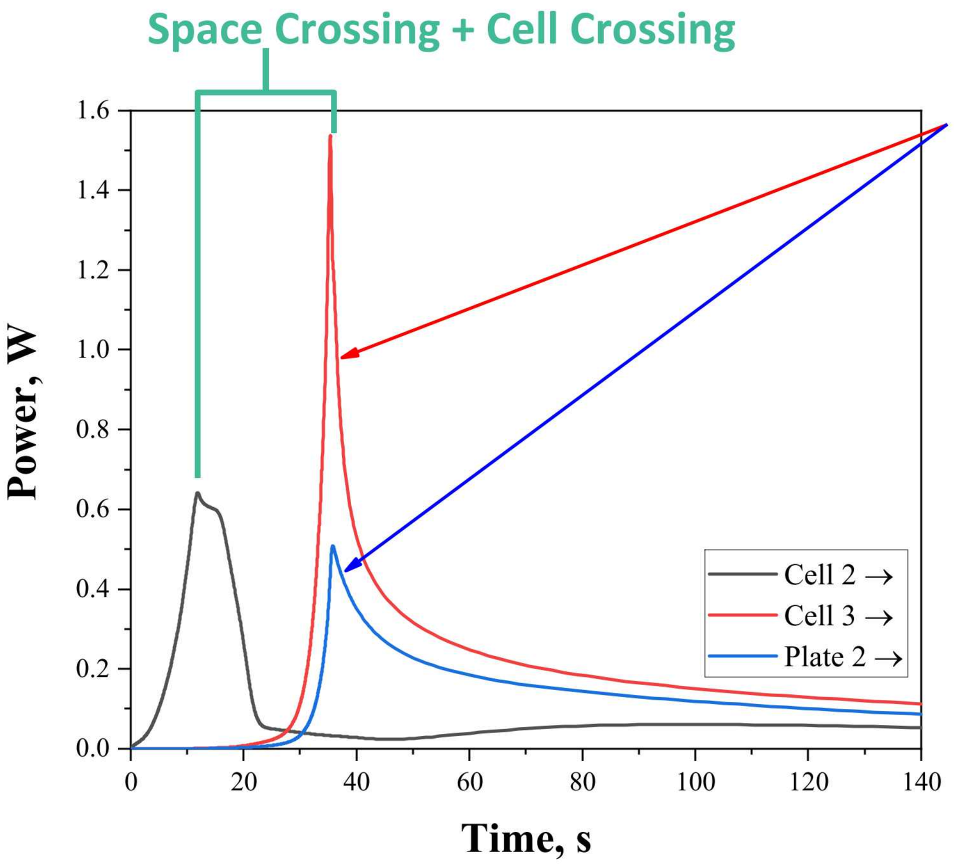
Reduce the risk of cell-to-cell propagation in multi-cells packs and multi-module battery systems

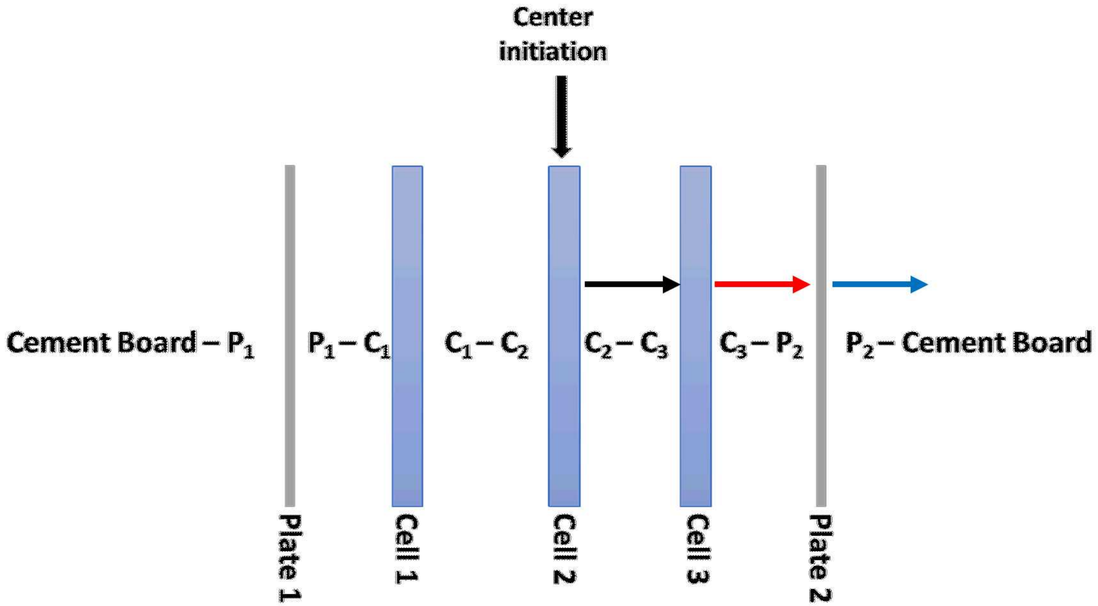
Project Objectives

	1.Milestones	1.Current Status
#1	•Develop a model-based experimental design of promising pack configurations	•The model-based design was completed
#2	Investigate the effect of active cooling in the heat transfer of single cells and multi-cell battery packs during failure	•The experiments were completed
#3	•Investigate the effect of active cooling on the onset threshold to thermal runaway	•Ideal conditions were identified to avoid failure during overcharge conditions.

Project Results: Predicting Thermal Runaway
by Randy Shurtz

Large-scale testing is costly and simulations allow exploration of the design space if well grounded in reality





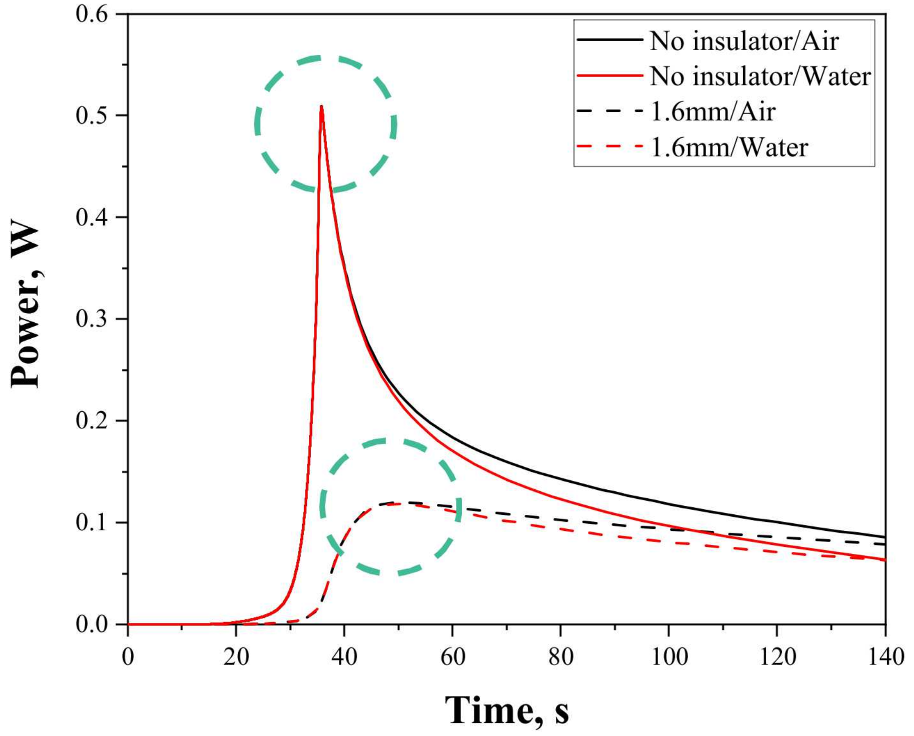
Measurements are reality but simulations allows us to better understand the behavior changes and explore boundaries between mitigation/cascading failure

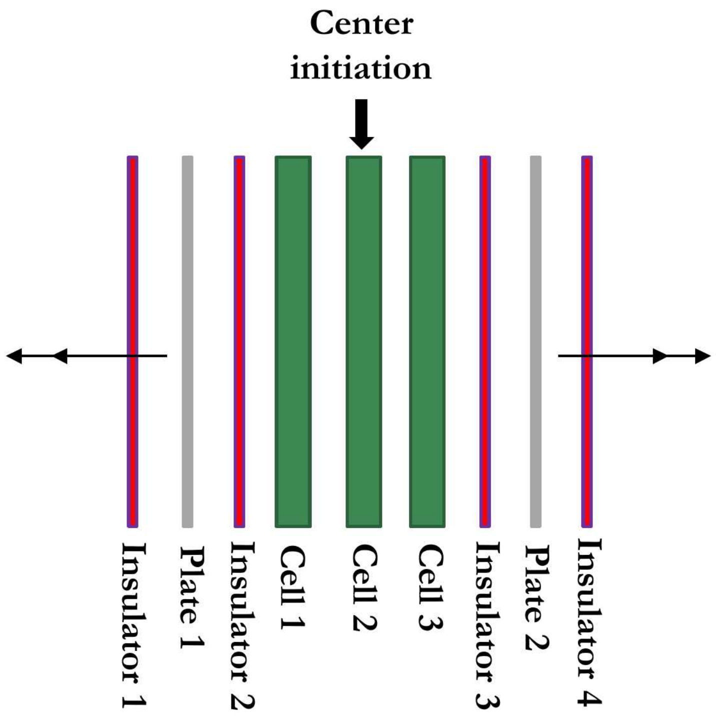
Milestone #1 – Develop a model-based experimental design of promising pack configurations

Project Results: Predicting Thermal Runaway

By Randy Shurtz

Effect of insulator thickness on the heat out of the battery pack





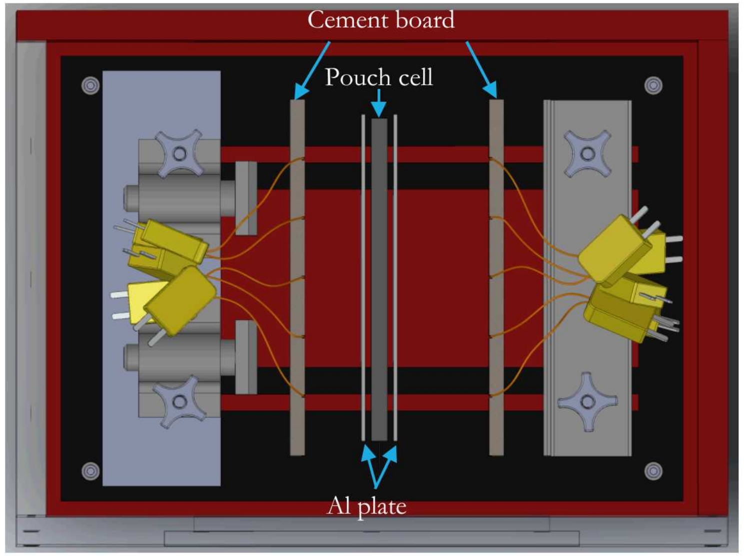
Water cooling increases decay rate of tails, indicating more heat transfer out of the stack

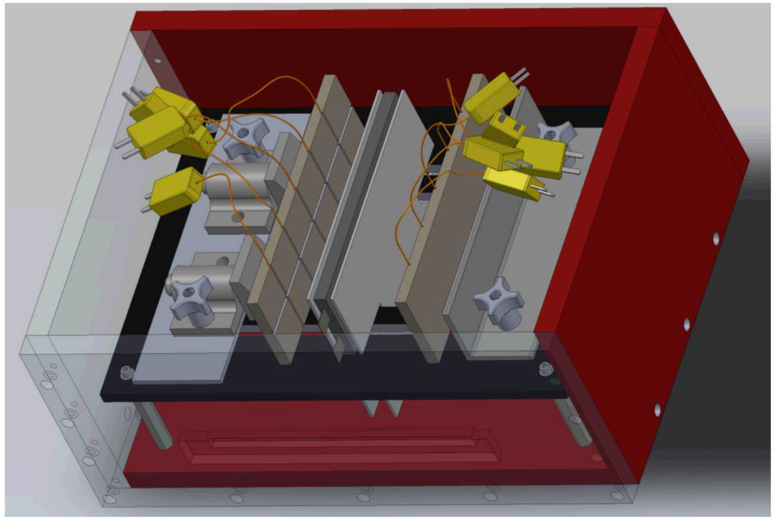
Milestone #1 – Develop a model-based experimental design of promising pack configurations

Project Results: Experimental Design

Test apparatus

by Chris Grosso



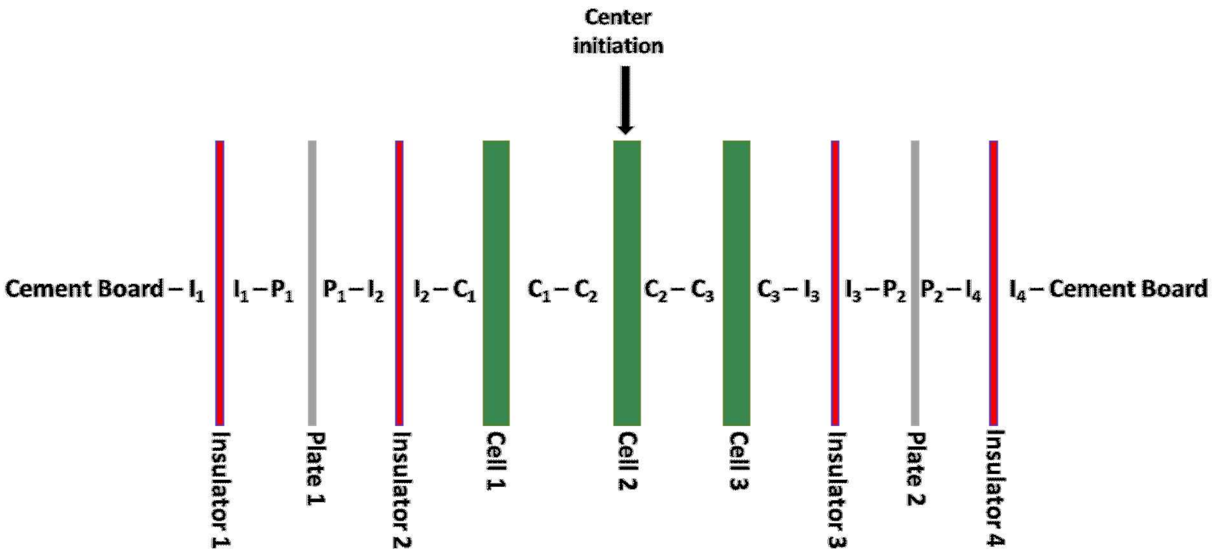


Test matrix

- 3x pouch cells
  - Baseline
  - Al Plate/Insulator
  - Al Plate/Insulator/Water

Al plate
0.8mm
G10 insulator
0.4mm or 1.6mm

Thermocouple map

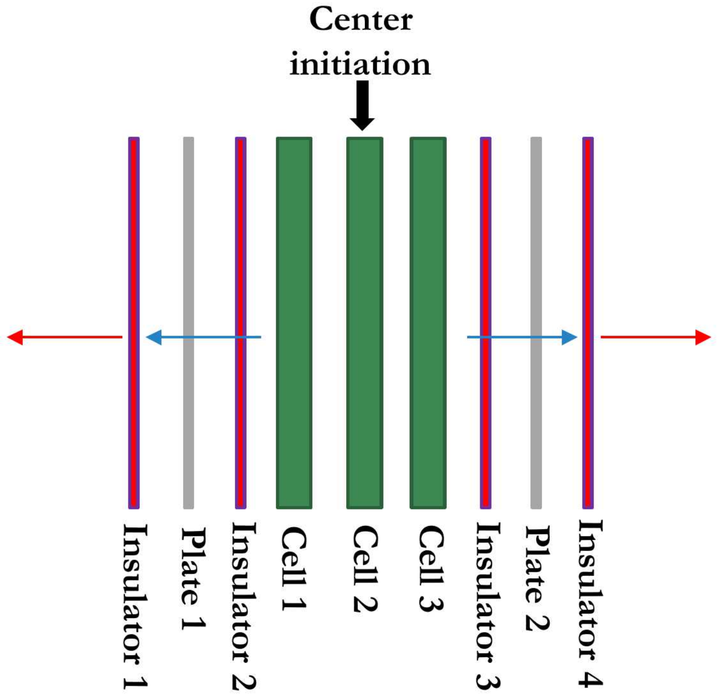


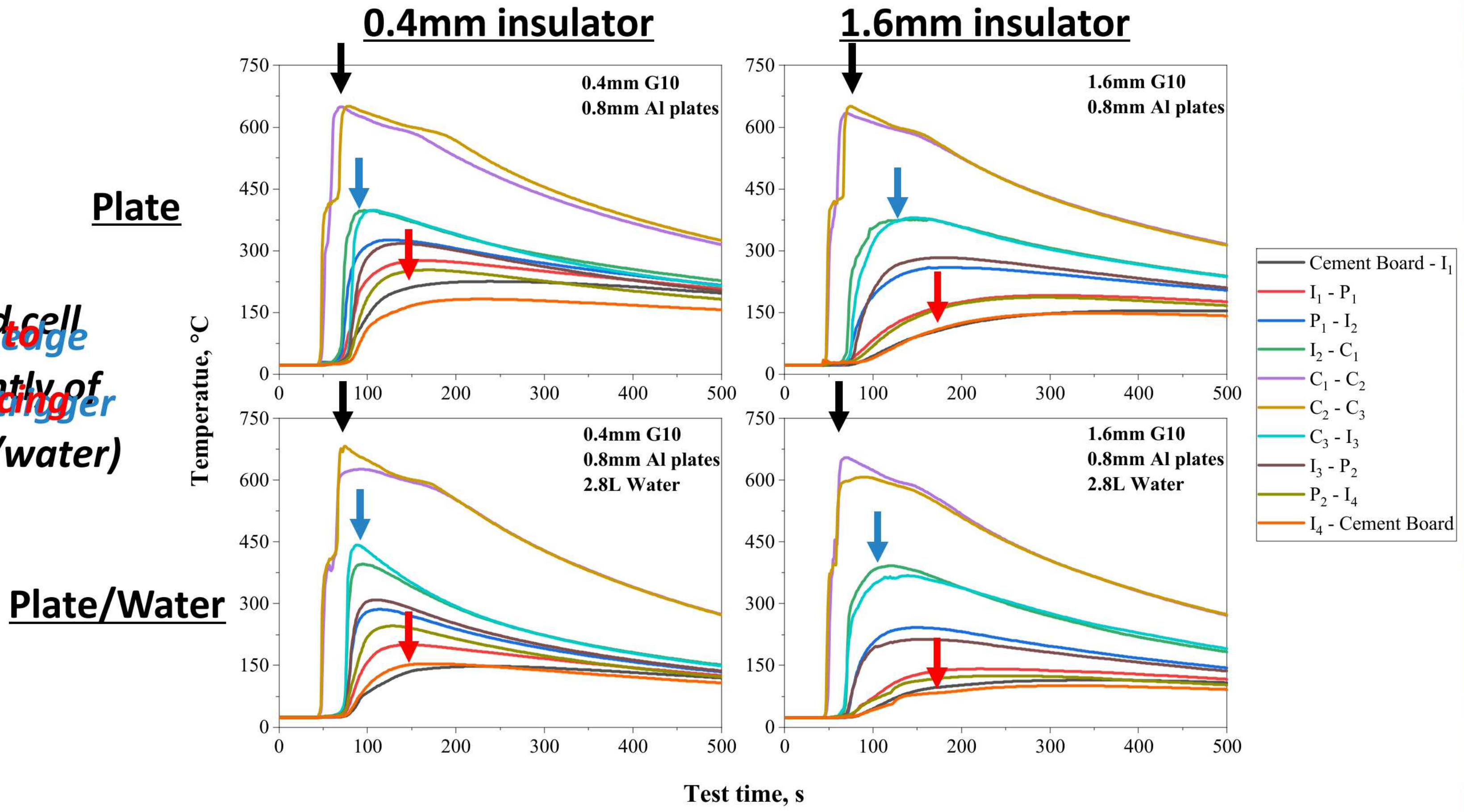
Project Results: Temperature Profile

The maximum temperature of the failed cell remained in the same region independently of insulator thickness or level of cooling (air/water)

Mitigation – Adjacent module exposed to temperature between 100°C-150°C, reducing the risk of thermal propagation

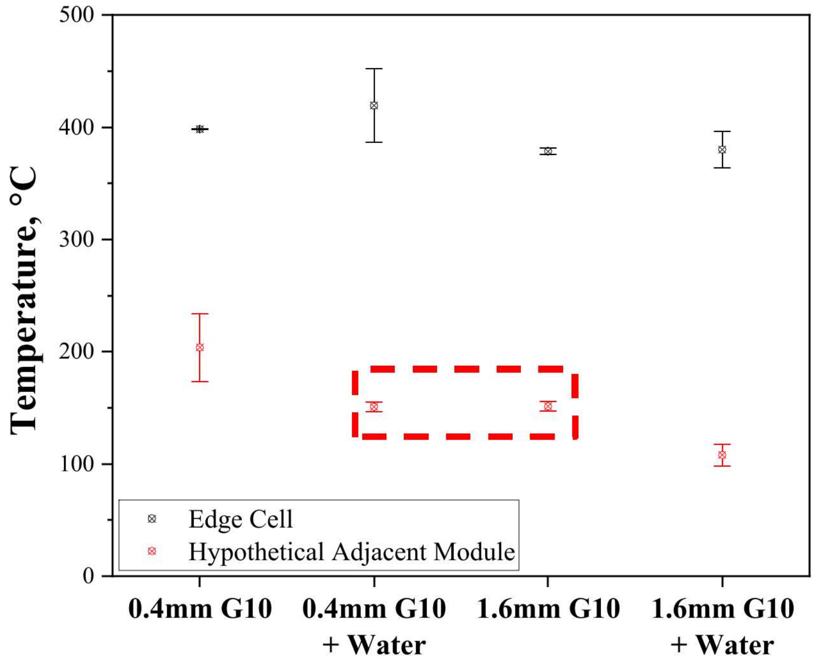
No mitigation – transfer from the edge cell to the adjacent module sufficient to trigger thermal runaway





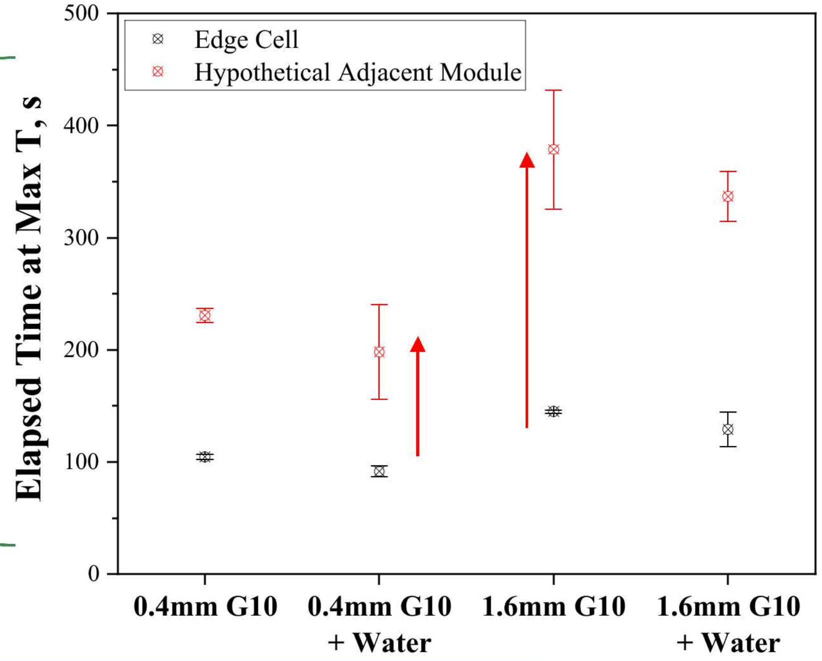
Milestone #2 – Investigate the effect of active cooling in the heat transfer

Project Results: Hypothetical Adjacent Module Temperature Exposure



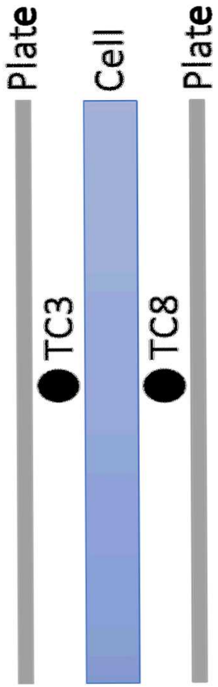
- **The hypothetical adjacent module will be exposed to temperatures nearly identical when using 0.4mm G10/Water or 1.6mm G10/no water**
- **Thicker insulators and the inclusion of water reduces the risk of failure propagation**

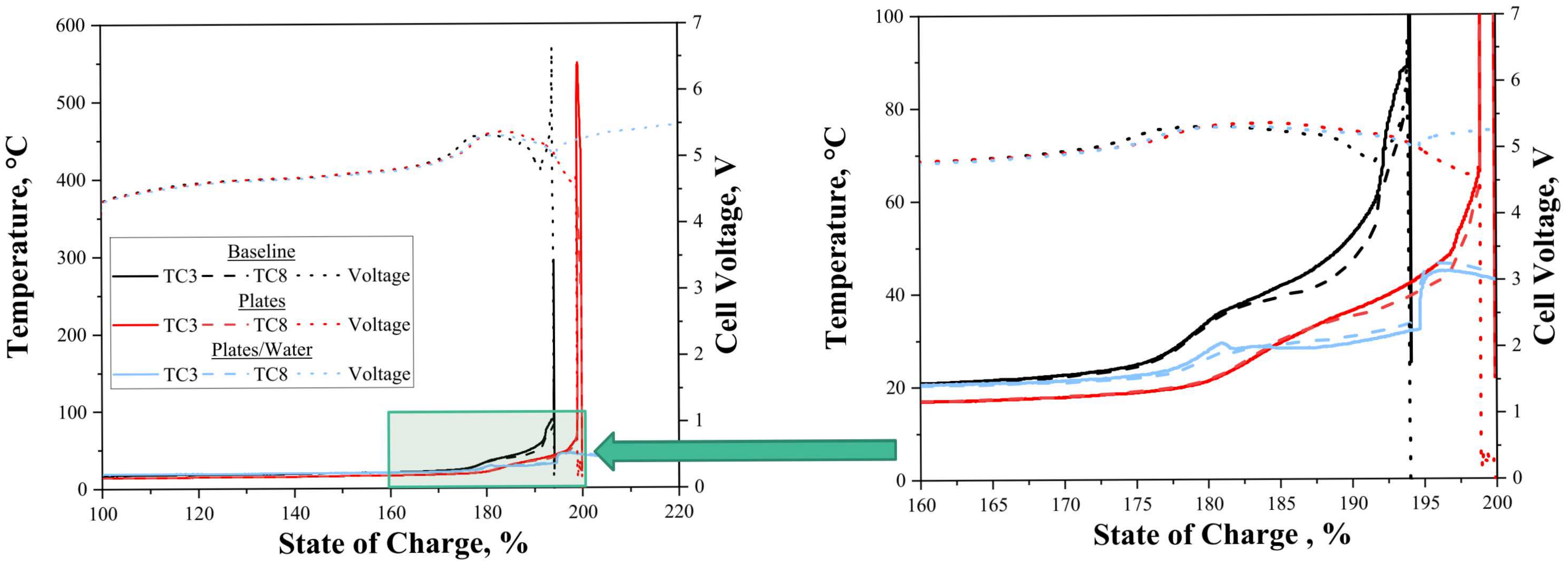
The elapsed time at the max. temperature further demonstrates that adding thermal mass slows down the heat transfer to the hypothetical adjacent module



<u>Milestone #2</u> – Investigate the effect of active cooling in the heat transfer

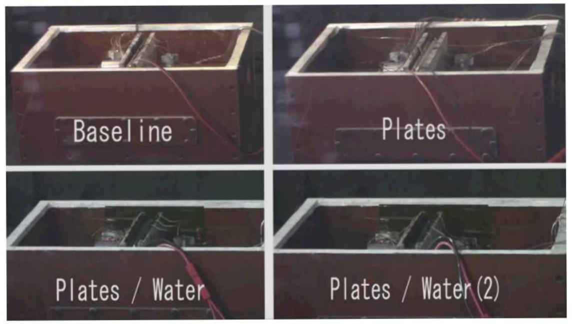
Project Results: Overcharge Behavior with Air and Water Cooling





For SOCs >175%

- ✓ Baseline - faster self-heating and an earlier onset SOC to thermal runaway
- ✓ Plates - slower self-heating with maximum temperatures ~500°C
- ✓ Plates/Water - No thermal runaway



Milestone #3 – Investigate the effect of active cooling on the onset threshold to thermal runaway

PUBLICATIONS AND PRESENTATIONS

Presentations

- **Investigations of the Structural and Electrochemical Properties of Overheated Li-Ion Batteries and Its Effects in Single Cells Vs. Multi-Cells Packs**; 236th ECS Meeting; Atlanta, GA; October 2019
- **Analyzing the Effects of Lithium Plating on the Safety Performance of Lithium-Ion Batteries**; 236th ECS Meeting; Atlanta, GA; October 2019
- **Recent Progress in Alkaline Zn/MnO_2 Batteries**; NAATBatt International Workshop on Zinc Battery Technology II; New York, NY; November 2019
- **Understanding the factors impacting battery failure propagation and its mitigation**; Materials Research Society Fall Meeting; Boston, MA; December 2019.
- **Battery safety**; Public Safety Workshop, Case Western Reserve University; February 2020.
- **Impact of energy density on thermal runaway**; Energy Storage Systems Safety & Reliability; Richland, WA; March 2020.
- **Understanding the factors impacting battery failure propagation and its mitigation**; Energy Storage Systems Safety & Reliability Forum; Richland, WA; March 2020.
- **Accelerating rate calorimetry of large format cells**; International Battery Seminar; Virtual Meeting; July 2020

Publications

- L. Torres-Castro, A. Kurzawski, J. Hewson, J. Lamb, "**Passive mitigation of cascading propagation in multi-cell lithium ion batteries**," *Journal of the Electrochemical Society*, vol. 167, 2020
- D.M. Rosewater, J. Lamb, J.C. Hewson, V. Viswanathan, M. Paiss, D. Choi, A. Jaiswal "**Grid-scale Energy Storage Hazard Analysis & Design Objectives for System Safety**" Report prepared for Arizona Public Service, SAND2020-9360, August 2020
- A. Kurzawski, L. Torres-Castro, R. Shurtz, J. Lamb, J. Hewson, "**Predicting cell-to-cell failure propagation and limits of propagation in lithium-ion cell stacks**" Proceedings of the Combustion Institute (accepted)
- J. Lamb, L. Torres-Castro, J. Hewson, R. Shurtz, Y. Preger, C. Orendorff, "**The role of energy density in lithium-ion battery thermal runaway**" (in preparation)
- J. Obert, L. Torres-Castro, Y. Preger, R. Trevizan, "**Ensemble learning, prediction and Li-ion cell charging cycle divergence**" (in preparation)
- Y. Preger, L. Torres-Castro, J. Langendorf, J. Lamb, C. Orendorff, B. Chamalala, "**Review of the safety of aged lithium-ion batteries as a function of aging protocol and abuse method**" (in preparation)
- L. Torres-Castro, E. Deichmann, J. Lamb, J. Langendorf, S. Ferreira, S. Ivanov, M. Dubarry, A. Pimentel, M. Rodriguez, J. Kustas, B. Juba, **"Investigations of the Electrochemical and Material Properties of Overcharged Li-ion Batteries"** (in preparation)
- J. Stanley, L. Torres-Castro, J. Lamb, H. Wang, "**Standardizing Li-ion pouch cell tests to aid in thermal runaway predictions using machine learning**" (in preparation)

LOOKING FORWARD

Collaborations

- **I.ORNL**- Establishing thermal runaway risk test protocols and database
- **I.NITE** – Reliable and Repeatable Failure Initiation Techniques

Project #1

- Failure mechanisms of lithium-ion batteries up to and prior thermal runaway (continuation)

Project #2

- Understanding and mitigation cascading propagation (continuation)

Project #3

- Off-gassing analysis of lithium ion batteries during thermal runaway as a function of chemistry and state of health

PROJECT CONTACTS

- Funded by the U.S. Department of Energy, Office of Electricity, Energy Storage program. Dr. Imre Gyuk, Program Director.
- Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA-0003525.
- This work was performed, in part, at the Center for Integrated Nanotechnologies, an Office of Science User Facility operated for the U.S. Department of Energy (DOE) Office of Science by Los Alamos National Laboratory (Contract DE-AC52-06NA25396) and Sandia National Laboratories (Contract DE-AC04-94AL85000).

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For further details on experimental work, see the following posters:

- Materials characterization of abused cells