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Thermal runaway early warning: over-temperature detected by acoustic emission

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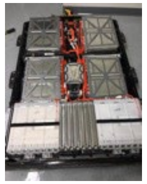
Oak Ridge National Laboratory

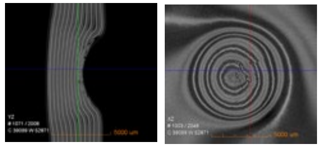
DOE OE Energy Storage Peer Review & Annual Meeting, 2026



Battery Pack

Battery Modules

Battery Cells



XCT: Indented Battery

July 29, 2026

ID#: 403

U.S. DEPARTMENT of ENERGY

Project Overview

- Goal: Establish a thermal runaway risk database to improve safety and reliability of energy storage systems (ESS)
- Current Practice:
  - Abuse studies of Li-ion batteries are isolated and hard to compare. Standard testing is needed and an accessible thermal runaway database is needed
  - No cell level temperature monitoring. Thermal runaway warning is not effective
- Why ORNL: Abuse testing started at ORNL in 1998. We have developed multiple abuse testing methods and formed partnership with DOE labs, industries and universities
- Innovation: We aimed to change qualitative safety tests into quantitative thermal runaway risk scores that can be used to compare cells with different chemistries, capacity and state-of-charge. This study also provides insights on the origins and how to detect early warning signs of thermal runaway
- Duration: FY20-FY26
- Impact:
  - An up-to-date thermal runaway risk database can inform the end users the relative risks of different Li-ion cells and how to design the ESS accordingly for safety and reliability
  - Over-temperature warning minutes or hours before thermal runaway event is critical for ESS
- Vertical/Investment Area:
  - Safety & Reliability: from cell materials to single cells, modules and ESS
- Alignment/Supports strategic pathway: Thermal runaway risk studies is a critical part of ESS Safety and Reliability. It aligns with DOE OE goals on Stabilize grid services, Optimize grid services, Grow grid capacity

Project Update FY2026

- Thermal runaway database: new data, accessibility, ML/AI functions
- ORNL-MIT collaboration: thermal abuse (Young Ko/Prof. Bazant)
- ORNL-MIT collaboration: gas generation study (Yash Samantaray/Prof. Bazant)

Li-ion Battery Safety Testing: Thermal Runaway

- **Mechanical Abuse**
  - Deformation: bending, dropping, impact, intrusion of external objects
  - Testing: Nail penetration, indentation, pinch, pinch-torsion
  - Mechanism: Induce internal short circuit -> thermal runaway
- **Thermal Abuse**
- Overcharging/discharging

Limitations of Safety Studies:
- Number of cells are limited
- Hard to compare results of different tests
- Safety Tests vs. Relative Risk

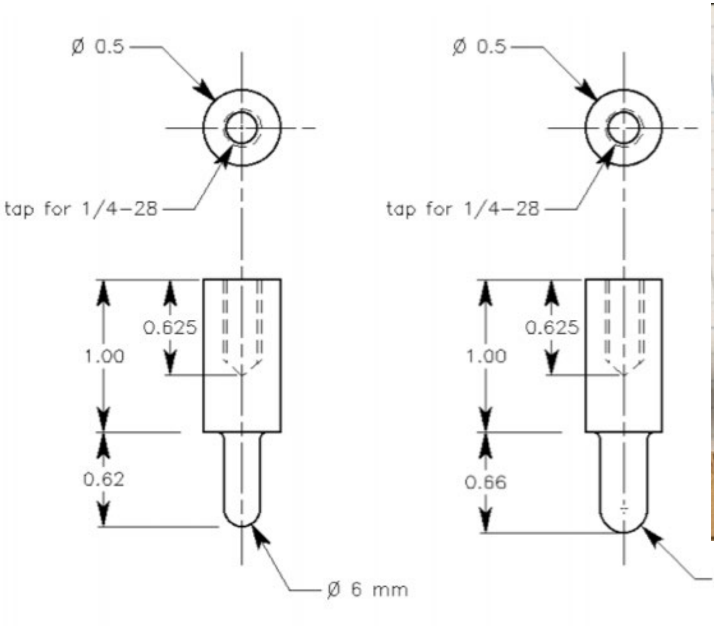
Approach: ORNL-Sandia Test Procedures and Standards

Internal Short-ciruit Induced Thermal Runaway

- Mechanical abuse (indentation)

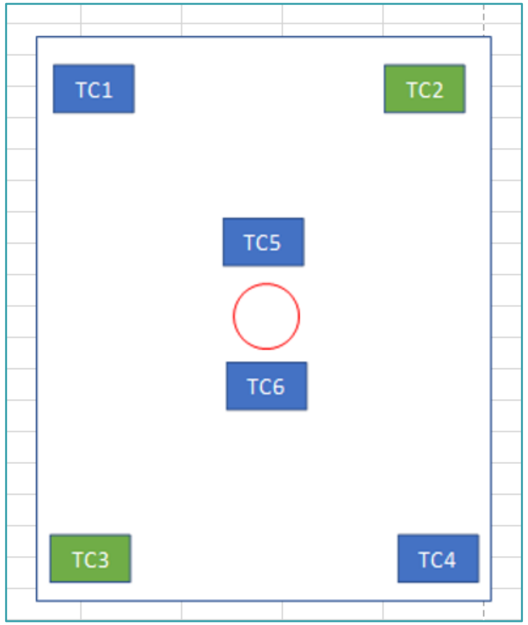
Updated Test Protocols:

- Cycle cell 3-5 times at C/2 between 3.0-4.2V to determine SOC and discharge to test SOC
- Hydraulic or servo-motor driven load frame
- 6 mm punch (most sensitive, small contact)
- 0.05 inch per minute compressive loading
- 25 mV V_{oc} drop
- Hold the punch after short circuit
- Temperature measurement:
  - 5 mm from the indenter
  - At cell corners when possible



Punches for Battery Testing		
ELC-2019.03.001	Scale: 1.5:1	
Dimensions: inches (unless otherwise specified)	Material: stainless steel	
Make four (4) pieces of each		
Edgar Lara-Curzio	ORNL	March 2019

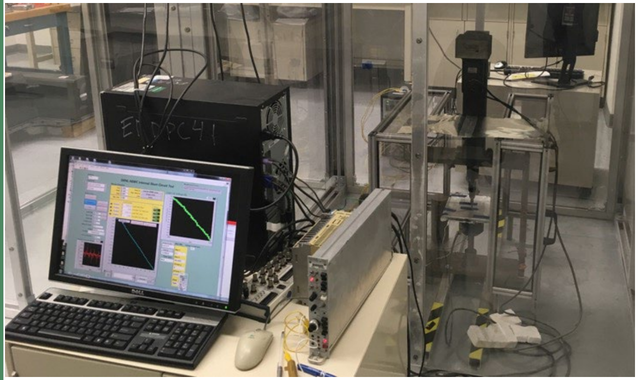
Thermocouple Locations on Large-format Cells

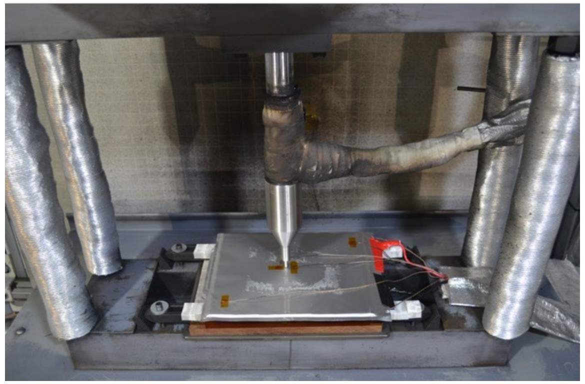


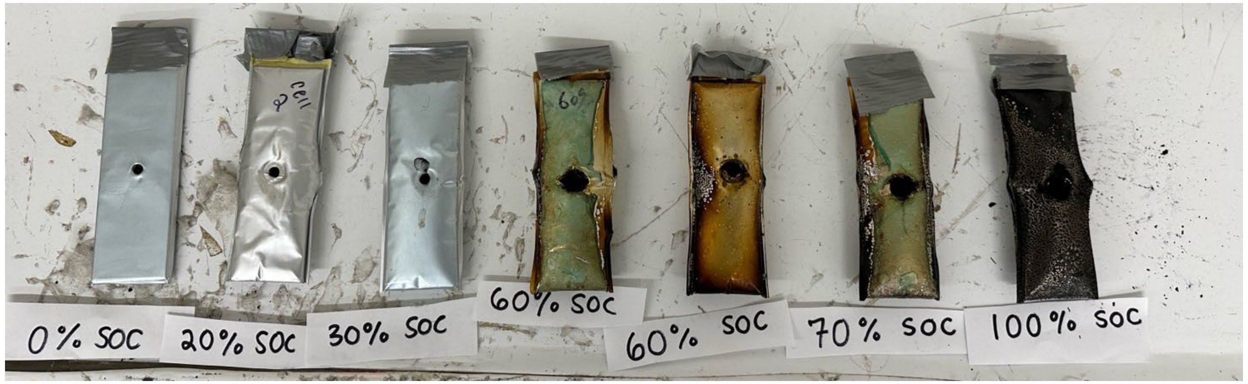
Select the most sensitive test to allow safety risk Ranking (similar to USABC and UL small indentation test)

Approach: Quantitative Risk Scores vs. Qualitative Observations

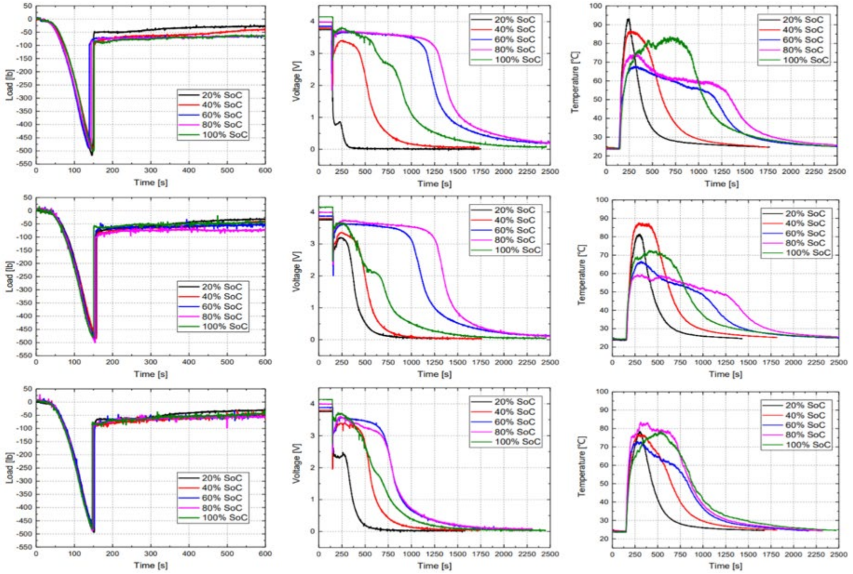
EUCAR Visual Observation: LCO 4000 mAh







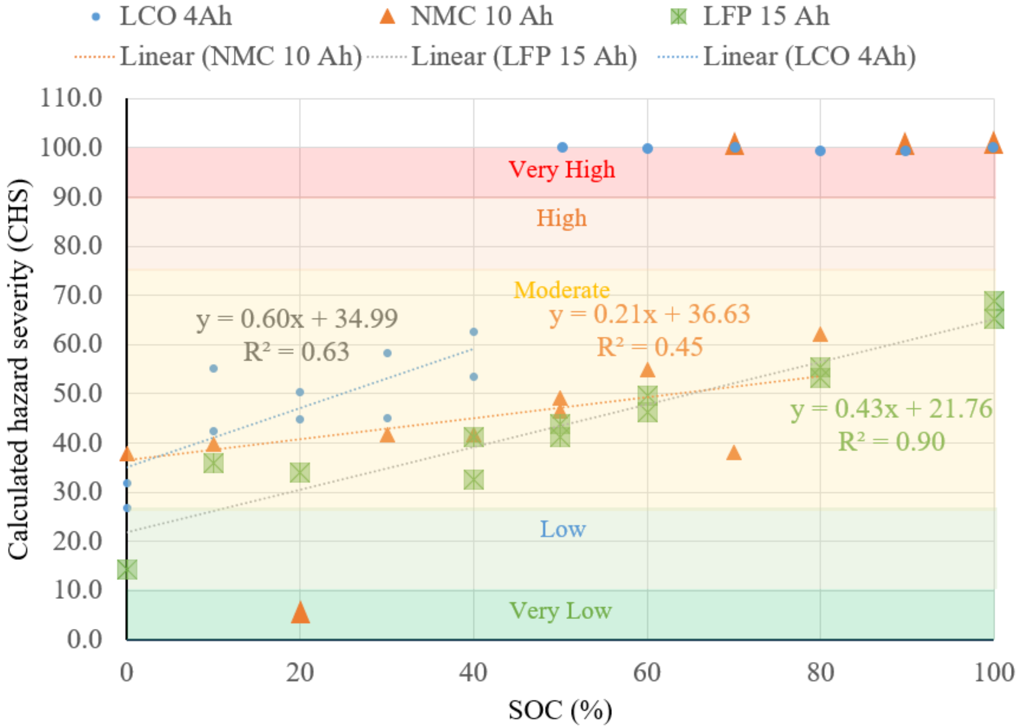
Load **Voltage** **Temperature**



Thermal Runaway Risk Score
Large Database
Ranking & Comparison of Risks
AI Tools and Machine Learning

Database access information
As of May 29,2026

Views; 2024
Download: 682



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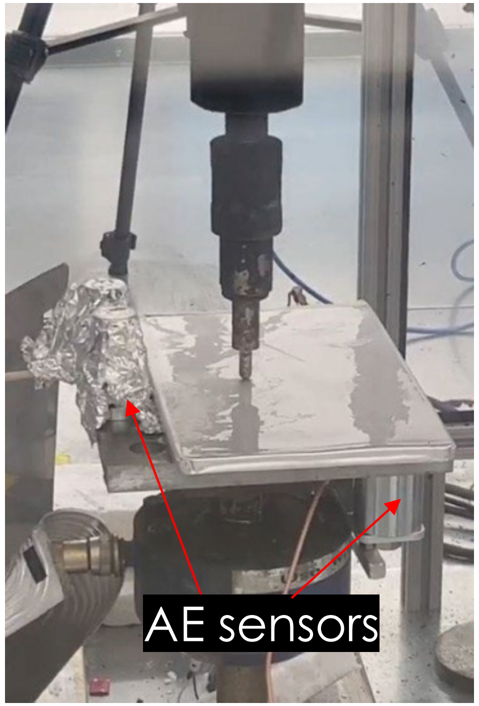
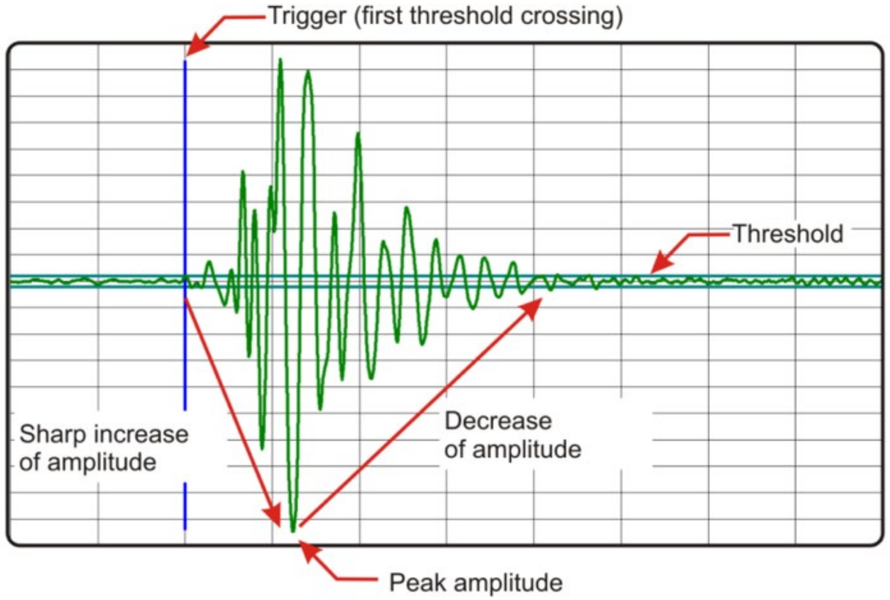
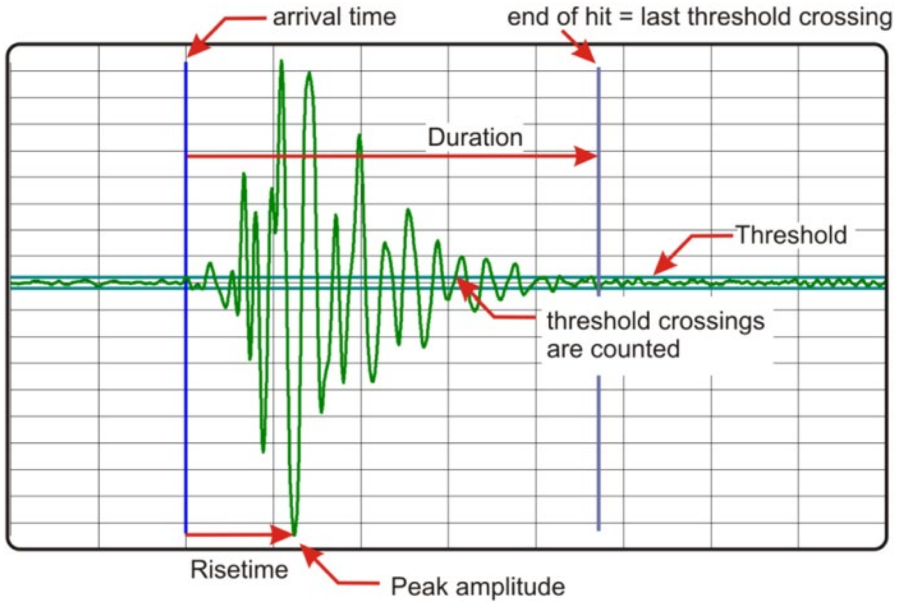
Lianshan Lin, Hsin Wang, Jianlin Li, Loraine Torres-Castro, Yuliya Preger, Valerio De Angelis, "Mechanically Induced Thermal Runaway for Li-ion Batteries", **Mendeley Data**, 2024

L. Lin et al. ***Journal of Energy Storage***, doi.org/10.1016/j.est.2023.106798, 2023

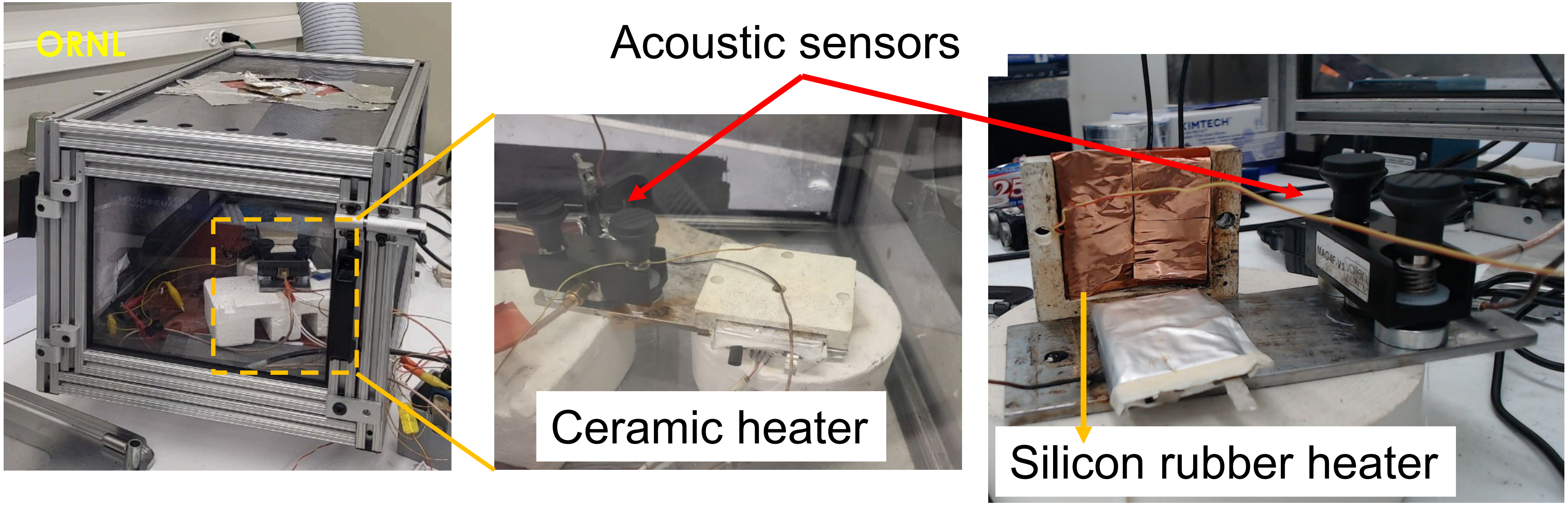
Acoustic Emission to Detect Cell Internal Damage During Indentation Test

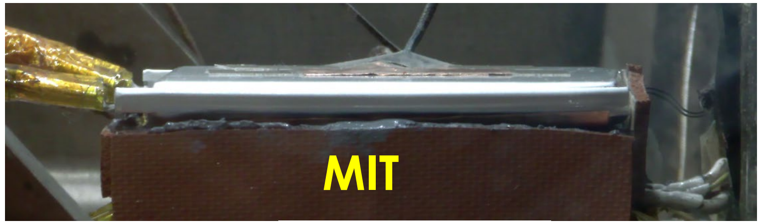


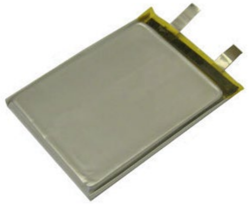


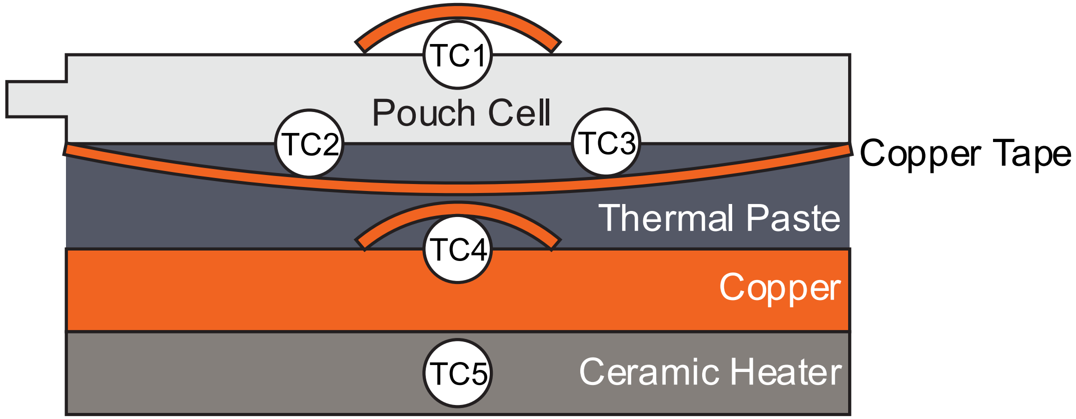


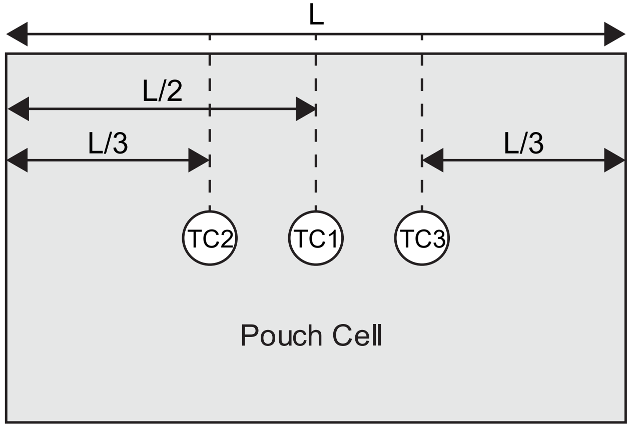
ORNL and MIT Thermal Abuse Setups and AE Signal Monitoring







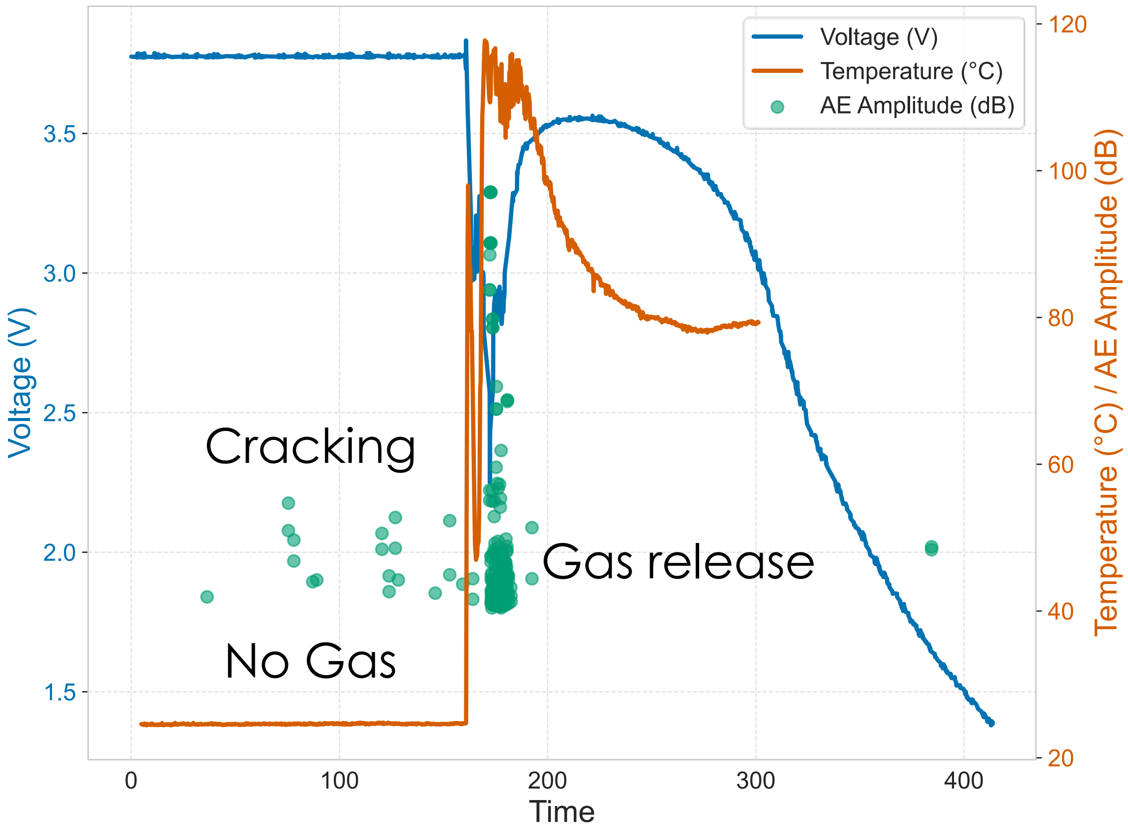




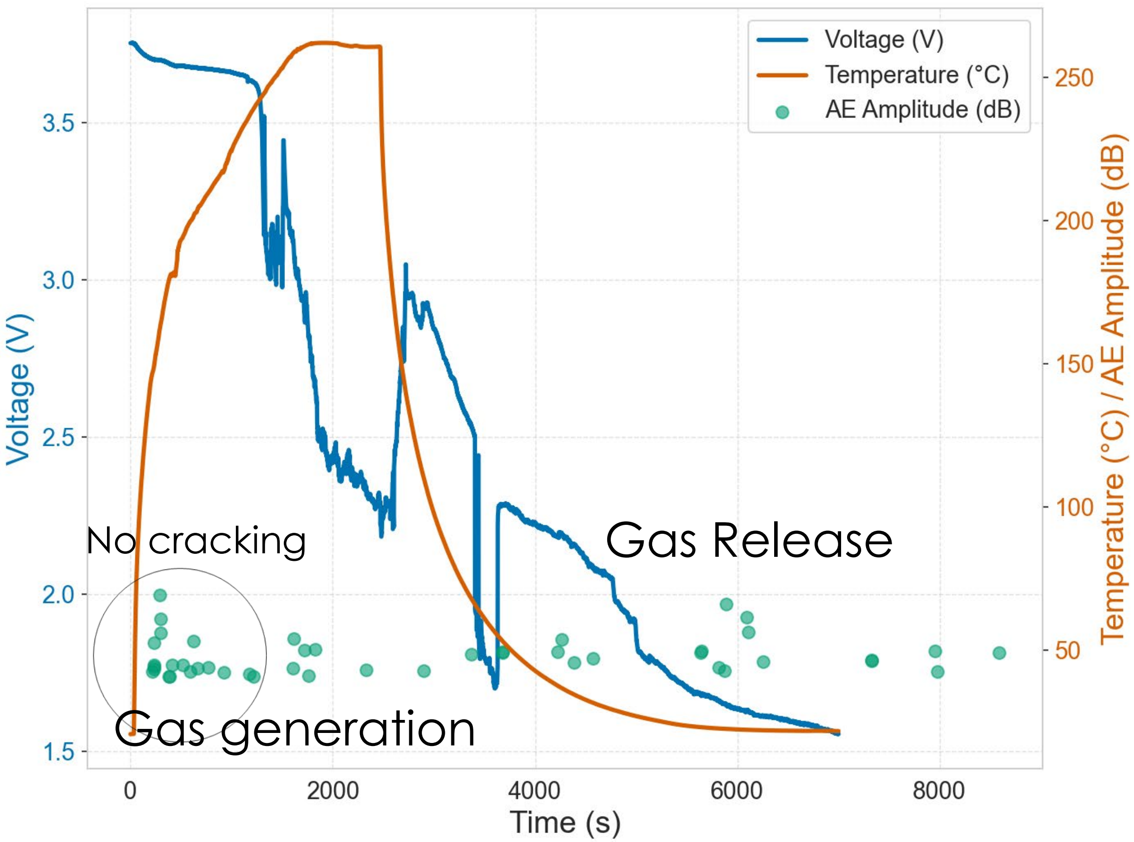
LCO/Gr 2 Ah
commercial pouch cells

AE Signals During Indentation and Thermal Abuse

Indentation



Thermal Abuse Overheating



AE signals from indentation and overheating have unique signatures and overlapping

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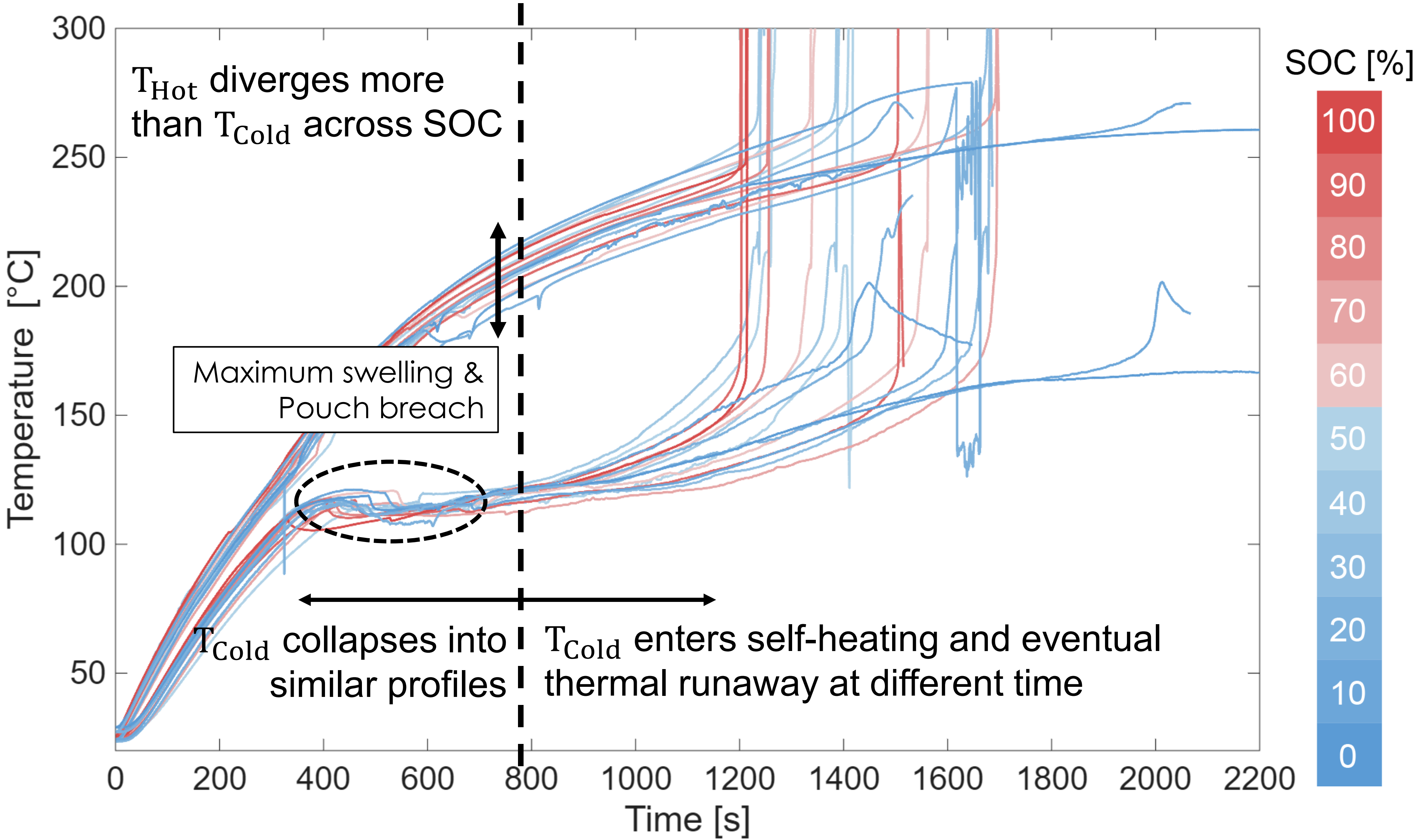
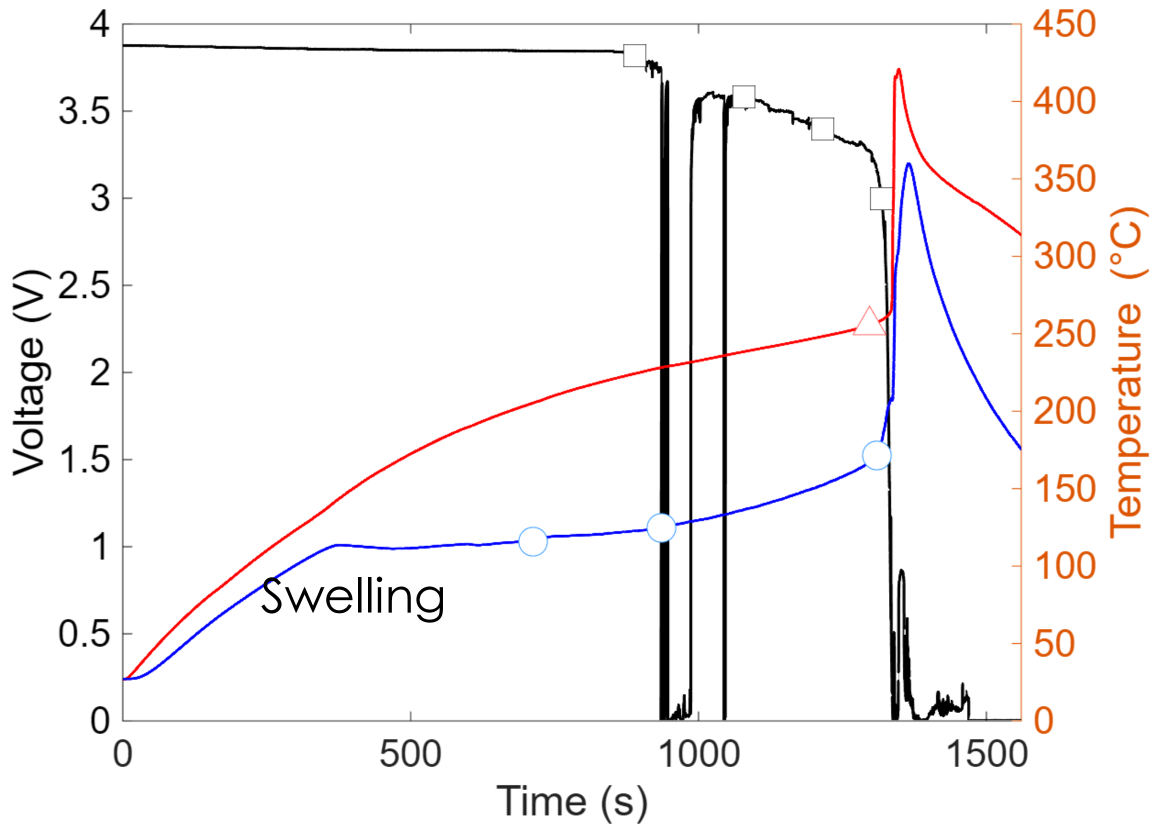
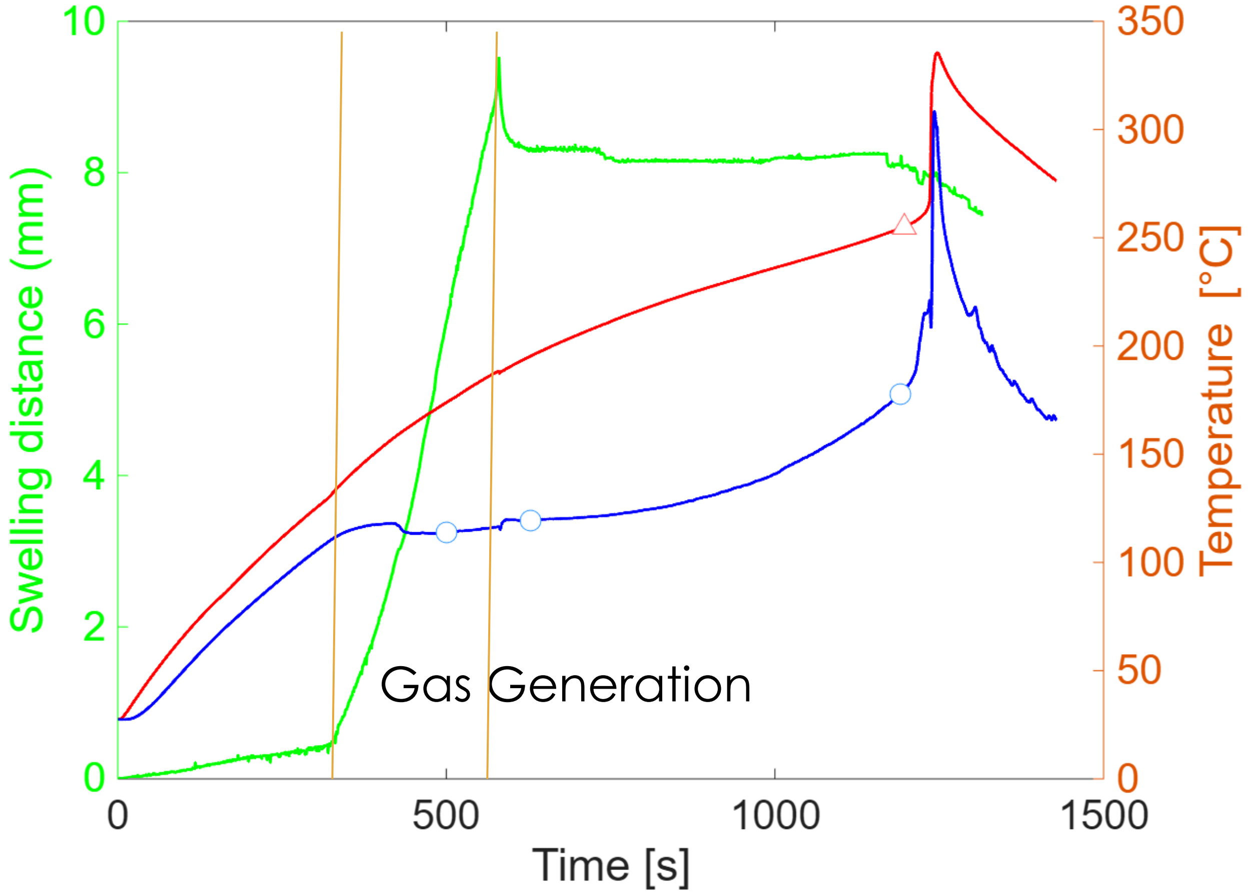
MIT Thermal Abuse Test Results Confirmed Pouch Swelling



MIT Overheating Results Confirmed Swelling/Gas Generation

More than 1000 second window to thermal runaway at heating rate of 10K/min

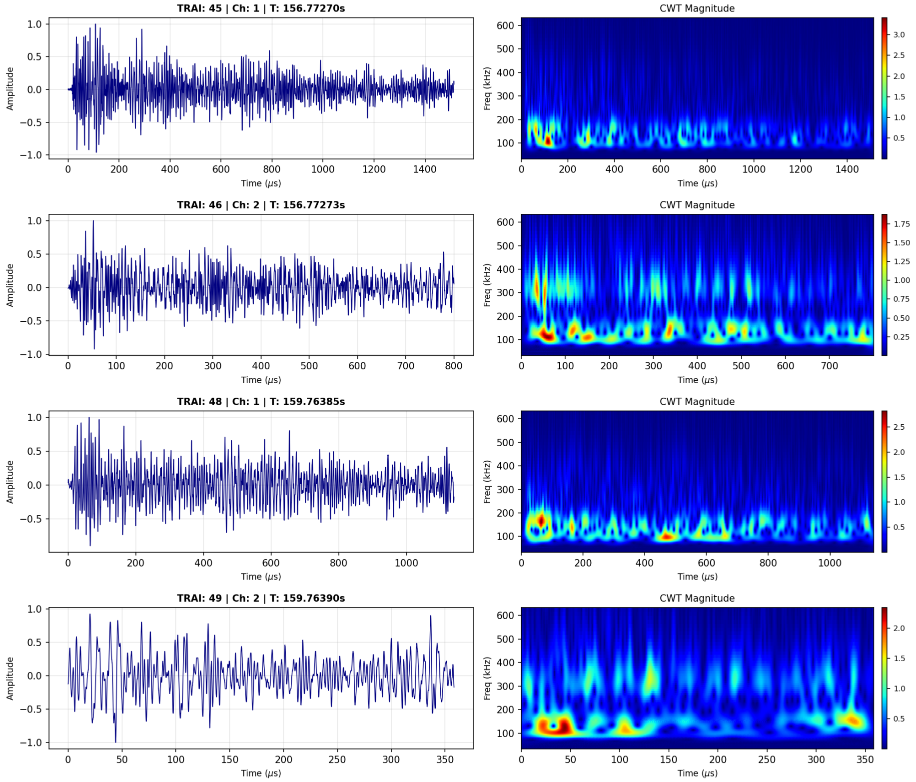




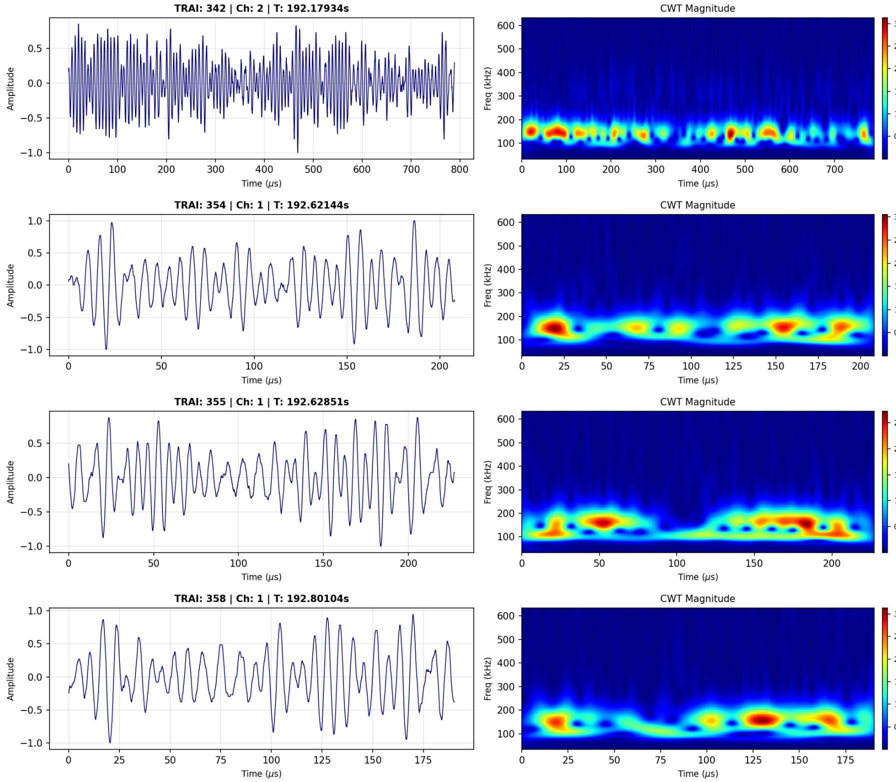
On-set of swelling: 350-400 second
Voltage drop: 900 second
Thermal runaway: 1400 second

Swelling measured by image analysis

FY26 New Approach: Analyzing Waveforms from Indentation Tests



LCO 10SOC Cell 2 Pre-ISC



LCO 10SOC Cell 2 Post-ISC

- Very few gas emissions pre-ISC for mechanical indentation; more during and post-ISC

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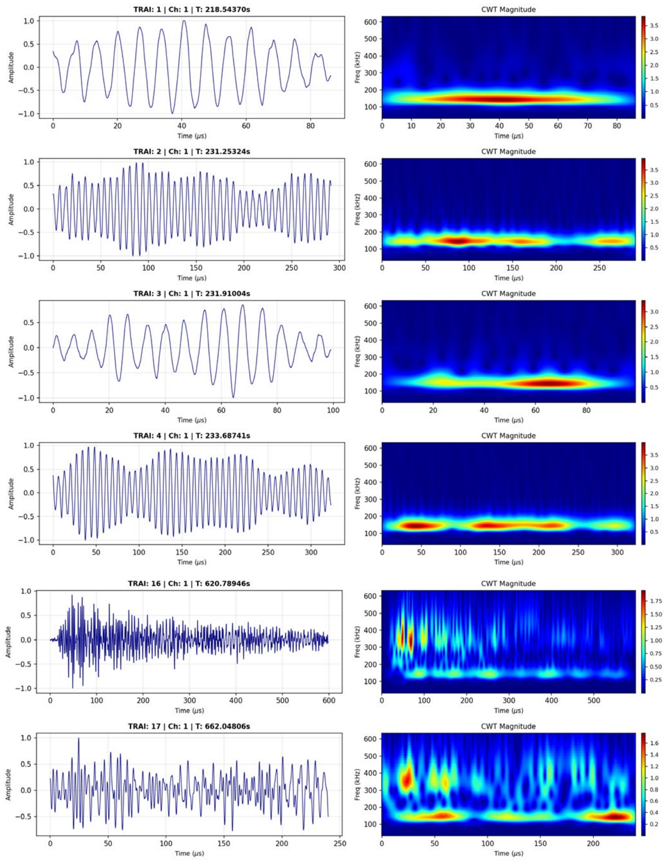
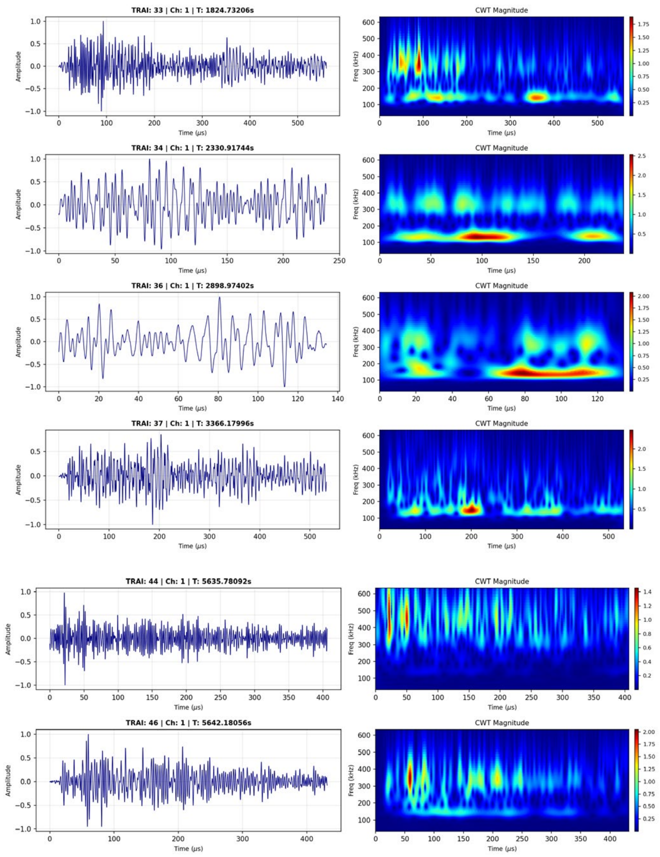
Analyzing Waveforms from Overheating Tests



LCO 20SOC Cell 1 Pre-V drop



LCO 20SOC Cell 1 Post-V drop

- Qualitatively, seems like we are getting both gas emissions and fracture pre and post voltage drop/ISC in overheating tests

Possible AE Signal Sources: cell thermal expansion and heater, fixture expansion

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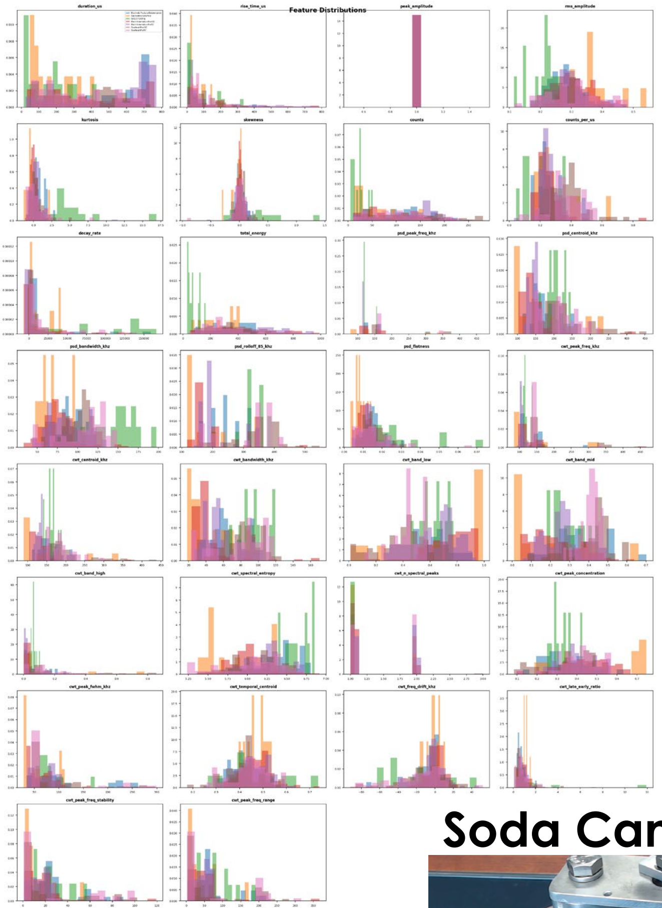
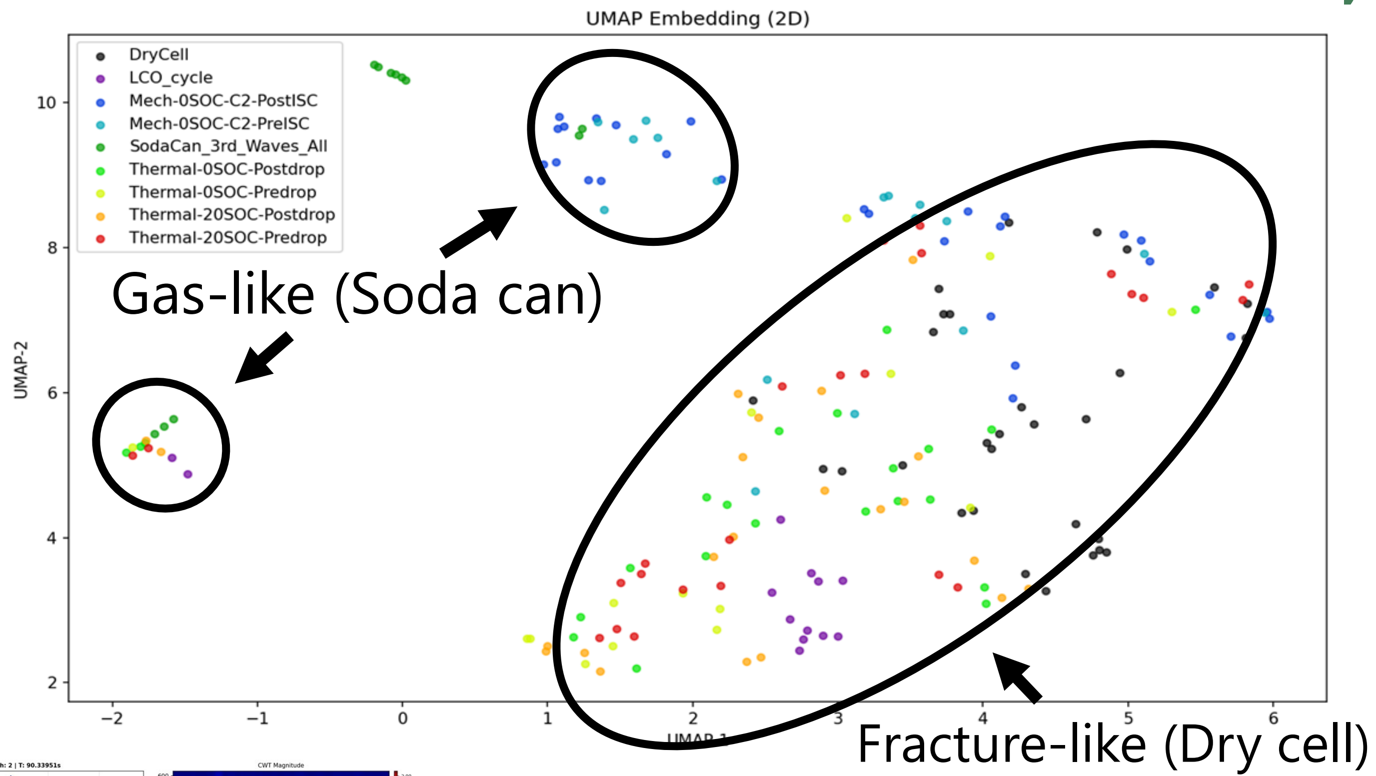
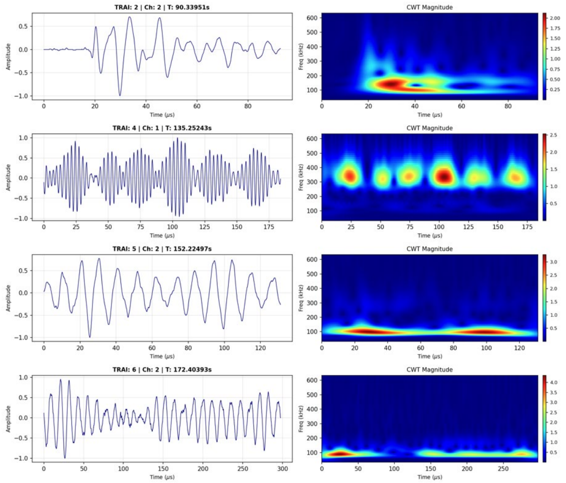
Visualization (Feature Distributions and PCA/UMAP)



AE Signal Classification



Soda Can Test



<u>AE Signal Processing and Dataset Training:</u>

- **Dry cell test**
- **Background noise collection**
- **Charging and discharging**
- **Soda can test**

Conclusion and Impact

- Thermal runaway database needs to stay up-to-date to be relevant
- Continued cells abuse testing and AI/ML tools development are important
- Mechanical indentation and overheating thermal abuse both generate strong acoustic emission signals on gas generation
- Classification of gas generation AE signals will allow early warning of thermal runaway
- Impact: AE signal detection of overheating below 100˚C will prevent thermal runaway

Future Direction/Next Steps

- Continue collaboration with MIT on thermal abuse testing and AE signal processing
- Adding AE signals to existing and future thermal runaway database: Voltage, temperature, load, AE
- Abuse testing of cylindrical cells and large pouch cells
- AE signal recognition to build “safety risk metric” and potential application as thermal runaway early warning in ESS

Acknowledgement

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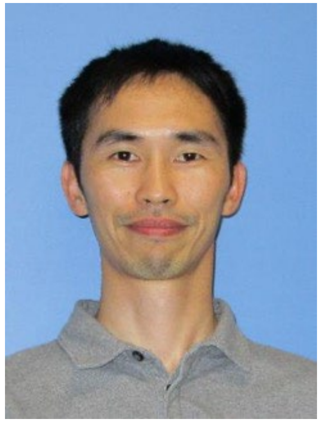

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Collaborators:
MIT: Professor Martin Bazant’s group, Young Ko and Yash Samantaray
DOE Sandia Labs: Loraine Torres-Castro and Team

FY26 Publications

- Lianshan Lin, Kathleen Hartono, Young Ko, Rahul Mallela, Yash Samantaray, Hugo Bouteiller, Martin Z Bazant, Hsin Wang, “Mechanically induced thermal runaway severity analysis of Li-ion batteries and continuous energy release monitoring”, ***Journal of Energy Storage***, Vol. 133 118078, October 2025
- Young Ko; Michael Lu Li; Yash Samantaray; Lianshan Lin; Kathleen Hartono; Rahul Mallela; Hsin Wang; Martin Zdenek Bazant, “Gas-driven short disconnection mitigates thermal runaway in Li-ion batteries under mechanical abuse”, ***Journal of Power Sources***, Volume 688, 240533 (2026)