

# ASSESSING THE SAFETY OF COMMERCIAL SODIUM-ION 18650 CELLS AT MULTIPLE SCALES

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# Motivation for Na-ion Safety Testing



*Na-ion technology has quickly transitioned to commercial availability with the promise of similar to Li-ion performance characteristics and fabrication requirements, and lower materials cost.*

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## This Presentation:

Comparison of:

- 1.5 Ah Na-ion 18650 cell
- 1.5 Ah Li-ion (NMC) 18650 cell



Na-ion crush test performed at SNL.

# Case Study– Molicel

## *Sufficient Safety Research is Necessary Before Commercialization*



- 1984 – Molicel developed a 2.2 V battery capable of powering laptops and cell phones
  - Utilizing a **Li-metal anode** and an  $\text{MoS}_2$  cathode
- 1988 – Molicel's technology hits market
- 1989 – Cellphone fire in Japan
  - Investigation determines battery as cause
- Result:
  - Physical injury to individual
  - 10,000 cellphones recalled
  - Stock market suspended trading
  - 30% of company laid off
  - Company entered receivership



# Na-ion Grid Installations



<https://cnevpost.com/2024/05/13/china-1st-large-sodium-battery-energy-storage-station-operation/>



<https://www.yicaiglobal.com/news/worlds-largest-sodium-ion-battery-project-starts-operation-in-china>

- Operational May 11, 2024
- 10 MWh
- Nanning, Guangxi, China
- China Southern Power Grid

- Second Phase
- 100 MWh



18650  
DESTRUCTIVE  
TESTING

# Na-ion Material Composition



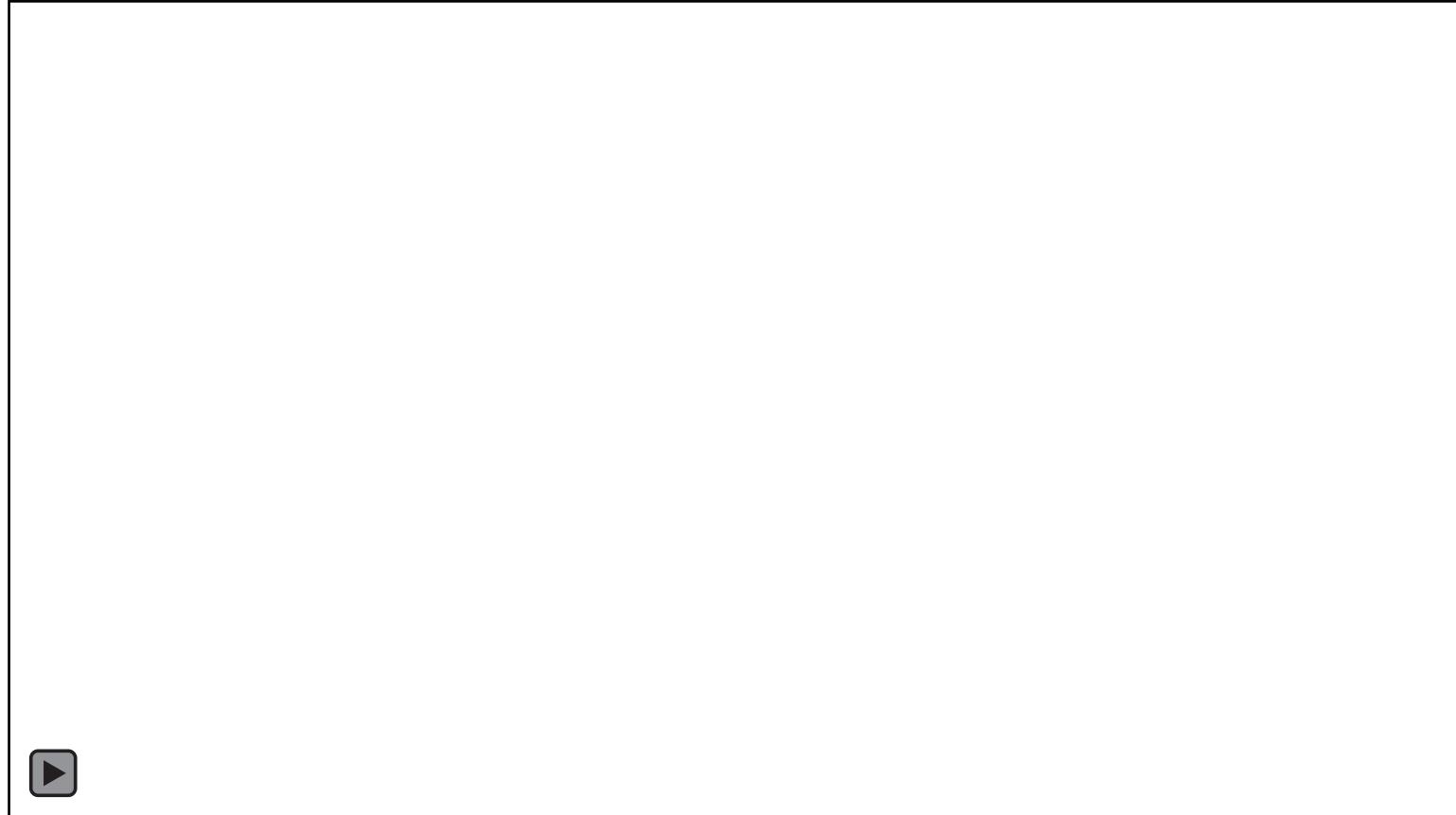
## Na-ion 18650 cells purchased commercially

Specification	Value	Notes
Rated Capacity	1.5 Ah	123 Wh/kg (including case)
Experimental Capacity	1.43 Ah	1.5 to 4.1 V, C/5 rate, C/20 taper charge
Cathode	$\text{Na}_{2.5}\text{Ni}_1\text{Mn}_1\text{Fe}_1\text{O}_2$	ICP-MS
Anode	Hard Carbon	XRD
Electrolyte – Salt	$\text{NaPF}_6$	Assumed based on ICP-MS
Electrolyte – Solvent	46% PC, 21% EC, 14% EMC, 13% DMC	Area% from GCMS



Company	Cathode	Anode	Electrolyte
Natron Energy (US)	Prussian Blue Analog	Prussian Blue Analog	Aqueous
Novasis (US)	Prussian Blue Analog	Hard Carbon	Organic
Faradion (UK)	Layered Oxide	Hard Carbon	Organic
CATL (China)	Prussian Blue Analog	Hard Carbon	Organic
TIAMAT (France)	NVPF	Hard Carbon	Organic
Rechargion (India)	Olivine	Hard Carbon	Organic

# Nail Penetration, Na-ion Cell Close-up Video

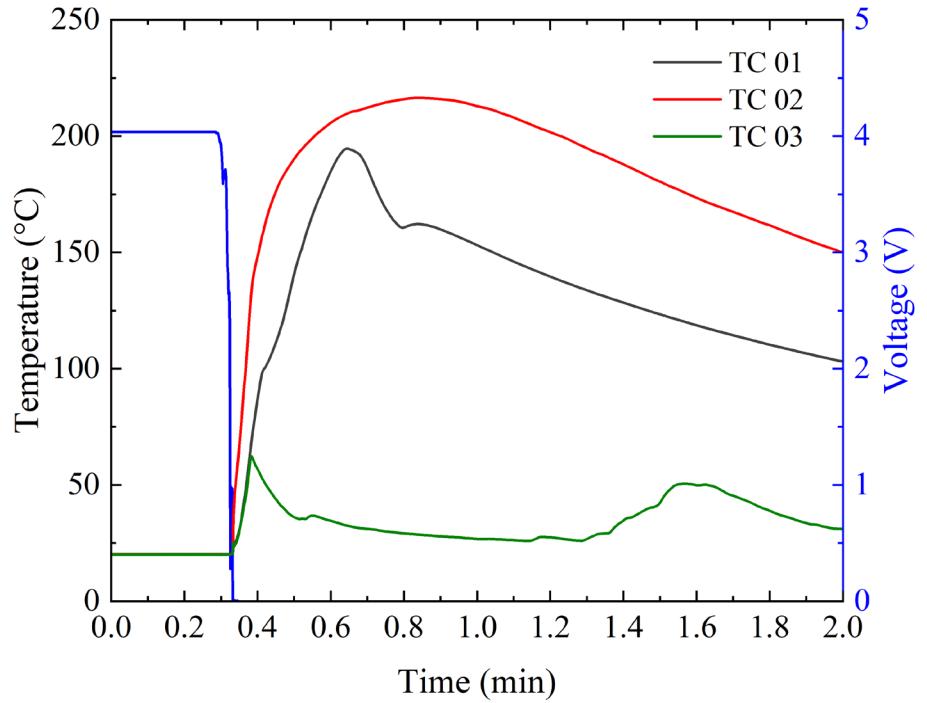


# Nail Penetration – Horizontal Orientation

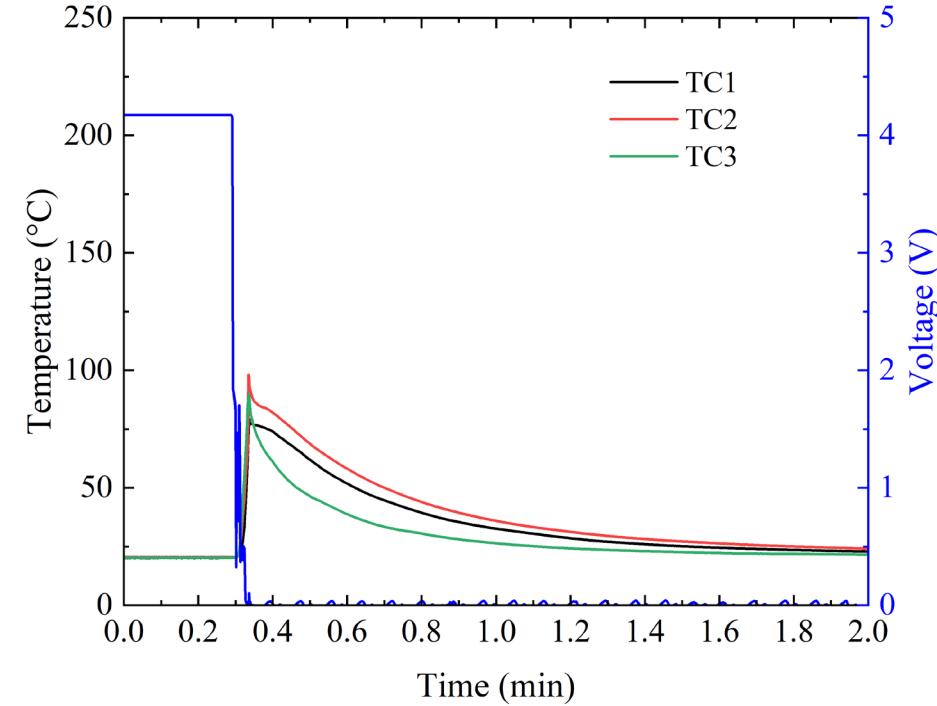
## 100% SOC, 3 mm sharp nail, 2 mm/s



Na-ion



Li-ion



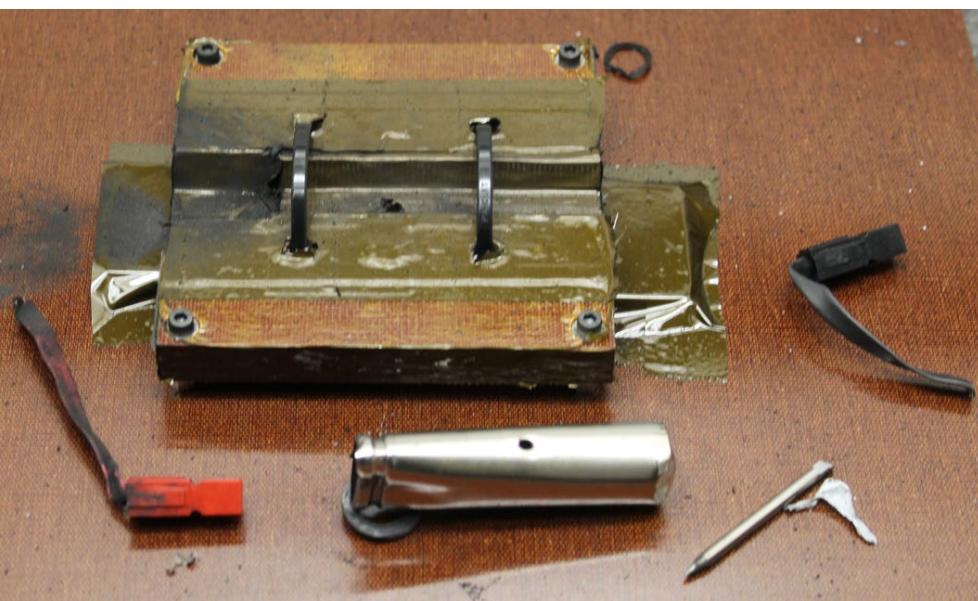
- Max temperature: 216.5 °C
- Nail penetration depth at voltage drop: 1.86 mm
- Venting, smoke, sparks, **violent pressure release**

- Max temp: 98.1 °C
- Nail penetration depth at voltage drop: 1.84 mm
- No observable features

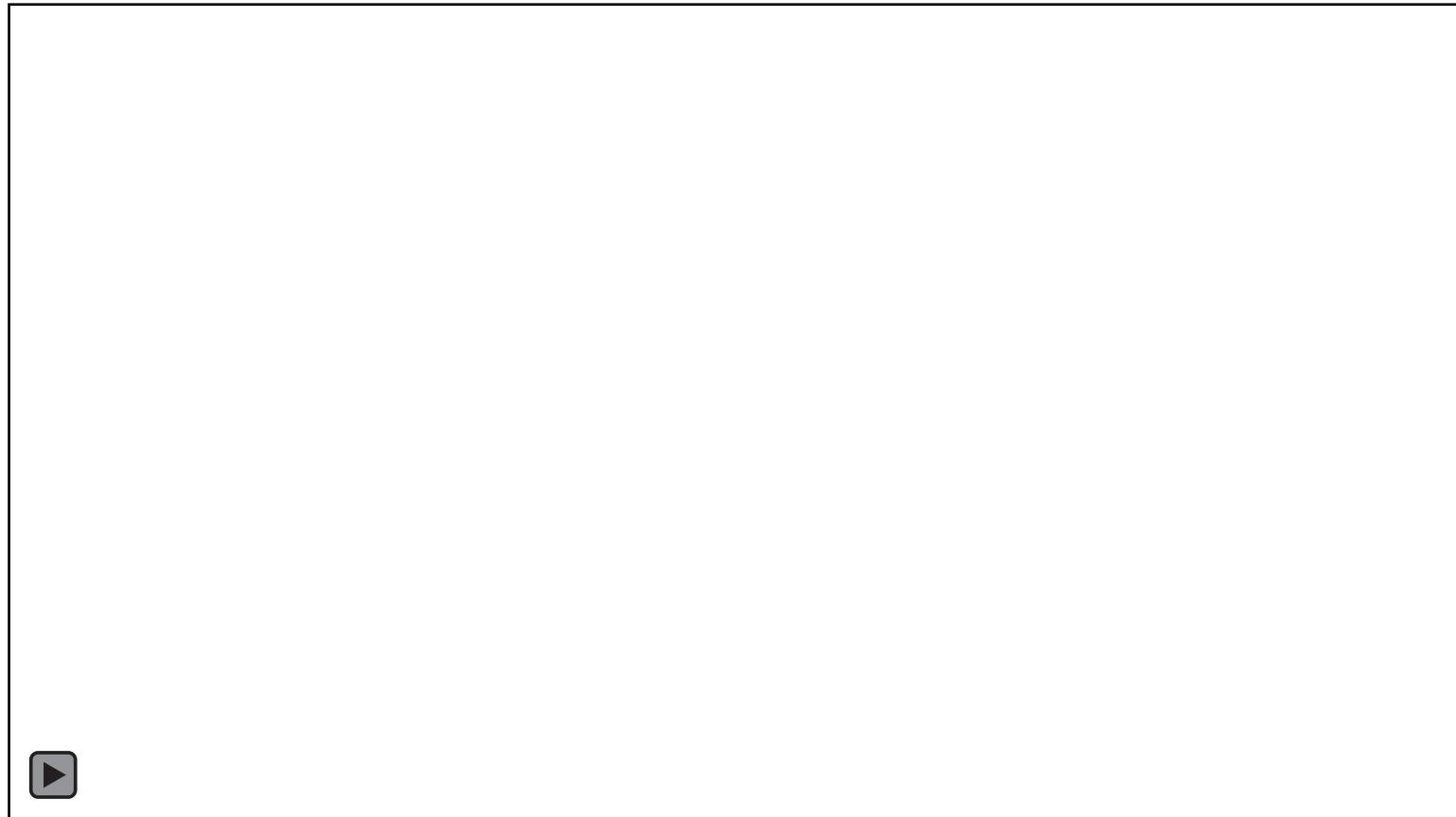
# Nail Penetration, Na-ion Cell Wide-angle Video



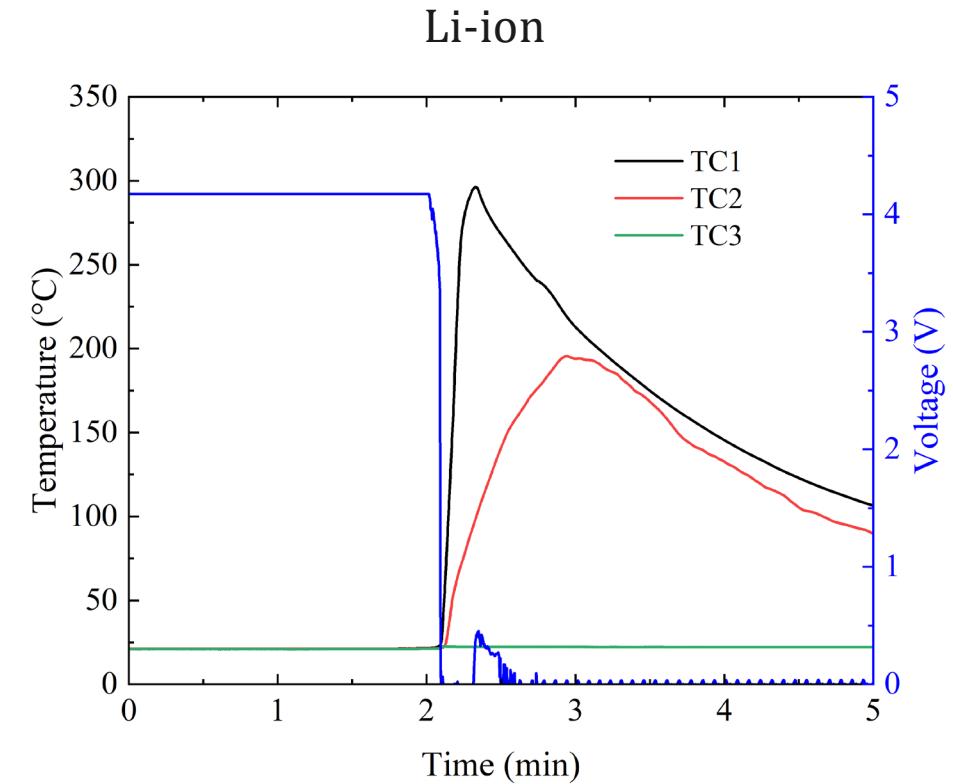
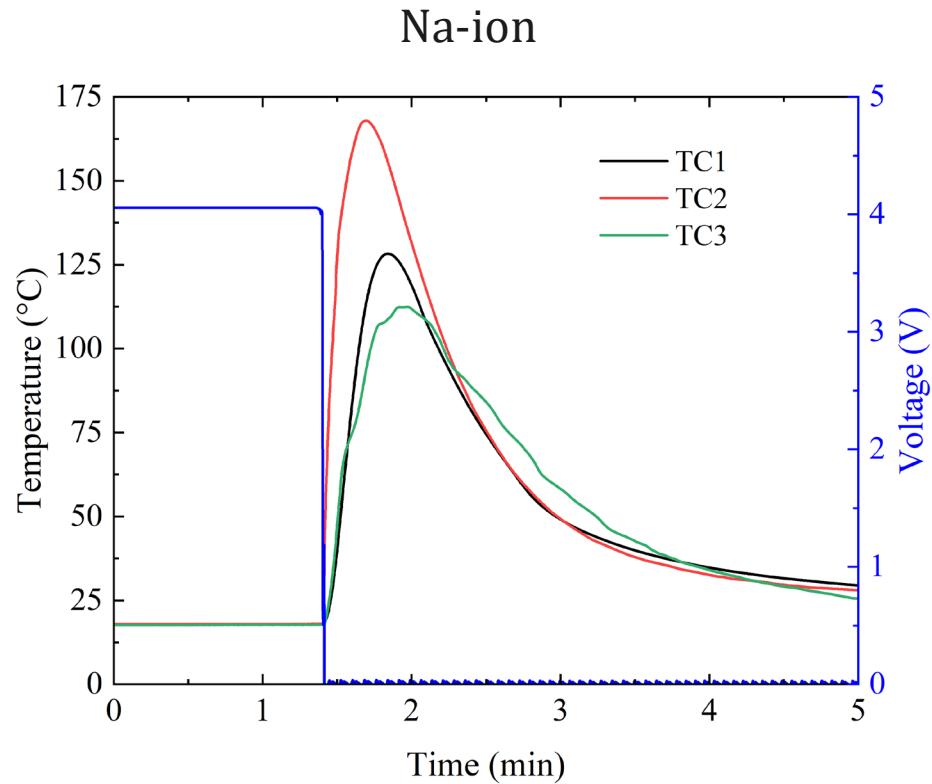
# Nail Penetration, Na-ion Cell Post-test Images



# Mechanical Crush, Na-ion Cell



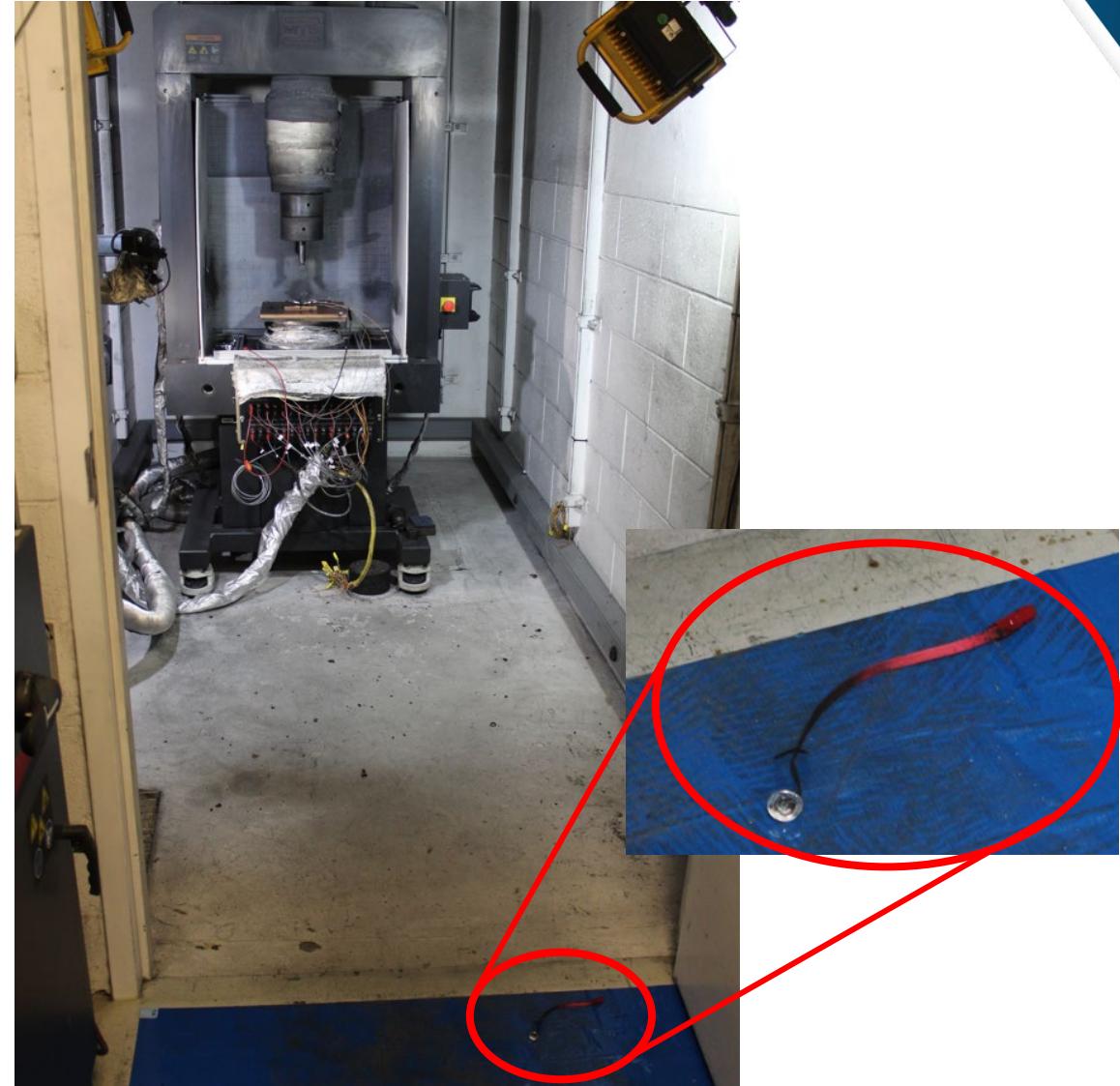
# Mechanical Crush 100% SOC, Hammer Implement, 0.1 mm/s



- Max temp: 167.9  $^{\circ}\text{C}$
- Crush depth at voltage drop: 6.46 mm
- Vent, smoke, sparks, lid pop, flame

- Max temp: 296.3  $^{\circ}\text{C}$
- Crush depth at voltage drop: 9.61 mm
- Vent, smoke, sparks, lid pop

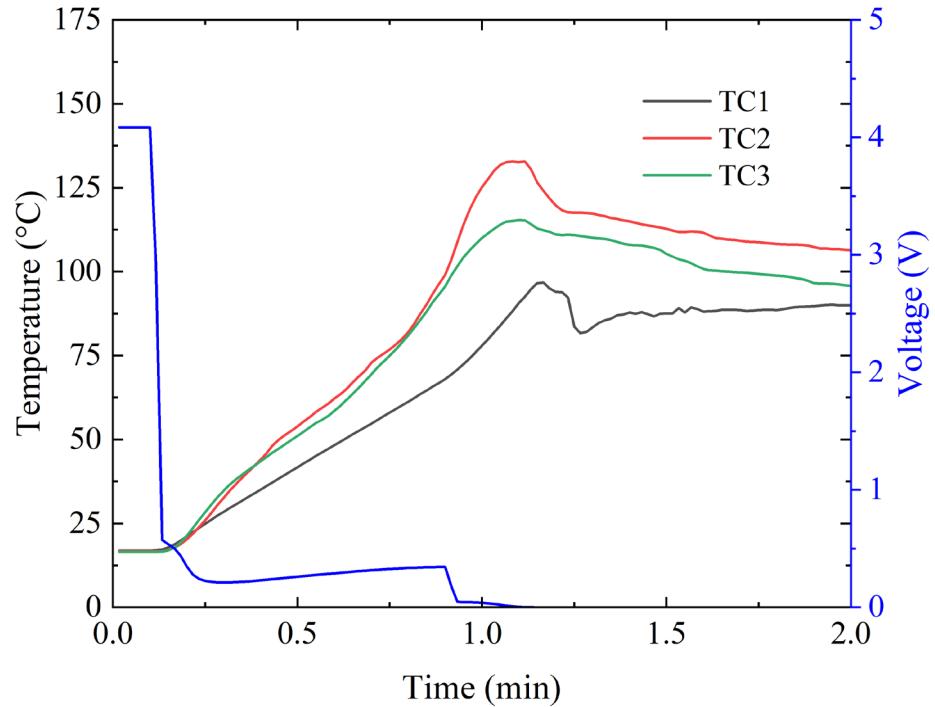
# Mechanical Crush, Na-ion Cell Post-test Images



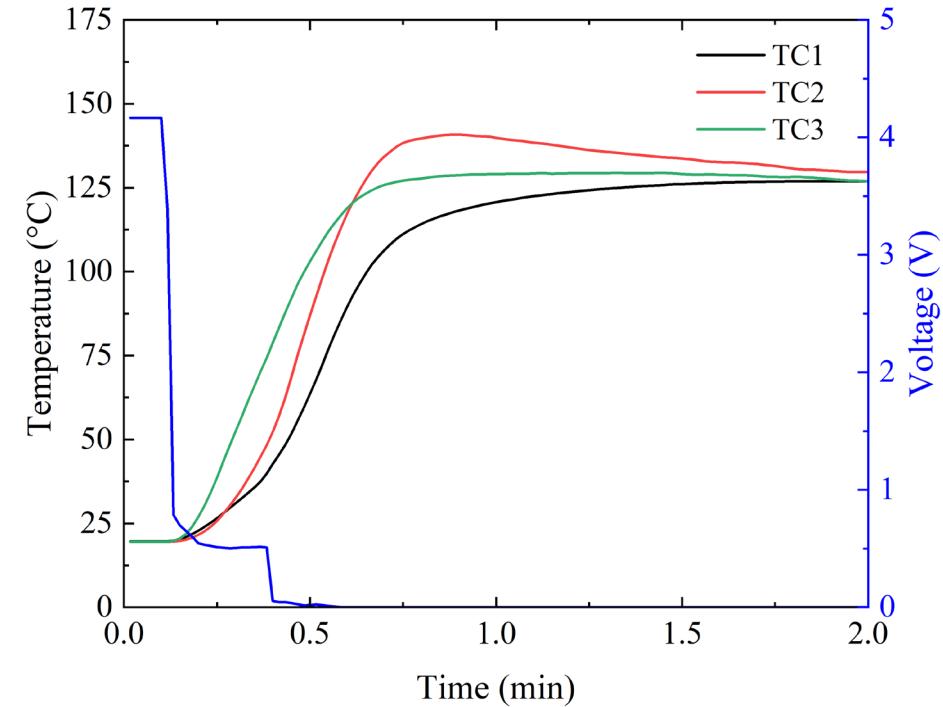
# External Short Circuit 100% SOC, 10 mΩ resistor



Na-ion



Li-ion



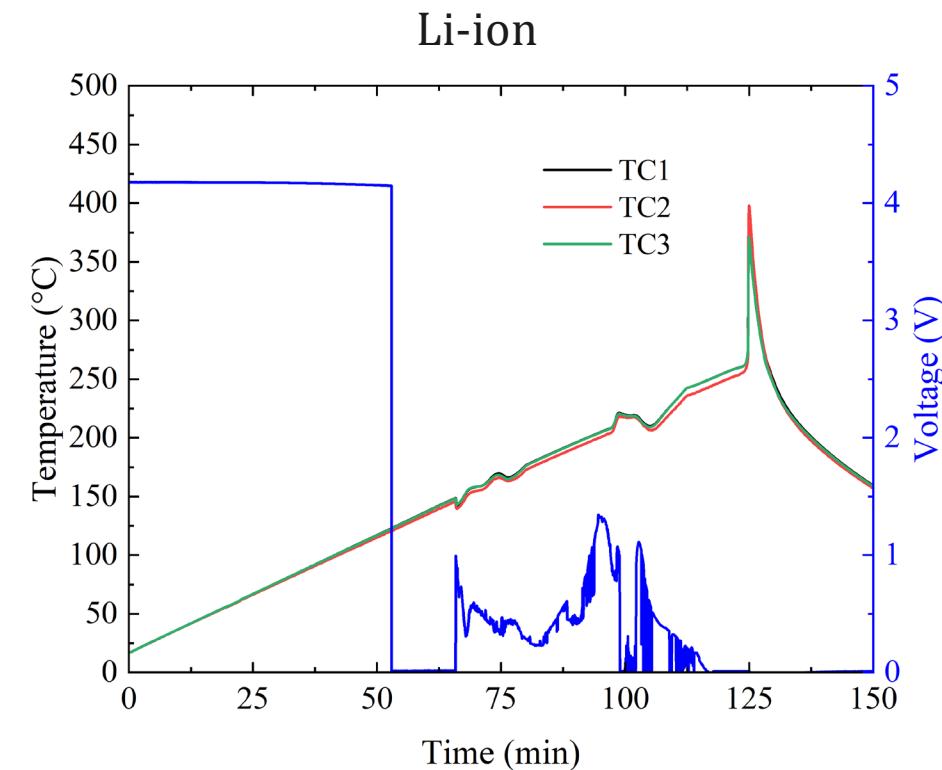
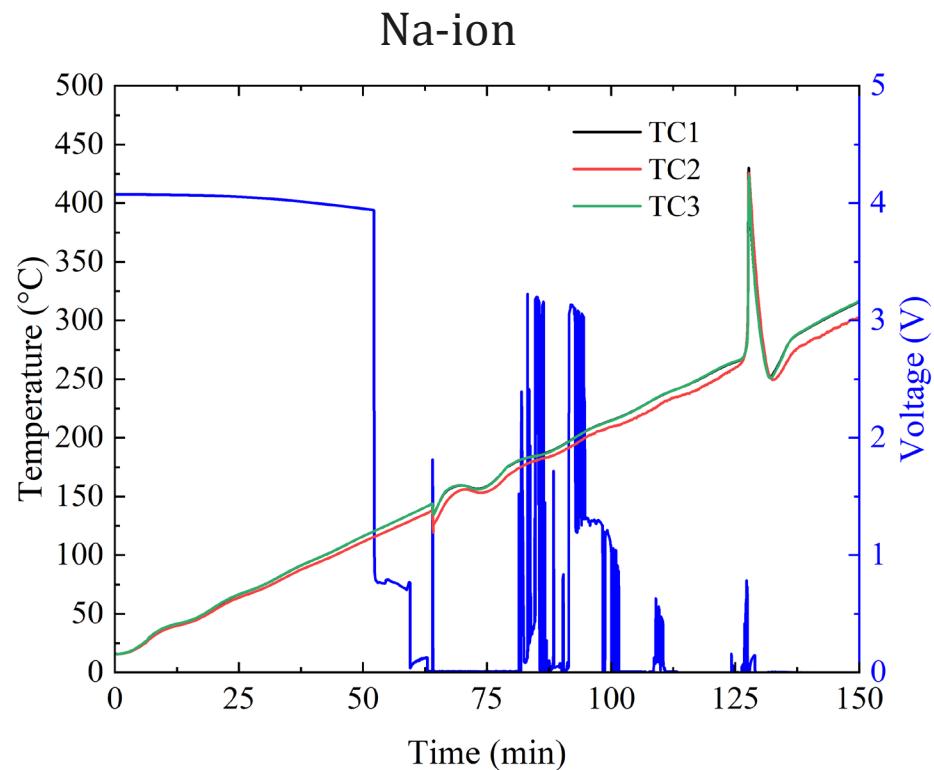
- Max temp: 132.8 °C
- Smoke, vent, electrolyte leak, swelling
- Discharge 159% more capacity than Li-ion

- Max temp: 140.8 °C
- Swelling

# External Short Circuit, Na-ion



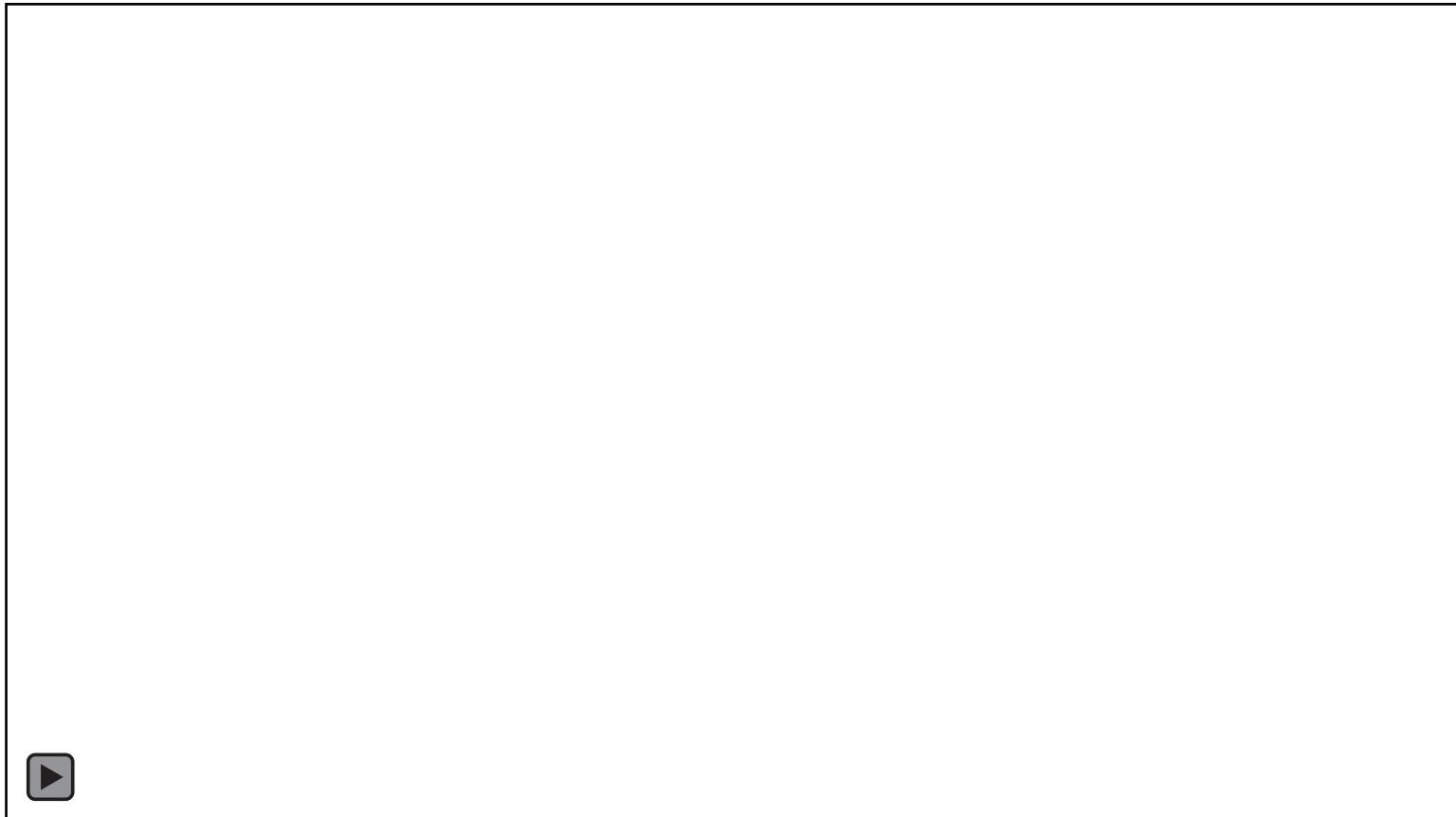
# Thermal Ramp 100% SOC, 2 °C/min, 500 °C or Failure



- Max temp: 430.1 °C
- Voltage drop: 120.4 °C
- Vent: 143.9 °C
- Thermal runaway (>10 °C/min): 271.1 °C
- Vent, electrolyte leak

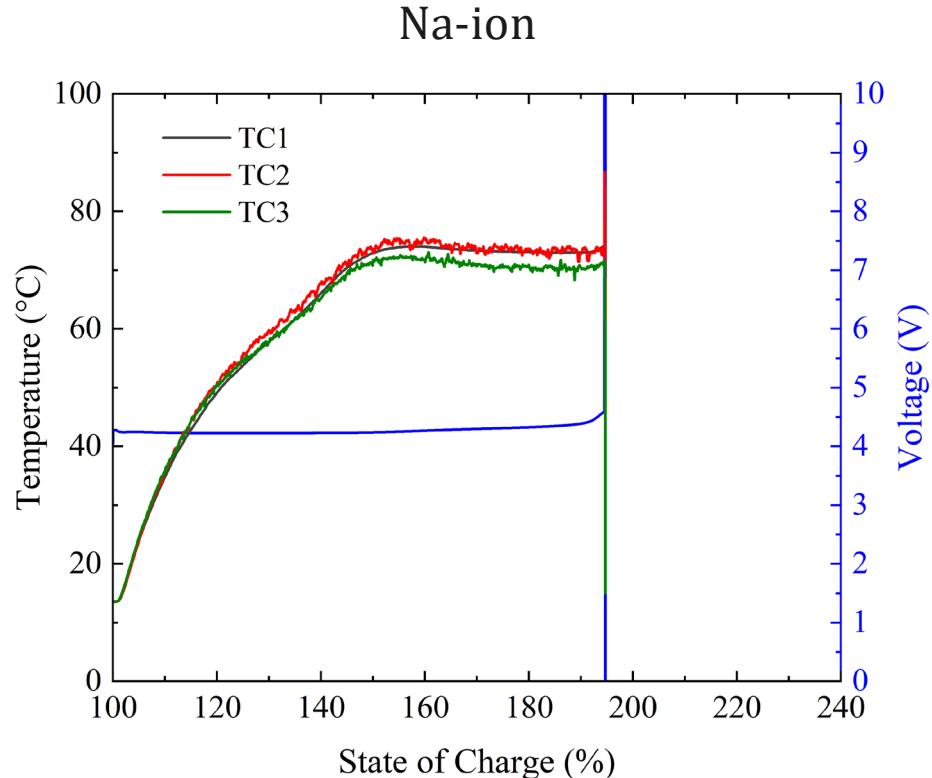
- Max temp: 398.1 °C
- Voltage drop: 122.2 °C
- Vent: 148.4 °C
- Thermal runaway (>10 °C/min): 269.1 °C
- Vent, electrolyte leak

# Thermal Ramp, Na-ion

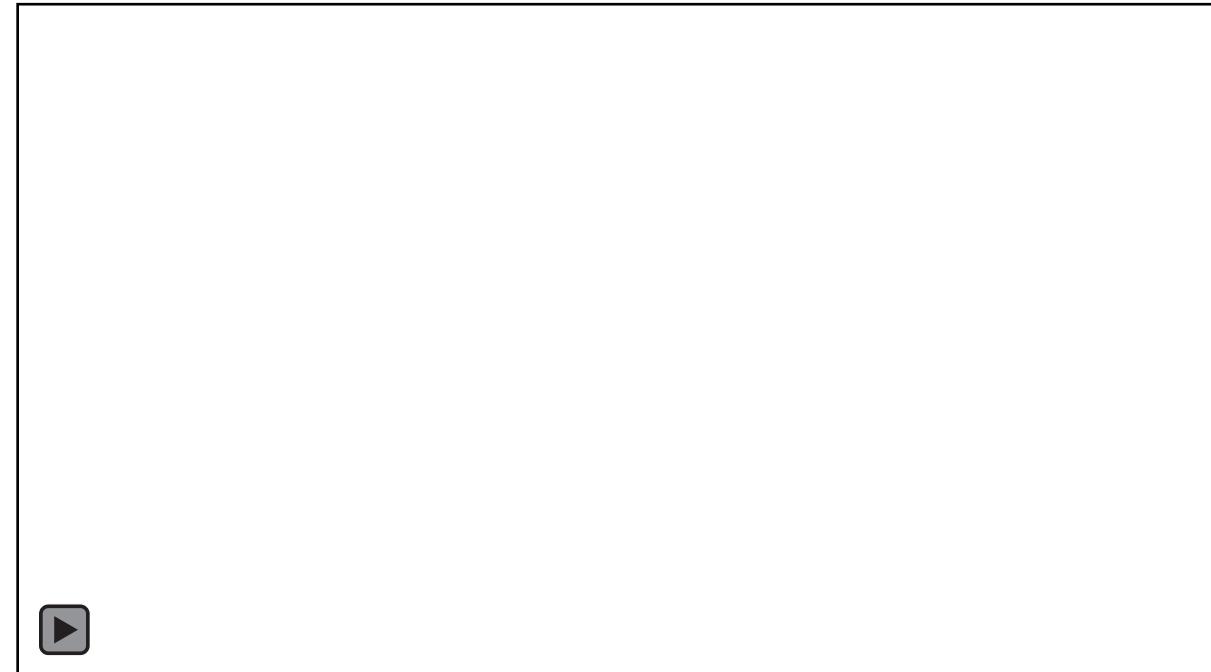


# Overcharge

1C to 250% SOC, Hold for 15 minutes or Failure



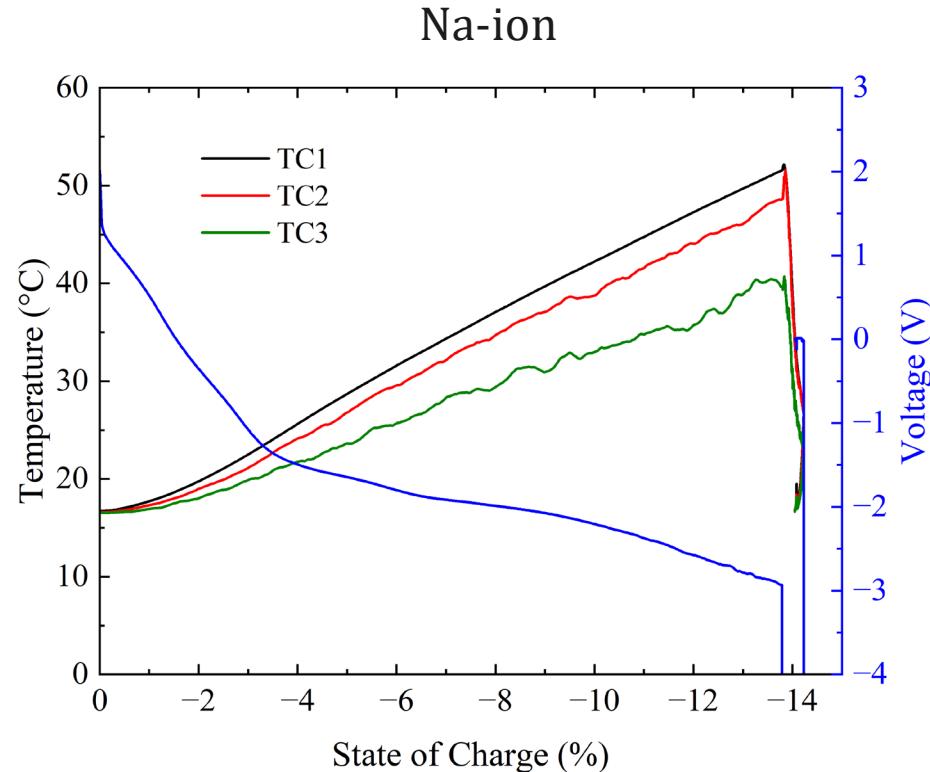
*Post Overcharge Crush*



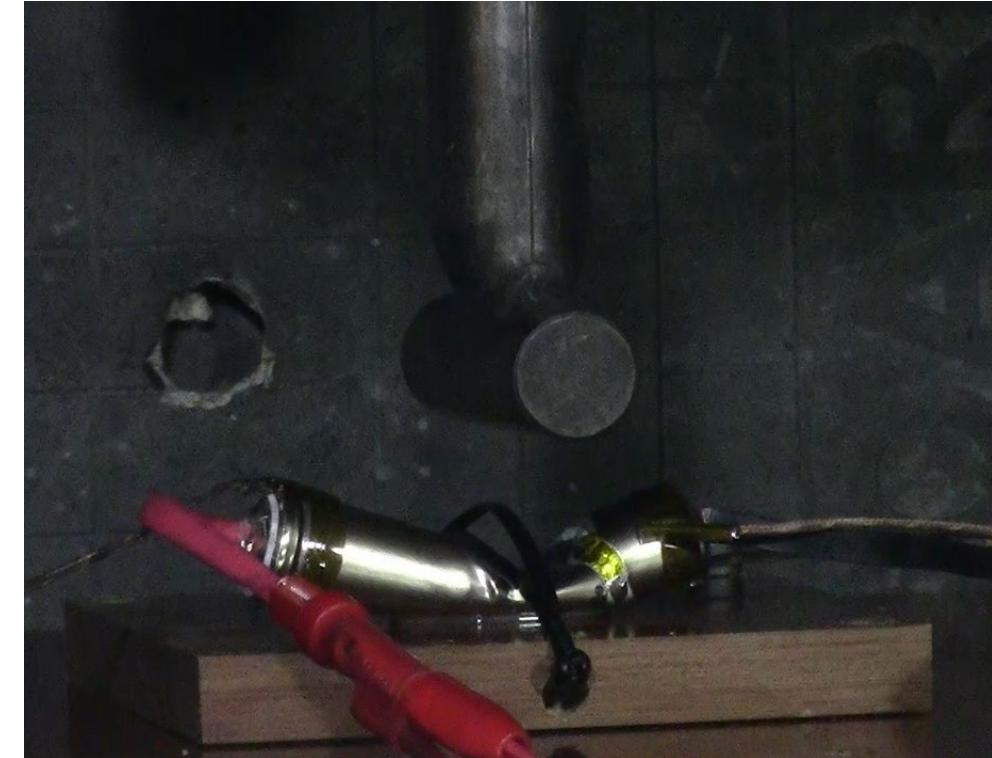
- Max temp: 75.4 °C
- Compliance voltage: 194.5% SOC
- No observable event

Cell had no voltage but, energy remained.

# Overdischarge 1C to -150% SOC, Hold for 15 minutes or Failure



*Post Overdischarge Crush*



- Max temp: 52.1 °C @ -13.8% SOC
- Voltage polarization: -13.8% SOC
- Realistic practical discharge capacity: 0.023 Ah
- No observable event

Liquid electrolyte leakage.  
IR camera showed no signs of heating.

# Comparison Summary



Destructive method	Cell Type	Max Temperature (°C)	Thermal Runaway Onset	Observable response
Nail Penetration	Na-ion	216.5	1.91 mm	Vent, smoke, sparks, violent pressure release
	Li-ion	98.1	1.88 mm	No observable effect
Crush	Na-ion	167.9	6.67 mm	Vent, smoke, sparks, lid pop
	Li-ion	296.3	9.71 mm	Vent, smoke, sparks, lid pop
External Short Circuit	Na-ion	132.8	N/A	Vent, smoke, electrolyte leak, swelling
	Li-ion	140.8	N/A	Swelling
Thermal Ramp	Na-ion	430.1	271.1 °C	Vent, LE leak
	Li-ion	398.1	269.1 °C	Vent, LE leak

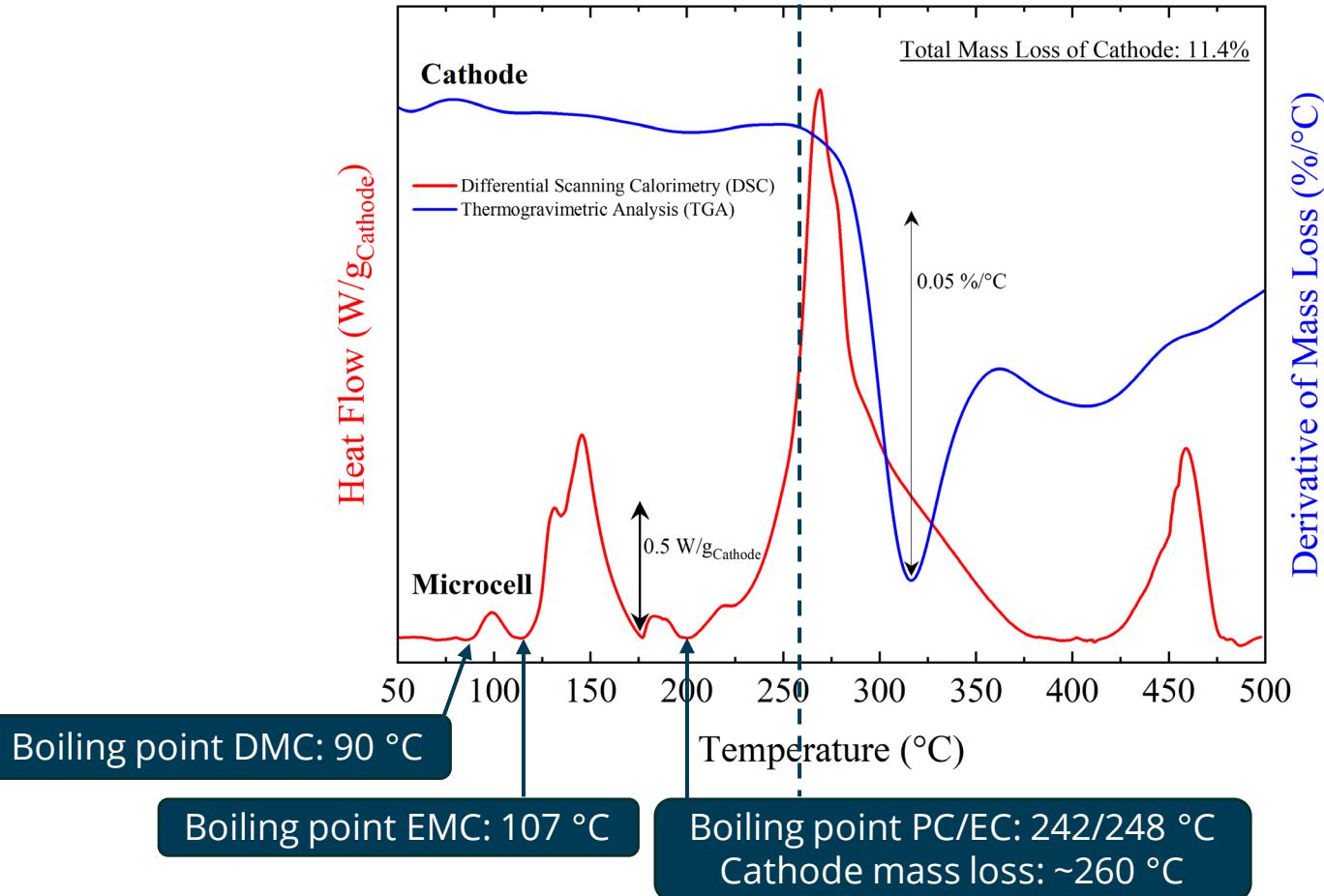
## Key Takeaway

- **Na-ion cells have a propensity for destructive failure under mechanical abuse**



# MATERIALS SCALE TESTING

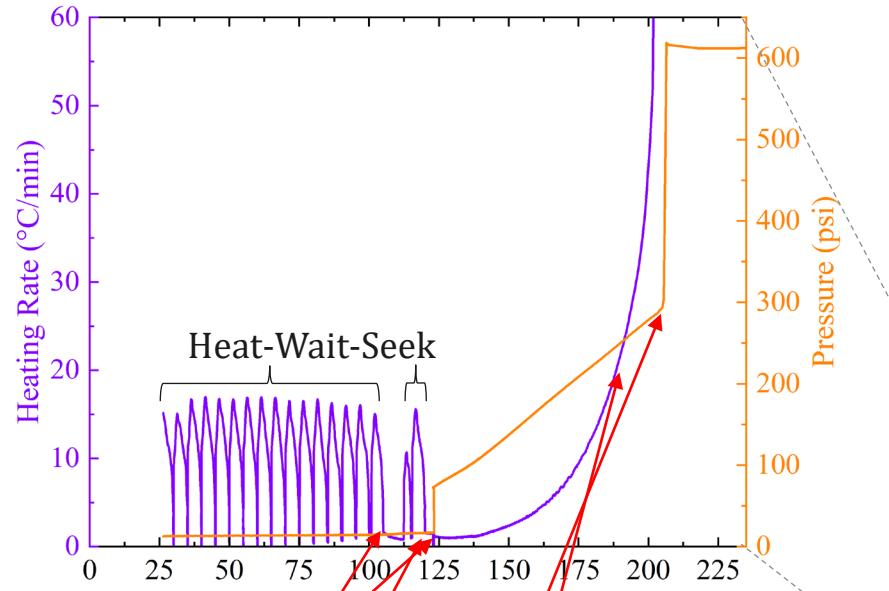
# METHODS TO UNCOVER REACTION PATHWAYS



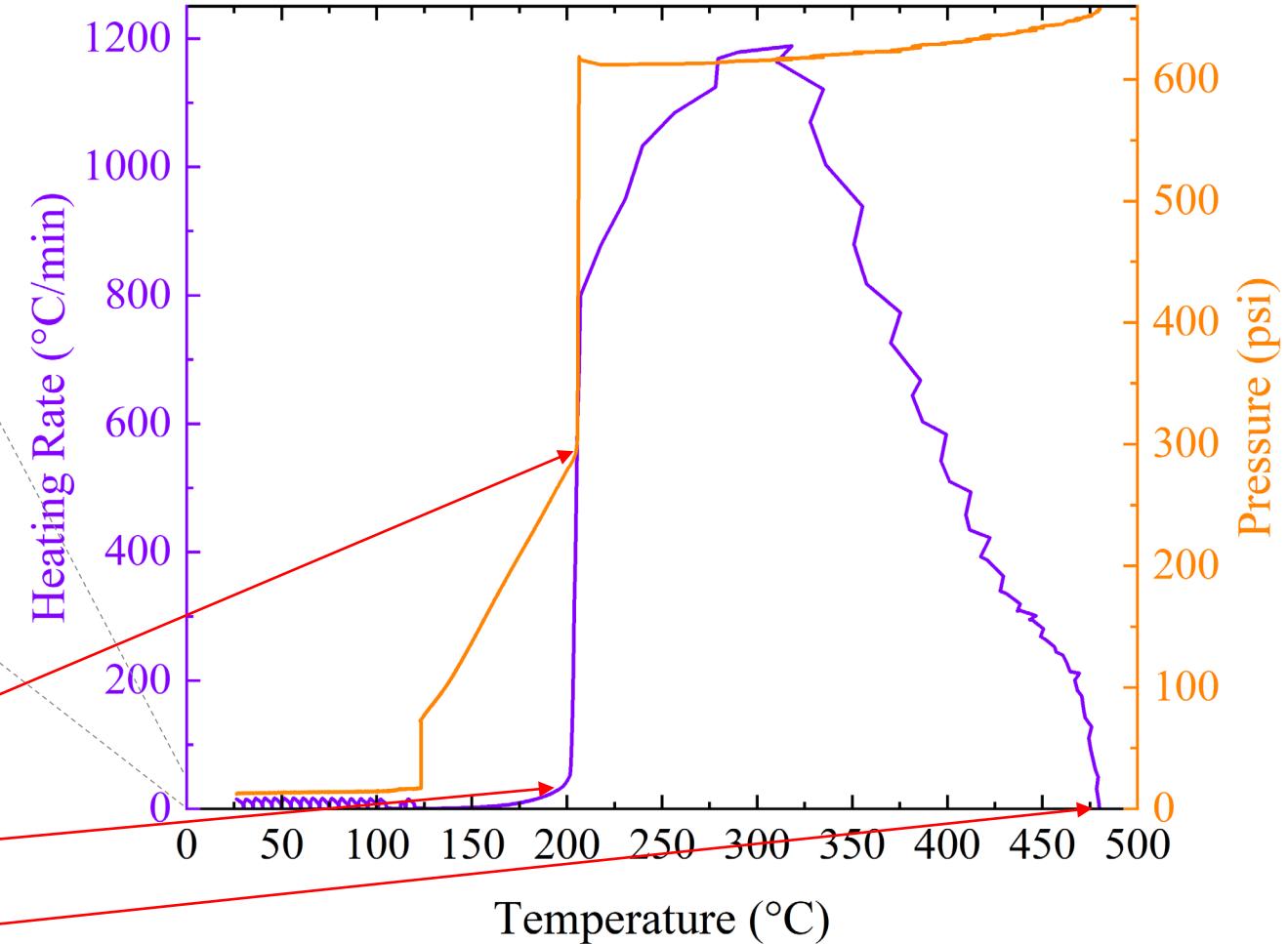
- Based on these results, we have an understanding of what chemicals are resident to the system.
- We can begin to formulate hypothesis on reaction pathways.

# Accelerated Rate Calorimetry

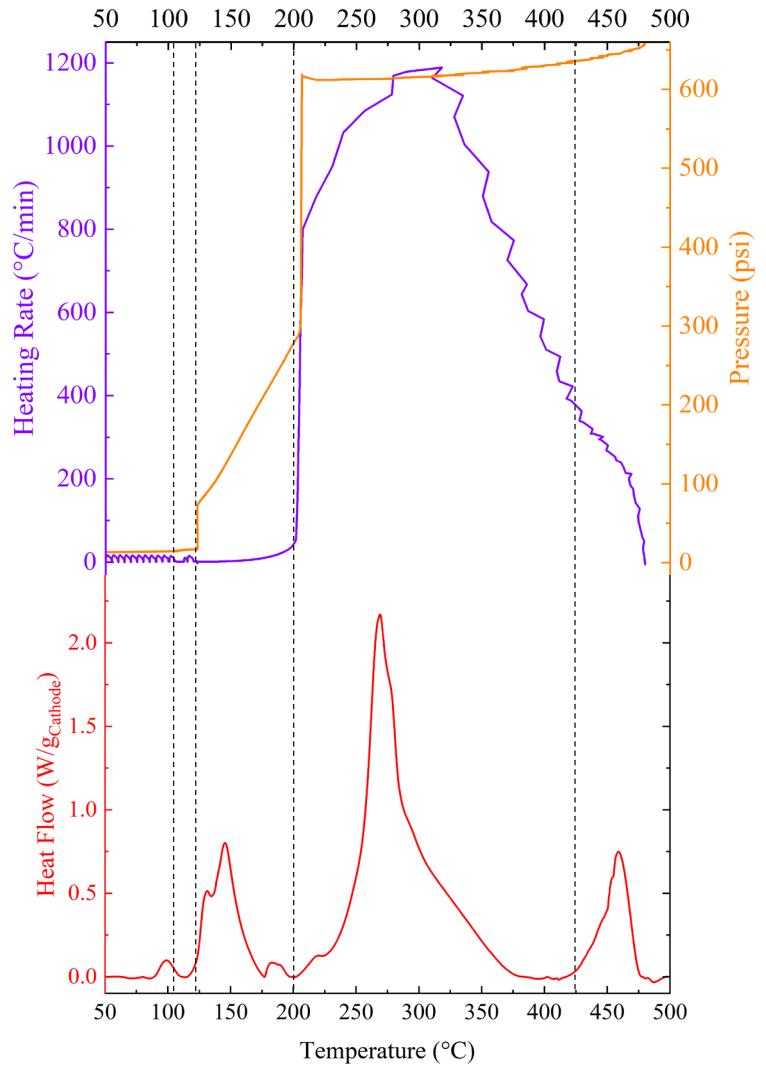
## Na-ion Cell



Condition	Temperature (°C)
First self-heating	105.1
Second self-heating	120.3
Vent	123.2
Thermal Runaway (>20 °C/min)	188.6
Pressure Ramp (>300 psi)	205.5
Maximum	480.1



# Comparison of DSC and ARC Data

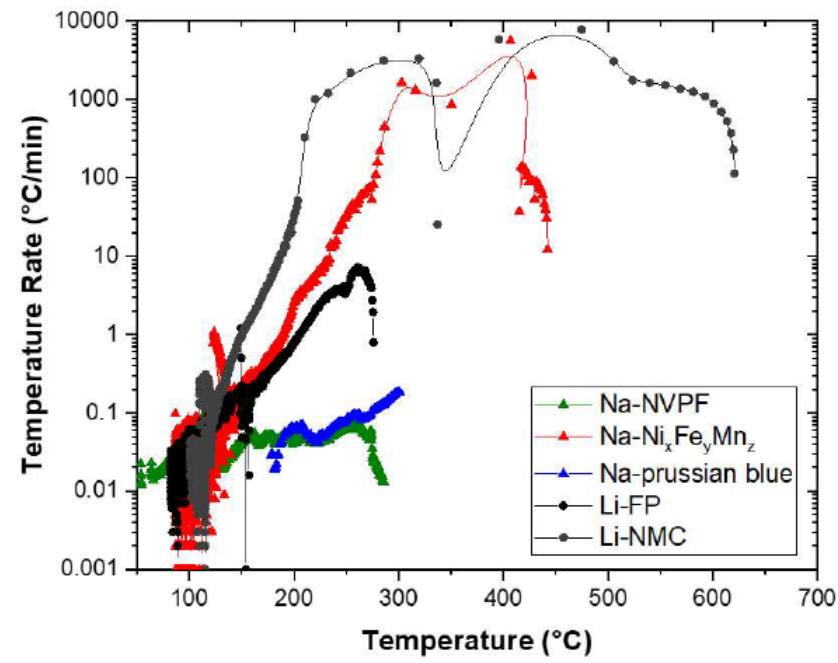
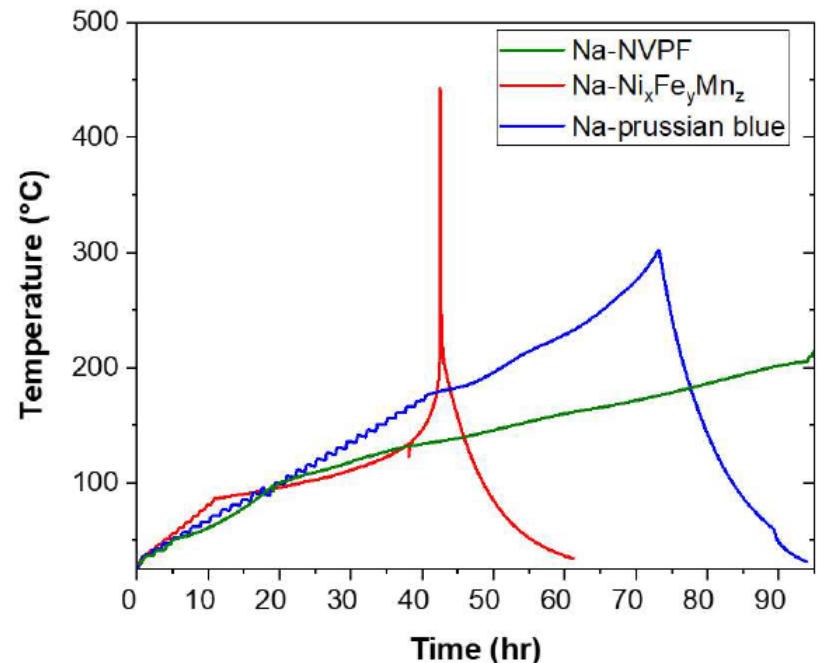


- Initial self-heating corresponds with small exothermic peak
- Return to heat-wait-seek mode in ARC corresponds with return to baseline in DSC
- Onset to high rate heating in ARC corresponds to onset to large exotherm in DSC
- At high temperature, reduction of heating rate in ARC has slowed corresponding with a high temperature exotherm in DSC

# Findings At Other Institutions – ARC Results



- US Naval Research Laboratory as presented by Rachel Carter at the 2024 Energy Storage Safety and Reliability Forum, May 16, 2024
  - Red curves come from same manufacturer as SNL cells

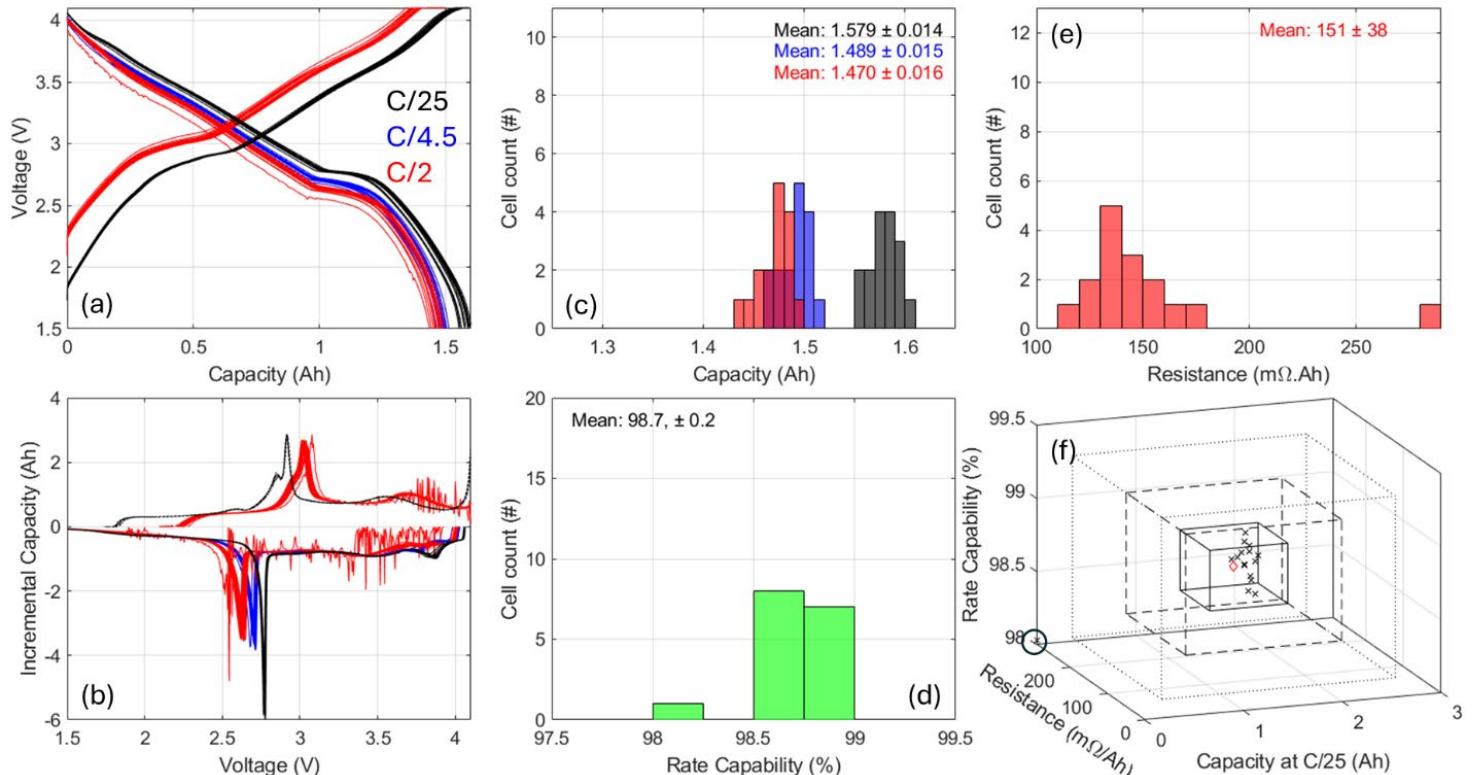


Na-Ni<sub>x</sub>Fe<sub>y</sub>Mn<sub>z</sub> exhibits similar thermal runaway to a much higher ED Li-NMC cell but the other Na cells exhibit less thermal event than Li-FP cells

# CYCLING RELIABILITY AND DEGRADATION



- Reed Wittman, Alex Bates, Loraine Torres-Castro
  - *Sandia National Laboratories*
- Matthieu Dubarry
  - *University of Hawai'i at Manoa*
- David Anseán
  - *University of Oviedo, Spain*



(a) Voltage vs. capacity curves at C/25, C/4.5, and C/2 for all the tested HKD cells with. (b) the associated incremental capacity curves, (c) their capacity distribution, (d and e) the rate capability and resistance distributions respectively, and (f) the summary of the cell to cell variations. The inner square represents a  $1\sigma$  spread, the dashed square  $2\sigma$ , and the dotted one  $3\sigma$ .

## Future Work



1. Destructive testing of other commercial 18650 Na-ion cells
2. Na-ion cell safety comparison of 18650 and 21700
3. Materials scale examination of Na-ion to delineate reaction pathways
4. Collaboration with PNNL to examine next generation Na-ion materials at the materials scale
  - a) This includes cathodes and electrolytes
  - b) This will evolve overtime to full cell testing

## Acknowledgements



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# Questions?

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