

Acoustic Emission During Thermal Runaway Induced by Mechanical Indentation and Thermal Abuse

Hsin Wang

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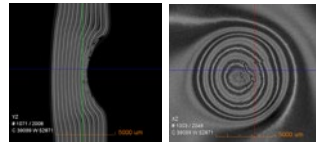
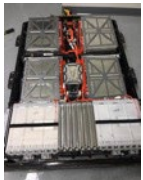
Oak Ridge National Laboratory

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U.S. DEPARTMENT
of ENERGY



Battery Pack

Battery Modules

Battery Cells

XCT: Indented Battery

ORNL Team Members



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Bradon Hopper
RSI student Tennessee Tech



Seokhoon Jang
Postdoc Fellow ORNL



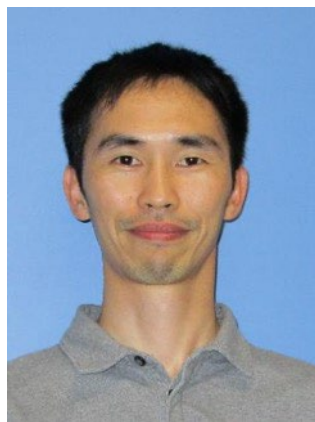
Lianshan Lin
MSTD ORNL
Thermally Sensitive Paint



Beth Armstrong
MSTD ORNL
Coating/Paint Development



Hsin Wang
Material Science & Technology Division
Material Scientist, Testing



Lianshan Lin
Material Science & Technology Division
Mechanical, Database



Hugo Bouteiller
Material Science & Technology Division
UT-OR II Joint Faculty
Material Scientist, Testing



Mali Balasubramanian
Emerging & Solid-State Batteries
Program Manager

Recent History and Project Progression

1998-2000

VTO HTML
User Program
Motorola
USABC

Appliances

- 1/1,000,000 failure chance
- Manufacturing defects, abuse
- Simulate internal short circuit: mechanical, thermal, electrical

2010-2013

GM Chevy VOLT
EREV
FORD Focus EV
DOE VTO
ARPA-E

Electric Vehicles

- Accident due to collision
- Mechanical abuse is real

2016-2020

DOE OE
VTO
ARPA-E

Thermal Runaway
Hazards

Energy Storage

- Stationary system deployment
- Accidents in EV and ESS increased

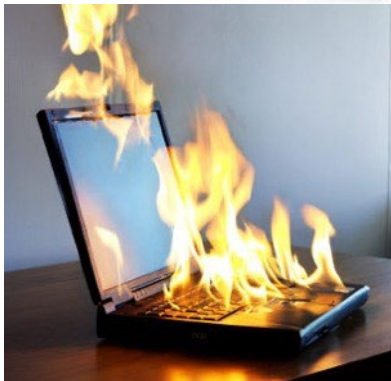
2023 ->

Safety Database
Development

Thermally Sensitive
Coatings

New Challenges

- Hazards vs Safety – data ML/AI
- Early Warning detection and pattern recognition



OE Annual Review Posters: Safety & Reliability

The best approach is: Early Detection of Thermal Runaway Signals

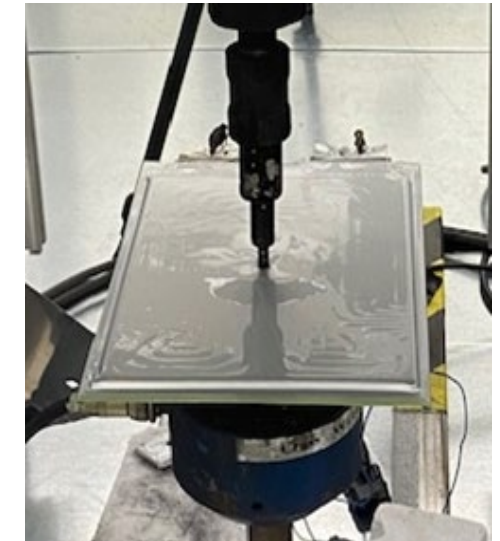
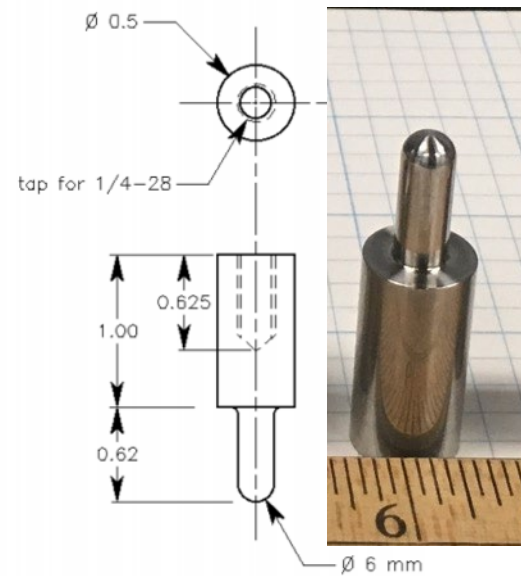
ORNL-Sandia Test Procedures and Standards

Thermal Runaway Testing

- Indentation-induced Internal Short Circuit

ORNL-Sandia Test Protocols:

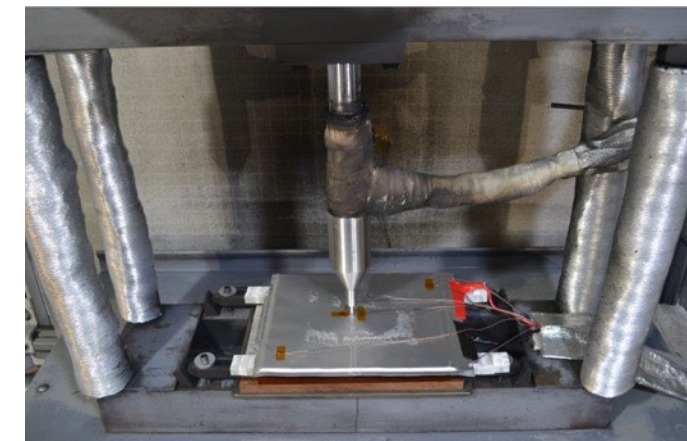
- Cycle cell 4 times at C/2 between 3.0-4.2V to determine SOC and discharge to test SOC
- Hydraulic or servo-motor driven load frame
- 6 mm punch (as-shown in the picture)
- 0.05 inch per minute compressive loading
- 25 mV V_{oc} drop
- Hold the punch after short circuit
- Temperature measurement:
 - 5 mm from the indenter
 - At cell corners when possible



ORNL Test Setup



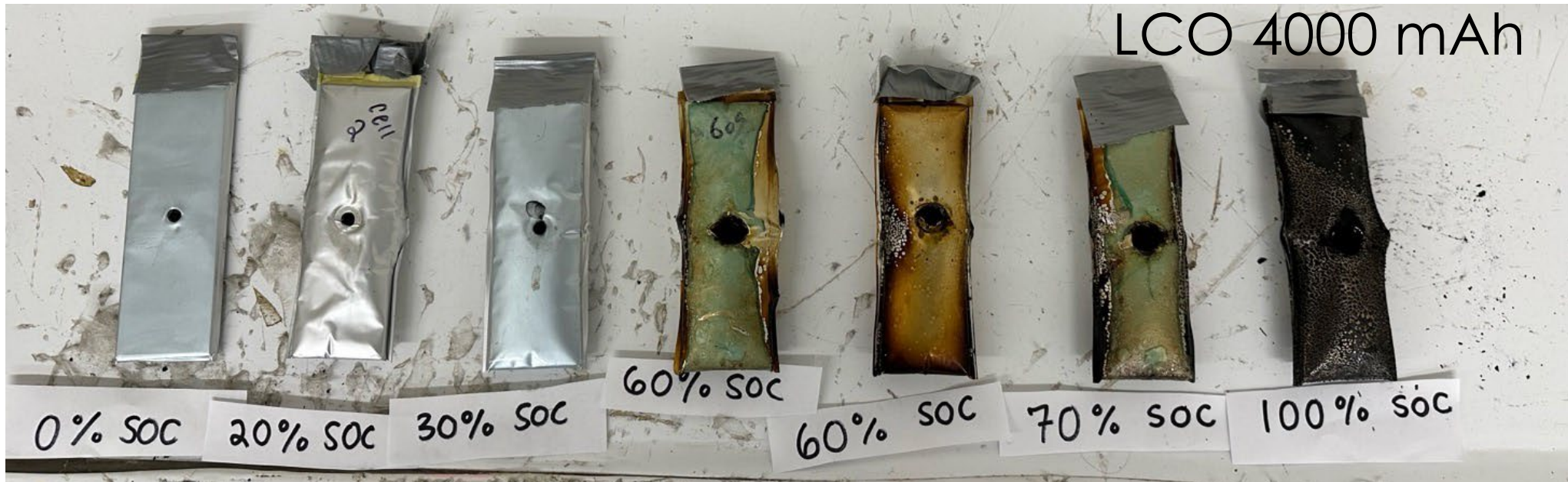
New ORNL Test Chamber



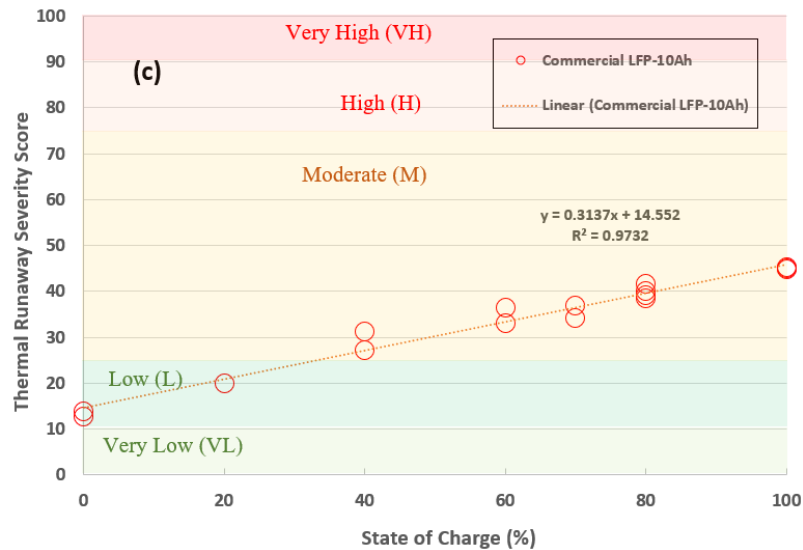
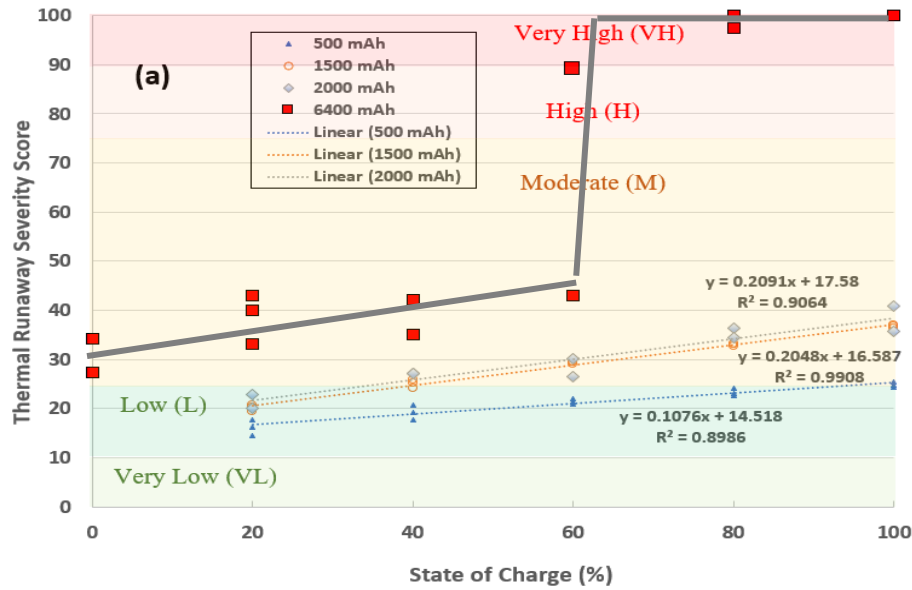
Sandia Labs Test Setup

Mechanical Abuse Thermal Runaway Tests: Visual Inspections

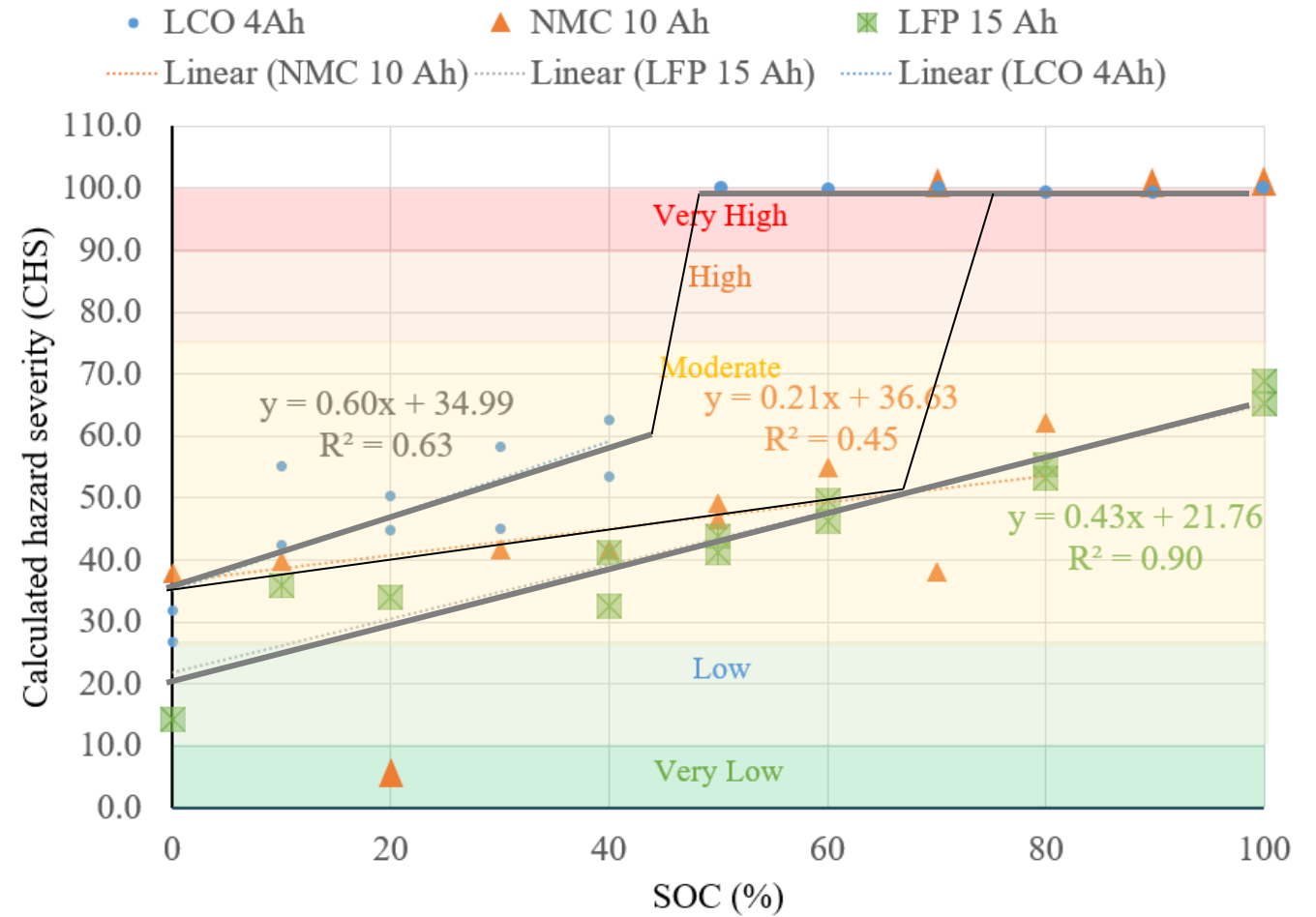
Post Indentation Test



Results: Severity Score Plots and Hazards Ranking/Prediction

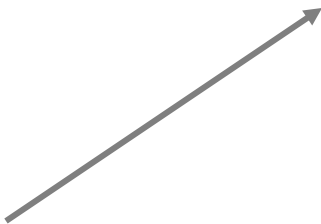


FY2025 New Data

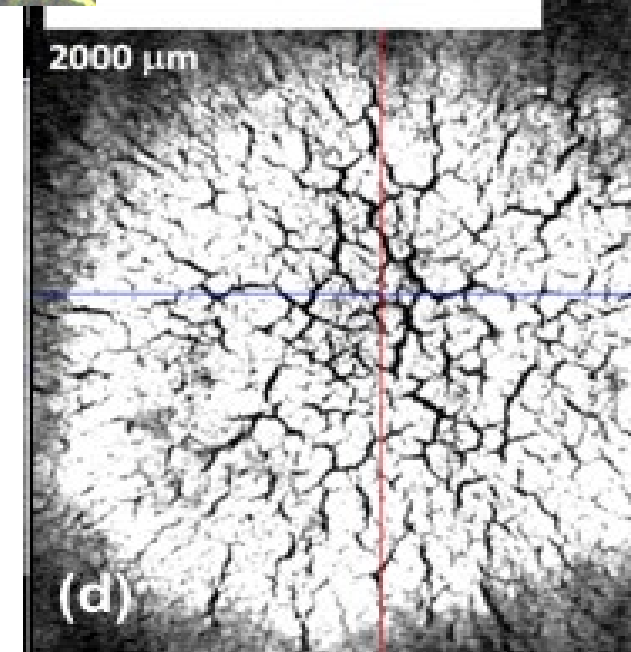
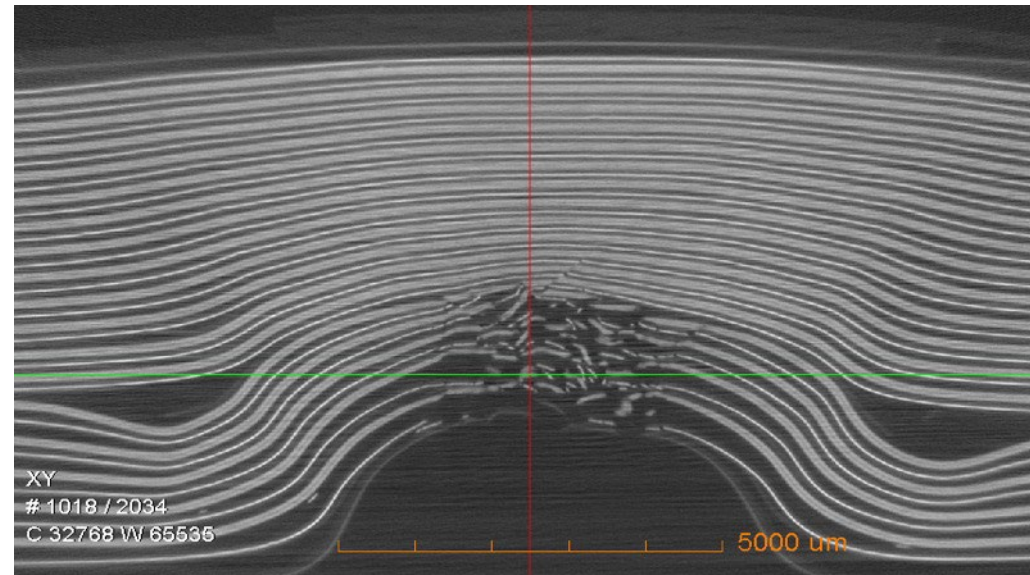
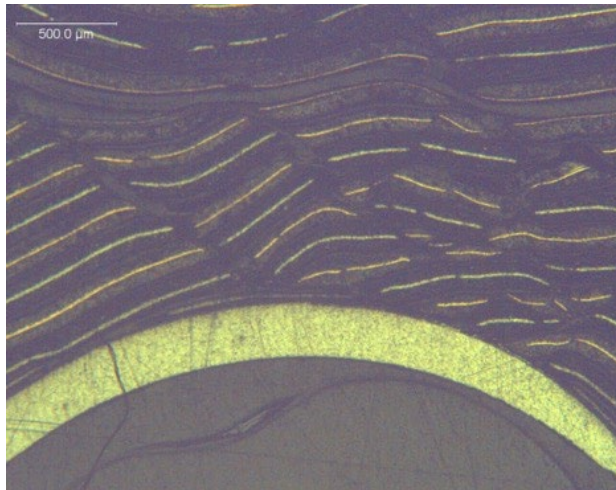
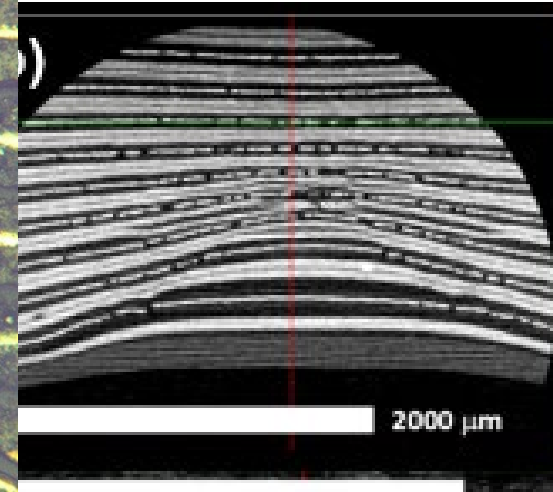
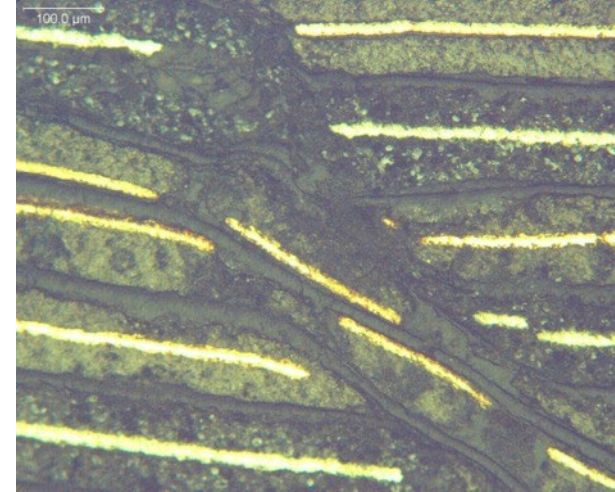


Thermal runaway originates from a localized short circuit

Acoustic Emission (AE) Battery Indentation Test

Listening Devices 

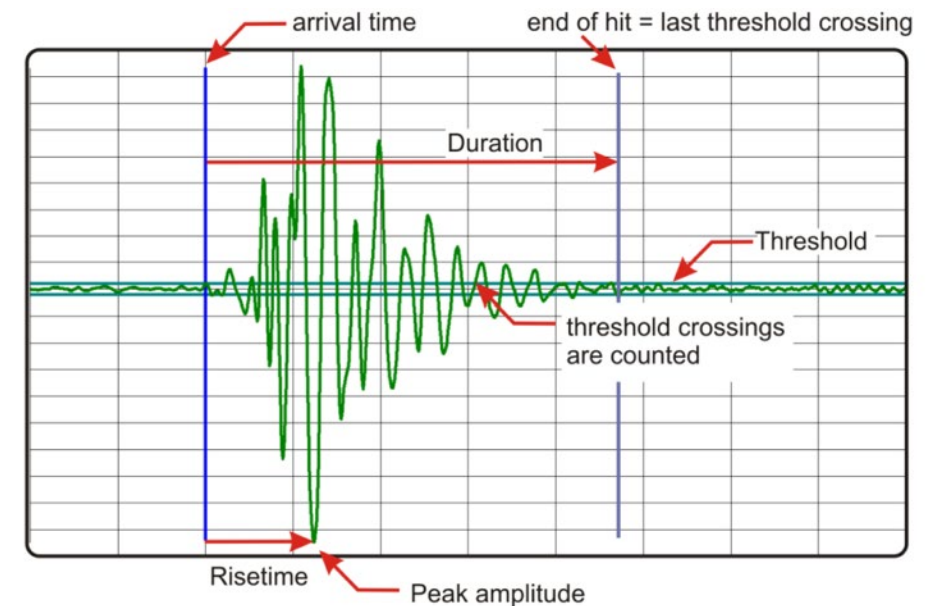
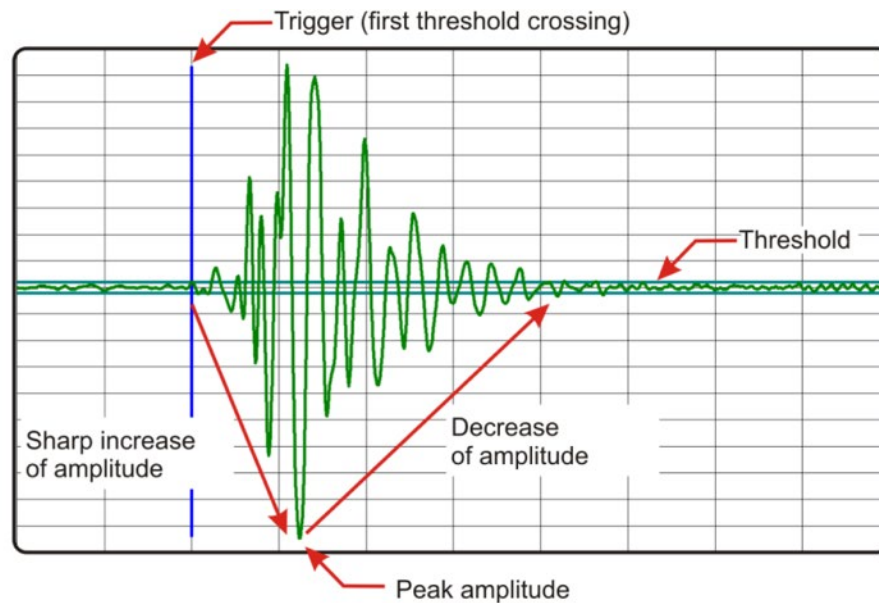
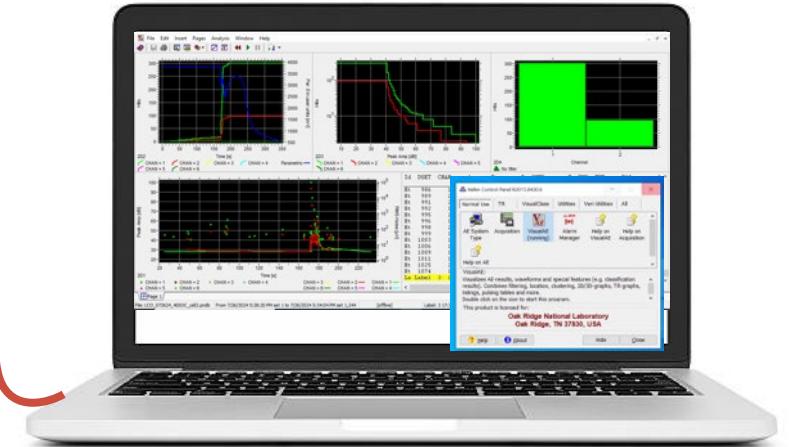
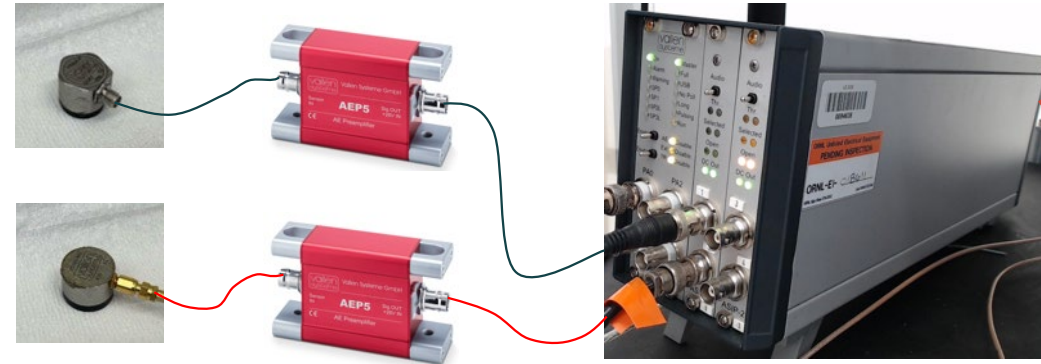
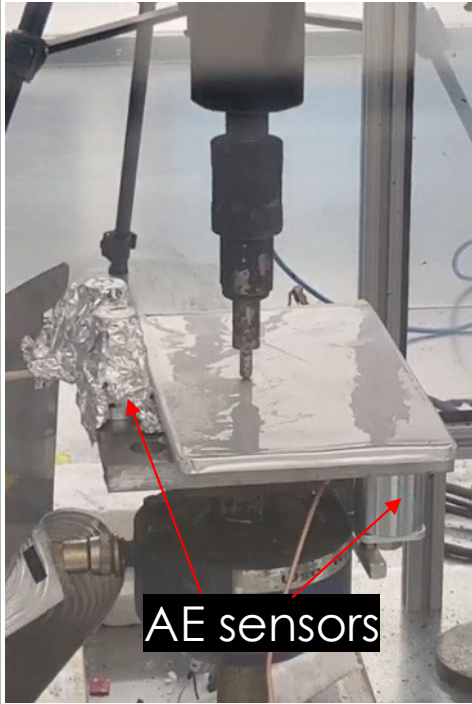
Mechanical Abuse: Deformation and Failure of Layers



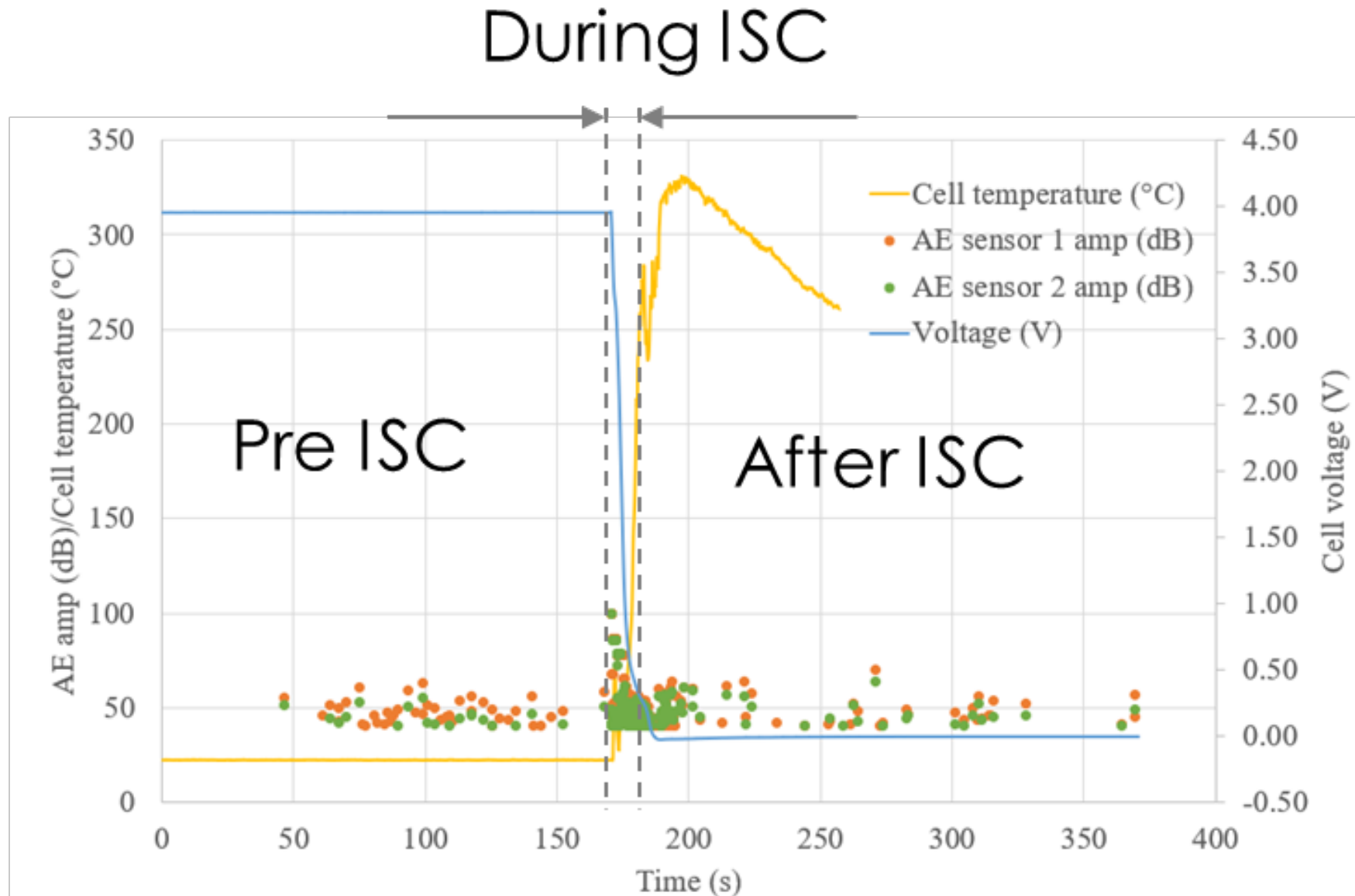
Acoustic Emission to Detect Cell Internal Damage During Indentation Test

Data processing software

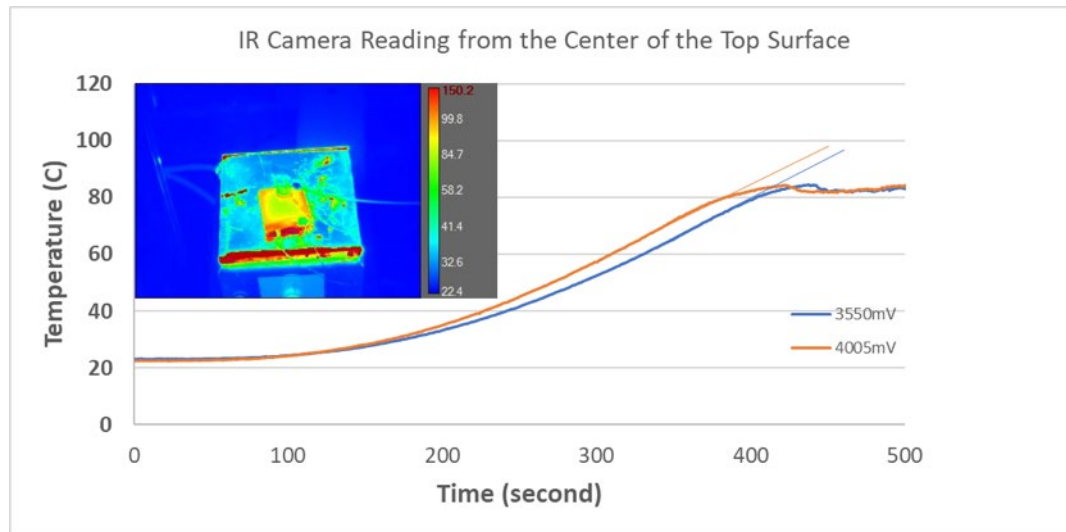
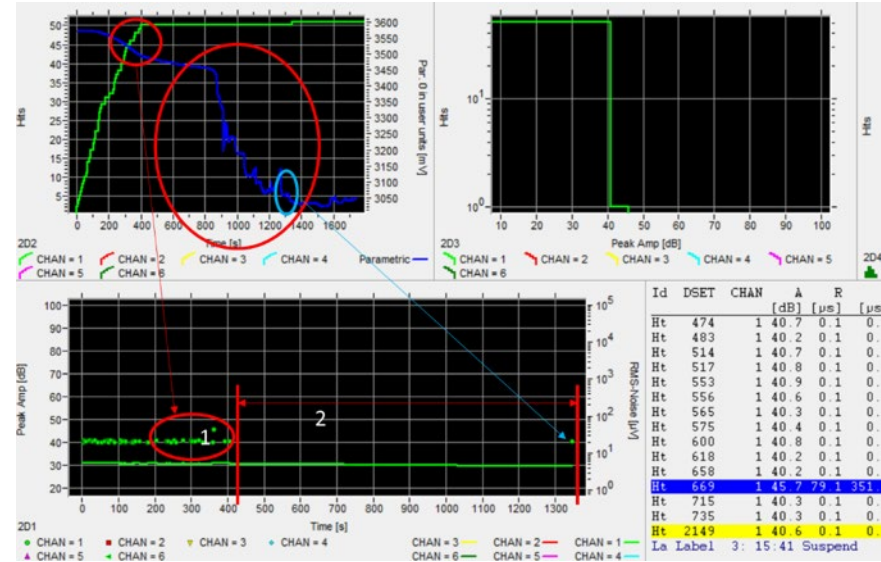
Sensors Preamplifiers Data acquisition unit



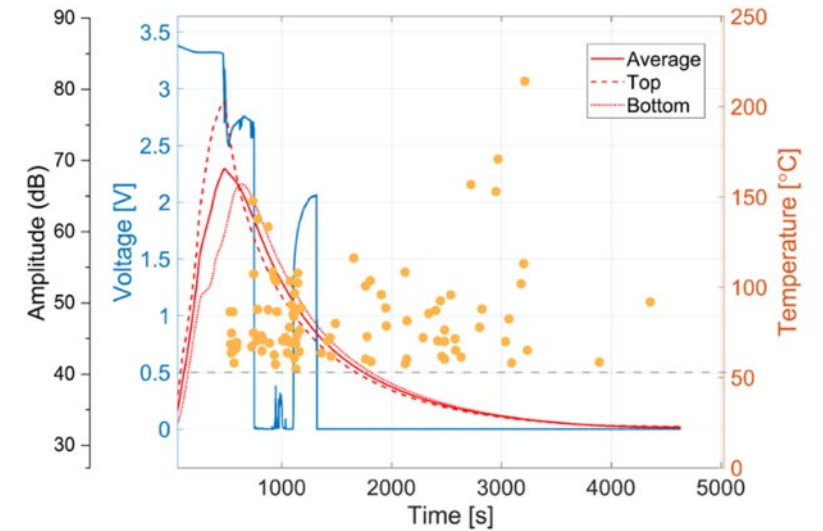
AE Signals During Indentation Tests



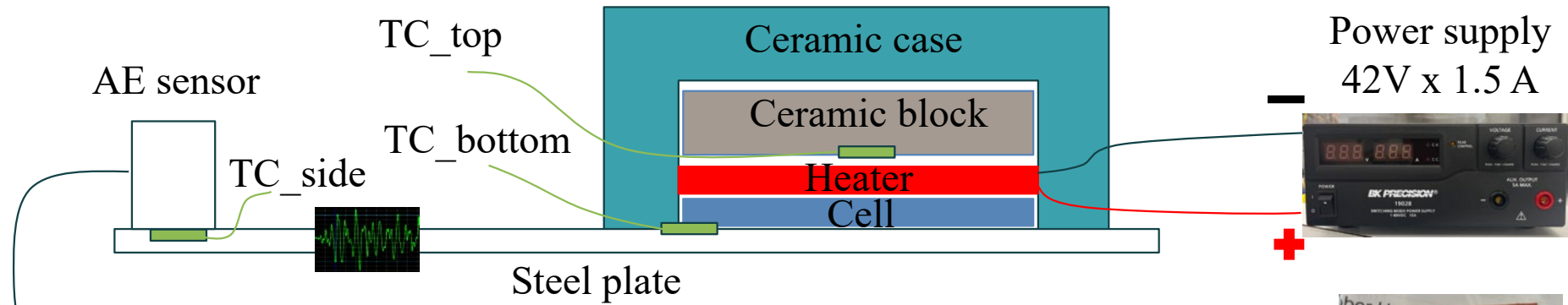
Thermal Runaway in Thermal Abuse Tests - Initial Configuration



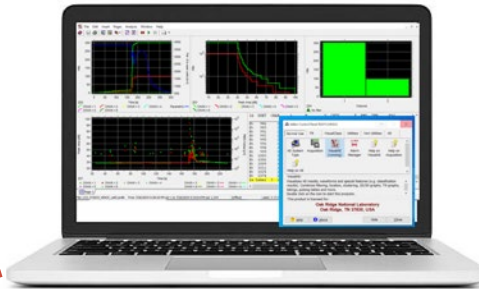
Thermal abuse test – LCO 2Ah 0% SOC



Thermal Abuse Test: Improved Configuration

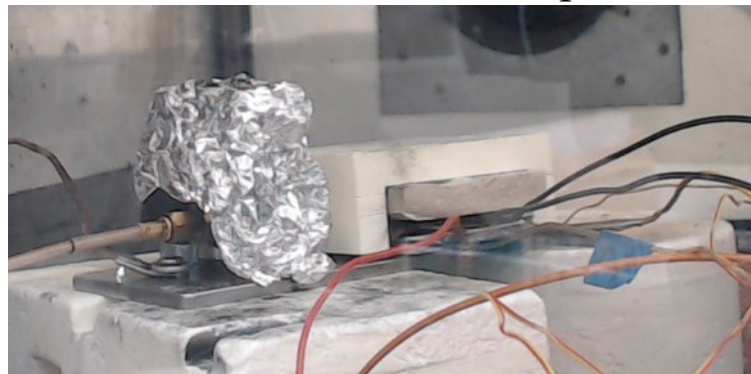


AE acquisition



Heater

Thermal abuse setup

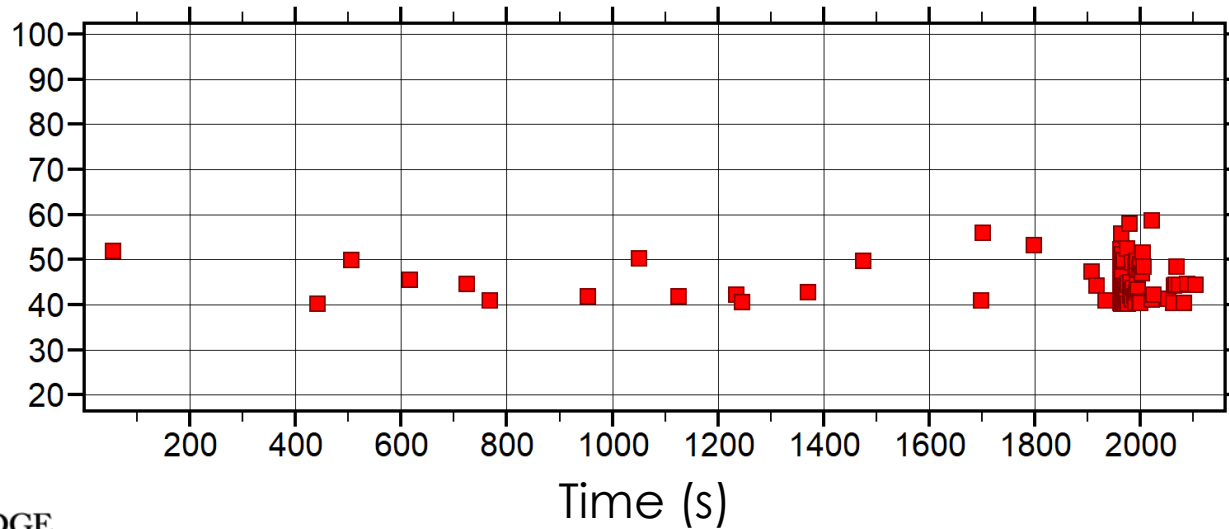
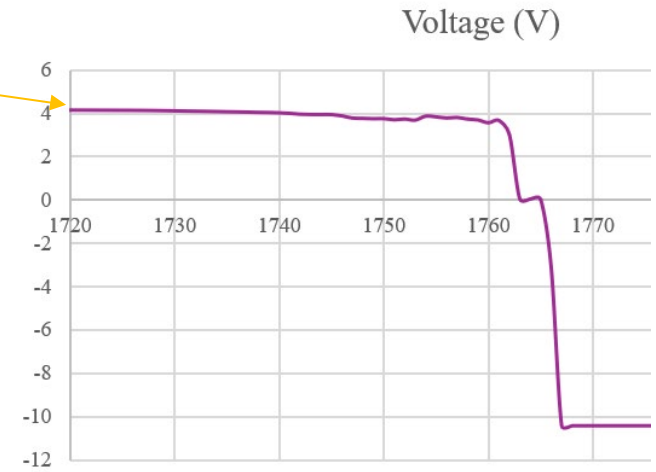
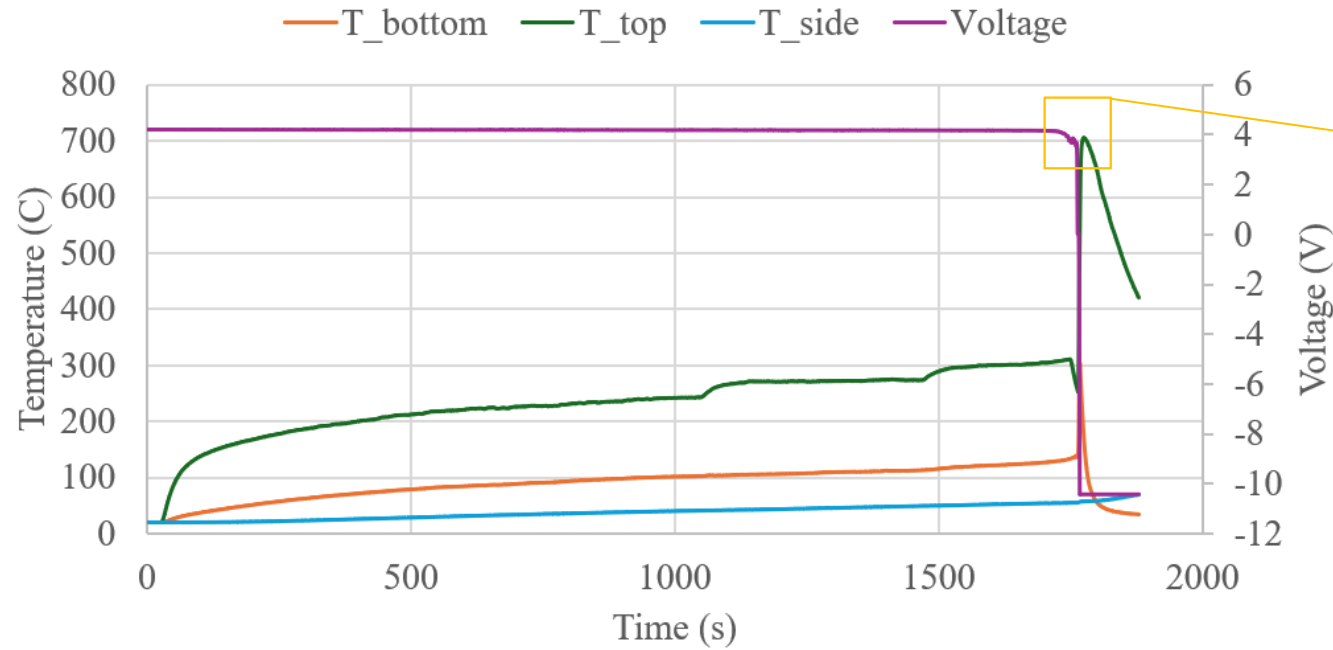


Cell after test

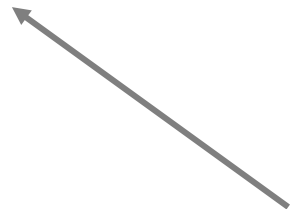


Thermal Runaway in Thermal Abuse Tests - Heater on Cell Top

LCO 2Ah 100% SOC

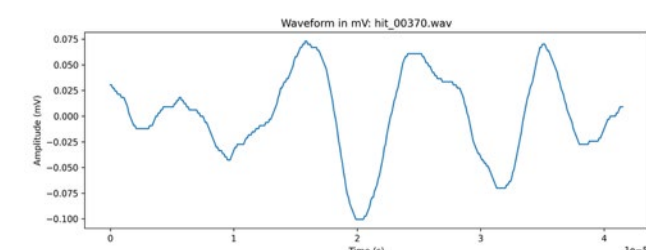
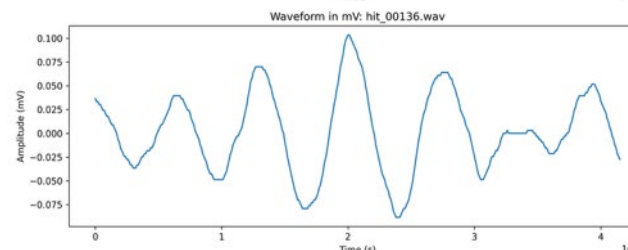
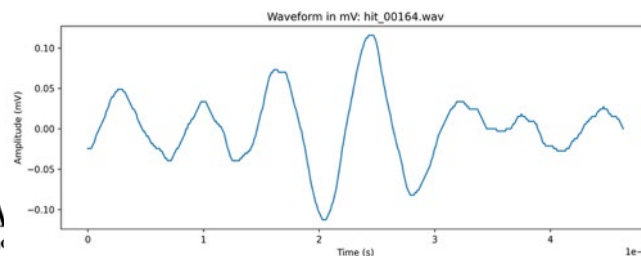
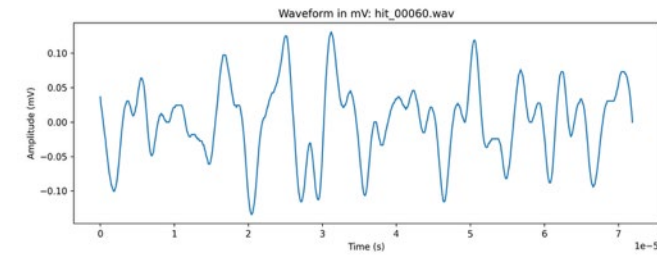
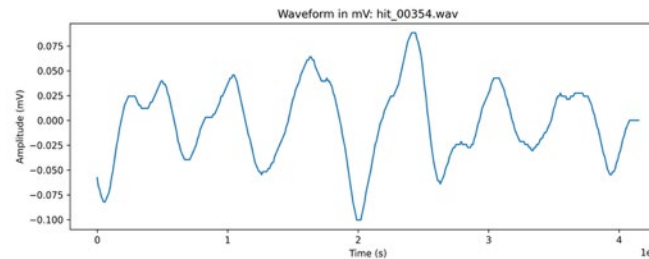
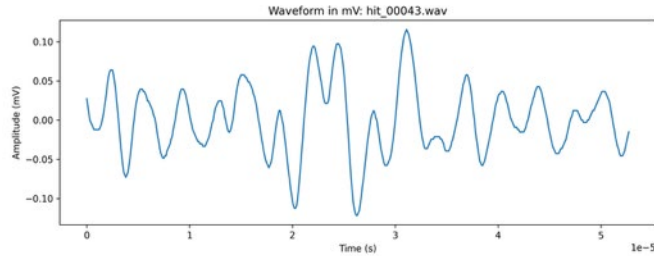
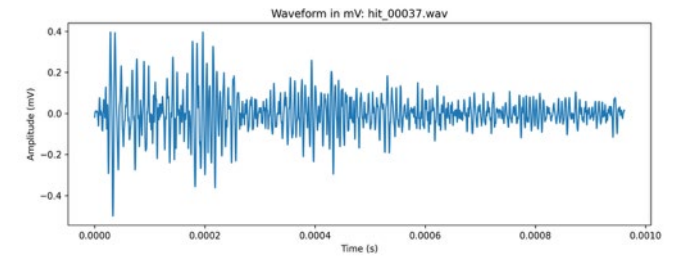
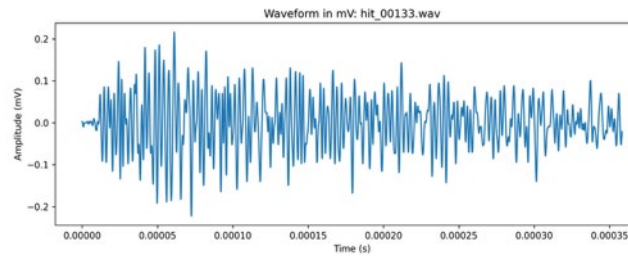
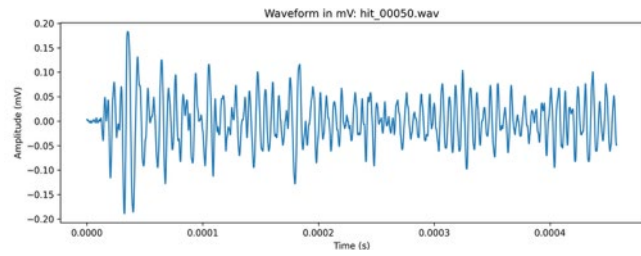
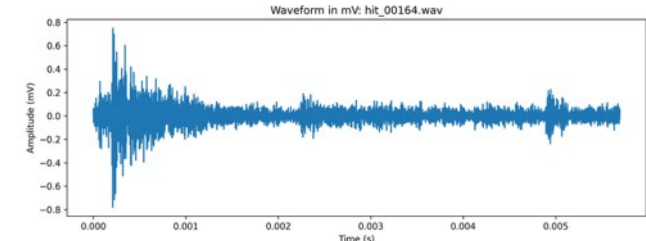
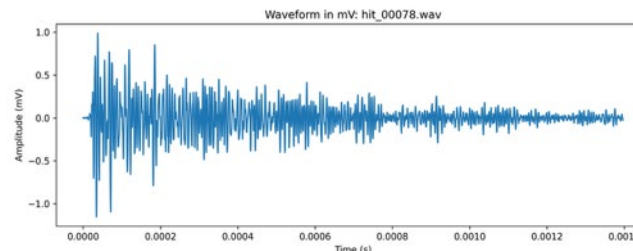
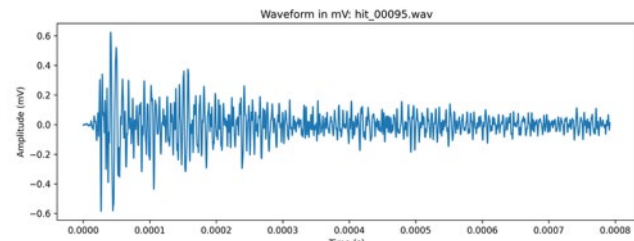
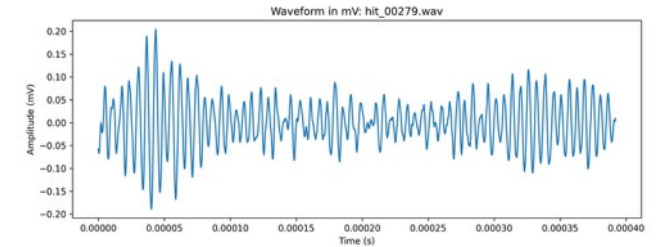
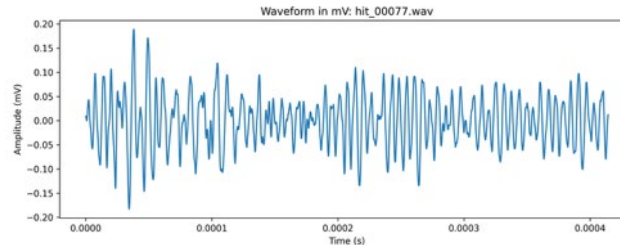
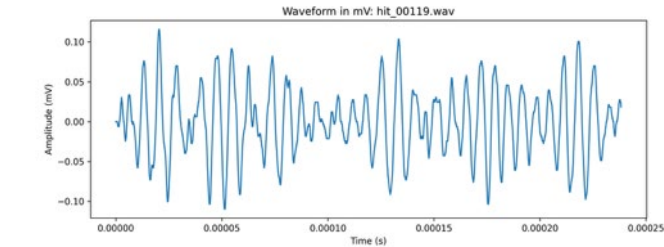


Asymmetric Thermal Abuse Signals



AE signals due to hating and gas generation

AE Waveforms Signatures: Cracking, Gas Generation (Time Domain)



AE Data Analysis, Pattern Recognition (ML and AI)

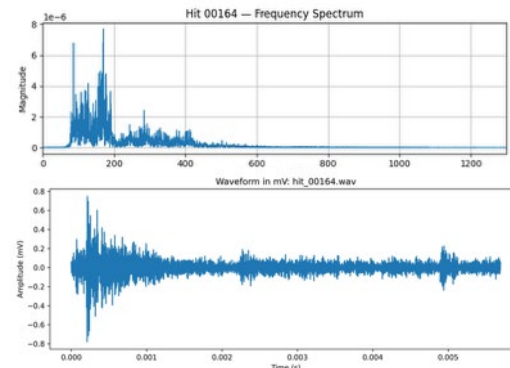
Principal Component Analysis (PCA)

Data visualization and Feature Extraction

Number of AE Features: n

- Spectral bandwidth
- Spectral centroid
- Spectral flatness
- Decay rate
- Rise time/duration ratio
- etc.

Recorded AE events: m

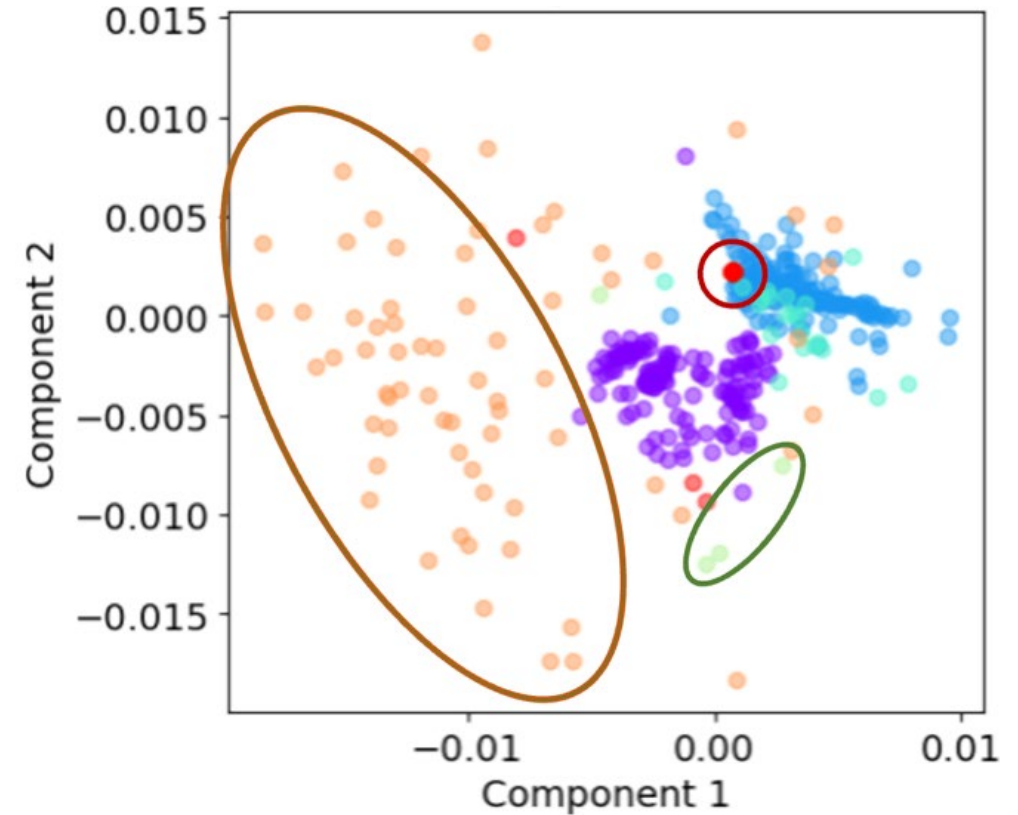
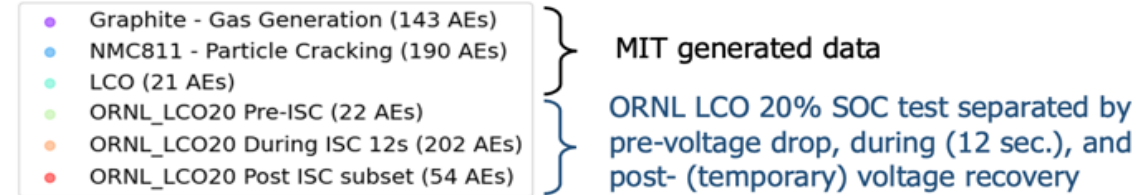


n x 5 Covariant Matrix

PC1 and PC2 are the maximum eigenvalues

Scaling and Normalization

Clustering



In above plot, axes represent a complex mix of frequency and time content. Each point represents one emission – closer points represent more similar waveforms.

Summary and Future Work

- Continue thermal runaway database development: user download and upload, data utilization
- Expanding acoustic emission (AE) testing to cylindrical cells
- Development of AE signal pattern recognition: Gas generation vs Mechanical failure
- Thermal runaway early detection: thermally sensitive paint and gas AE signals below 100°C

Thank You!

Collaborators:

MIT Professor Martin Bazant's group: Young Ko and Yash Samantaray

University of Delaware: Professor Jun Xu

DOE Sandia Labs: Loraine Torres-Castro and Alex Bates

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