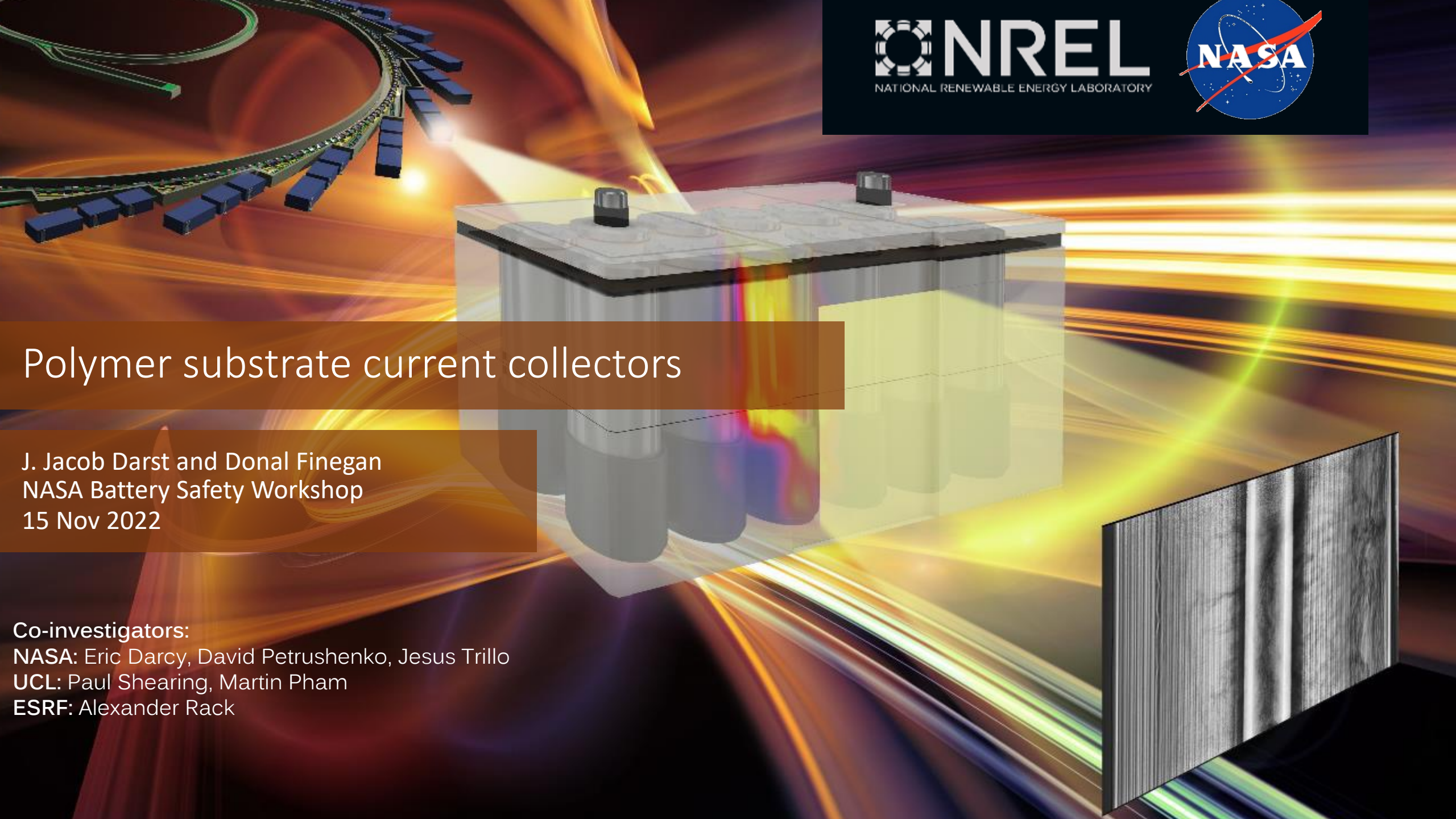


# Polymer substrate current collectors

J. Jacob Darst and Donal Finegan
NASA Battery Safety Workshop
15 Nov 2022

**Co-investigators:**
**NASA:** Eric Darcy, David Petrushenko, Jesus Trillo
**UCL:** Paul Shearing, Martin Pham
**ESRF:** Alexander Rack

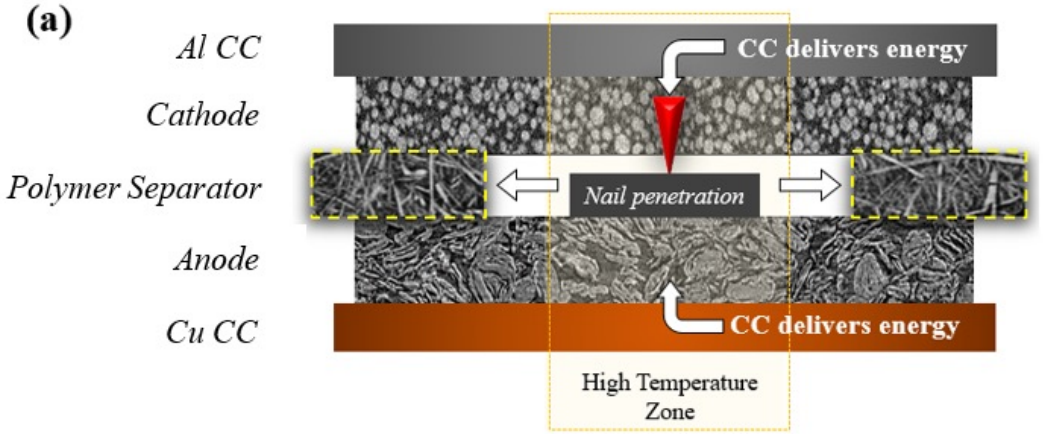
# Polymer Substrate Current Collectors (PCC)

*Soteria Battery Innovation Group*

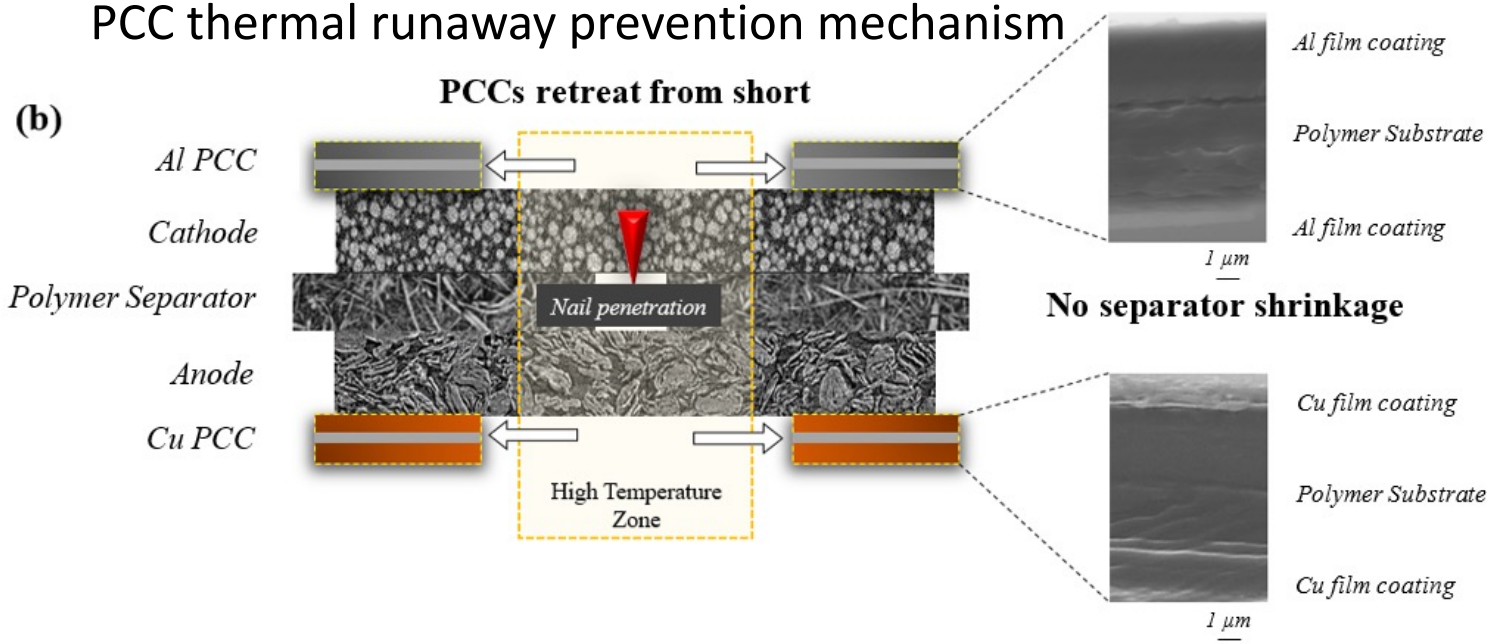
Data from 2020

- Anode and cathode contact via the nail causes an unmitigated short-circuit
- Elevated temperatures due to Joule heating causes thermal decomposition of electrode components
- The PCC withdraws from elevated temperatures before the separator fails, preventing sustained short circuit

Typical cell failure from nail penetration




PCC thermal runaway prevention mechanism



# Gravimetric Energy Density of Current Collectors

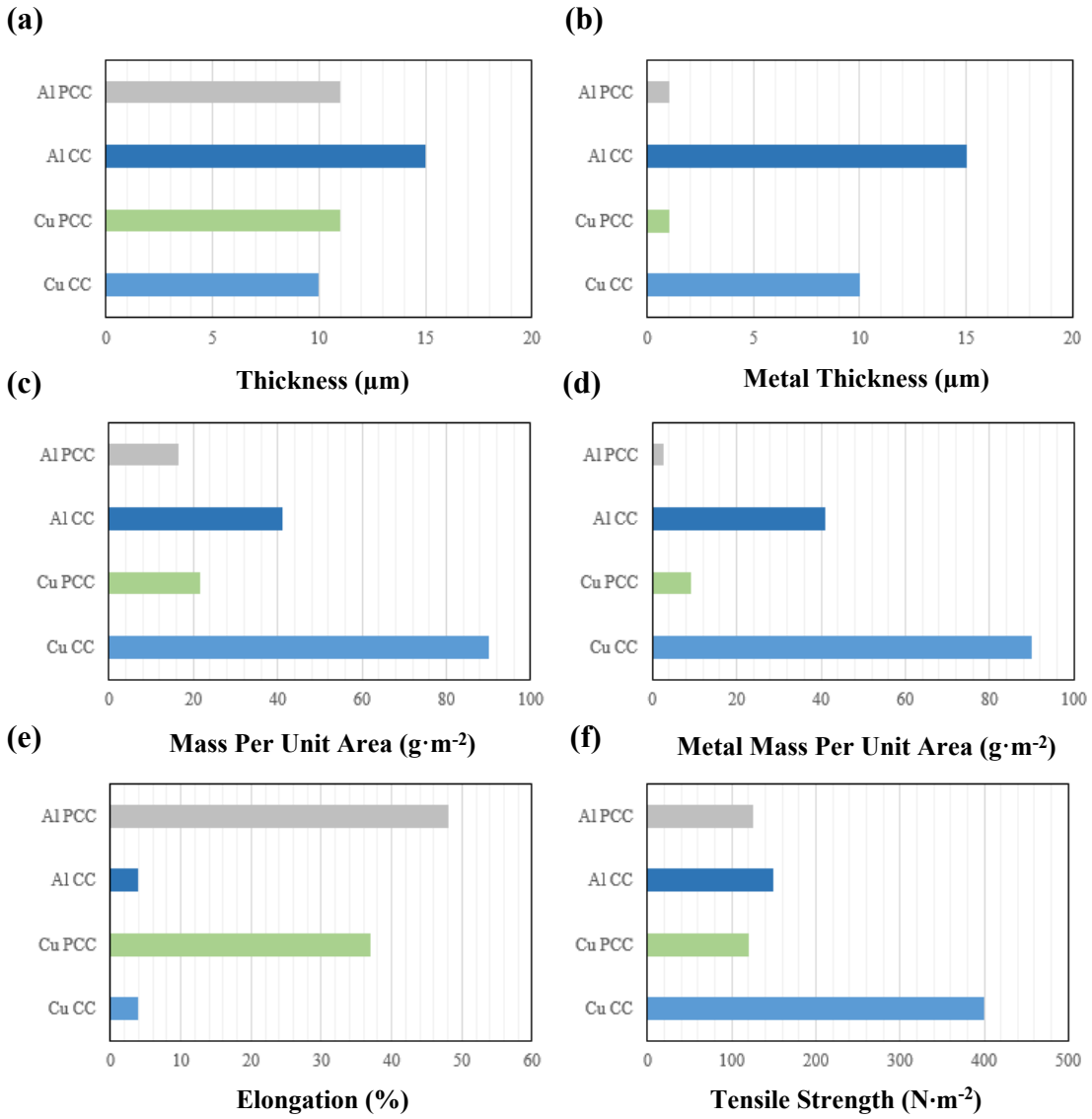
- Similar thicknesses to commercial metal foil current collectors (CCs):
  - Al CC: 15 µm vs. Al PCC: 11 µm
  - Cu CC: 10 µm vs. Cu PCC: 11 µm

- PCCs have a polymer substrate (ca. 10 µm thickness) with ca. 0.5-1 µm metal film coating of Al or Cu

- Significant reduction in the amount of metal required by the PCC compared to metal foils

  This reduction in metal is noticeable on the cell level as the average mass reduction was 2.2 grams, ca. 5% of total mass of a metal foil control cell

- Good mechanical properties



# Cell Categories Explored

## Data from 2020

2.1 Ah 18650 cells from Coulometrics
Tested at 100% SOC (4.2 V)

Cell Reports
Physical Science

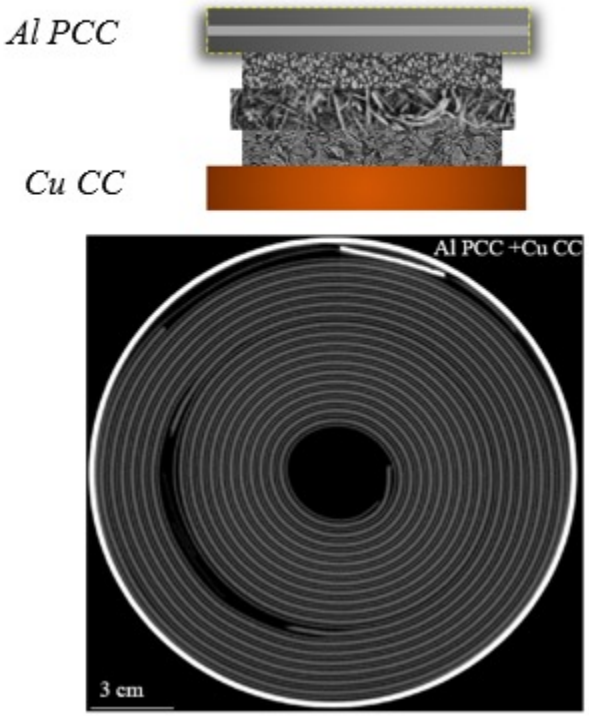
CellPress
OPEN ACCESS

Article

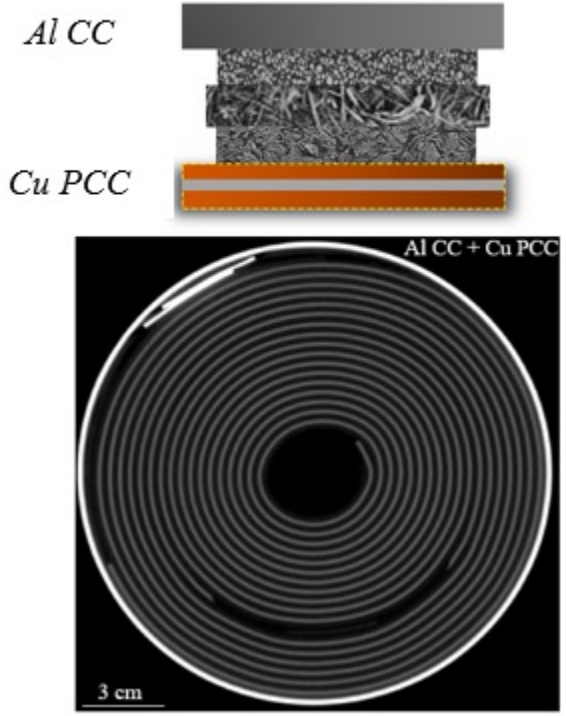
Prevention of lithium-ion battery thermal runaway using polymer-substrate current collectors

Martin T.M. Pham,[1] John J. Darst,[2] William Q. Walker,[2] Thomas M.M. Heenan,[1,3] Drasti Patel,[1] Francesco Iacoviello,[1] Alexander Rack,[4] Margie P. Olbinado,[4] Gareth Hinds,[5] Dan J.L. Brett,[1,3] Eric Darcy,[2] Donal P. Finegan,[6,*] and Paul R. Shearing[1,3,7,*]

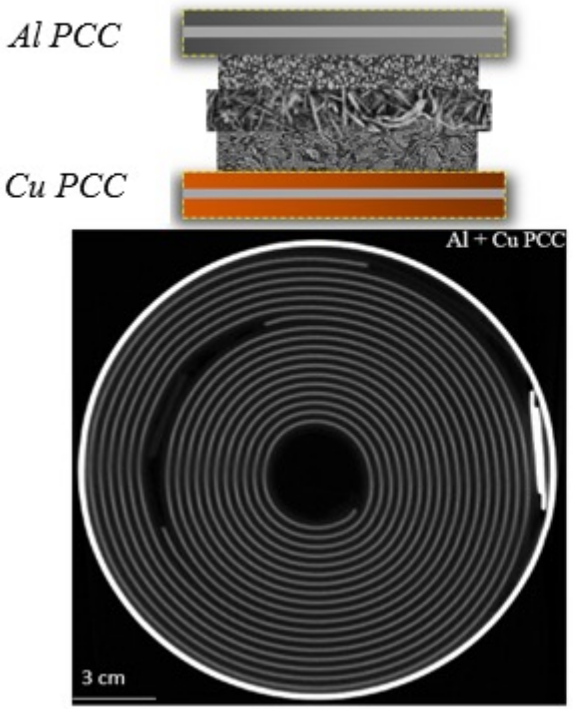
**Group 1, G1**



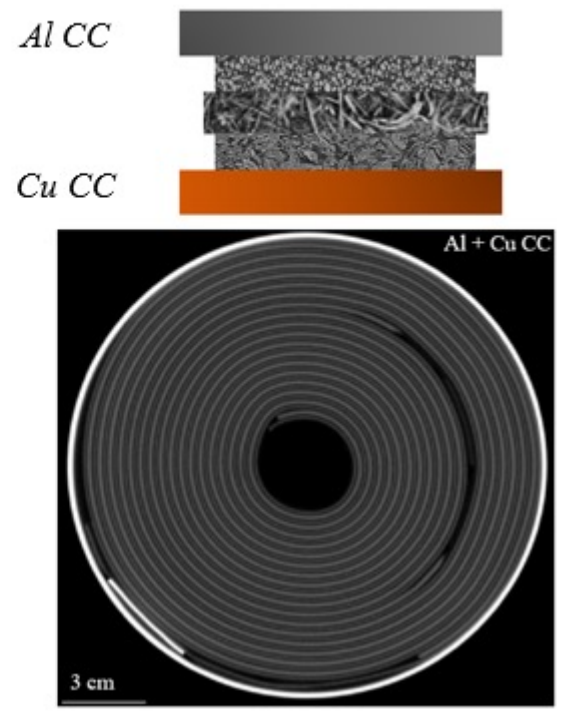

**Group 2, G2**




**Group 3, G3**




**Group 4, G4**

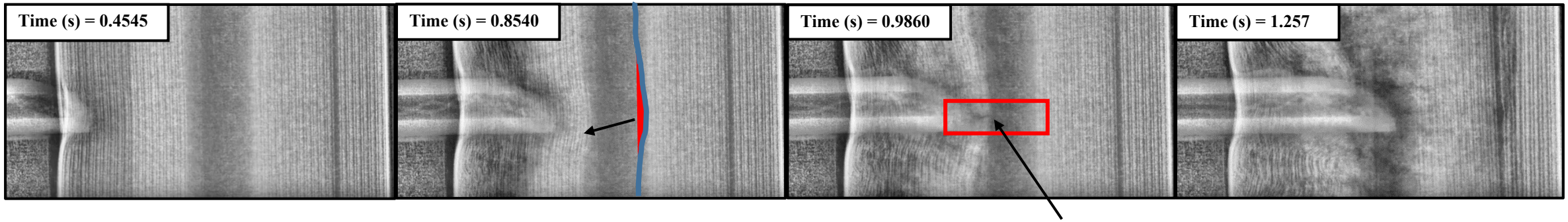


# Results: Mechanical Effect

## Data from 2020

**(a)** G4-01 (Al CC + Cu CC) Radiography

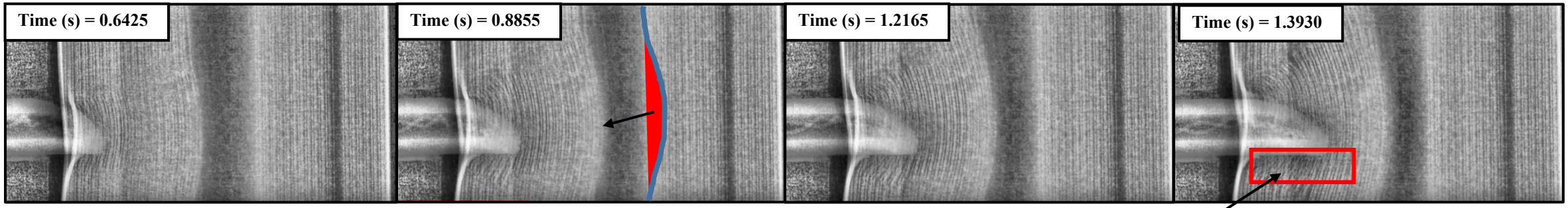
**Control cell**




**Characteristic cracking when Al PCC is absent**

**(b)** G1-01 (Al PCC + Cu CC) Radiography

**PCC cell**

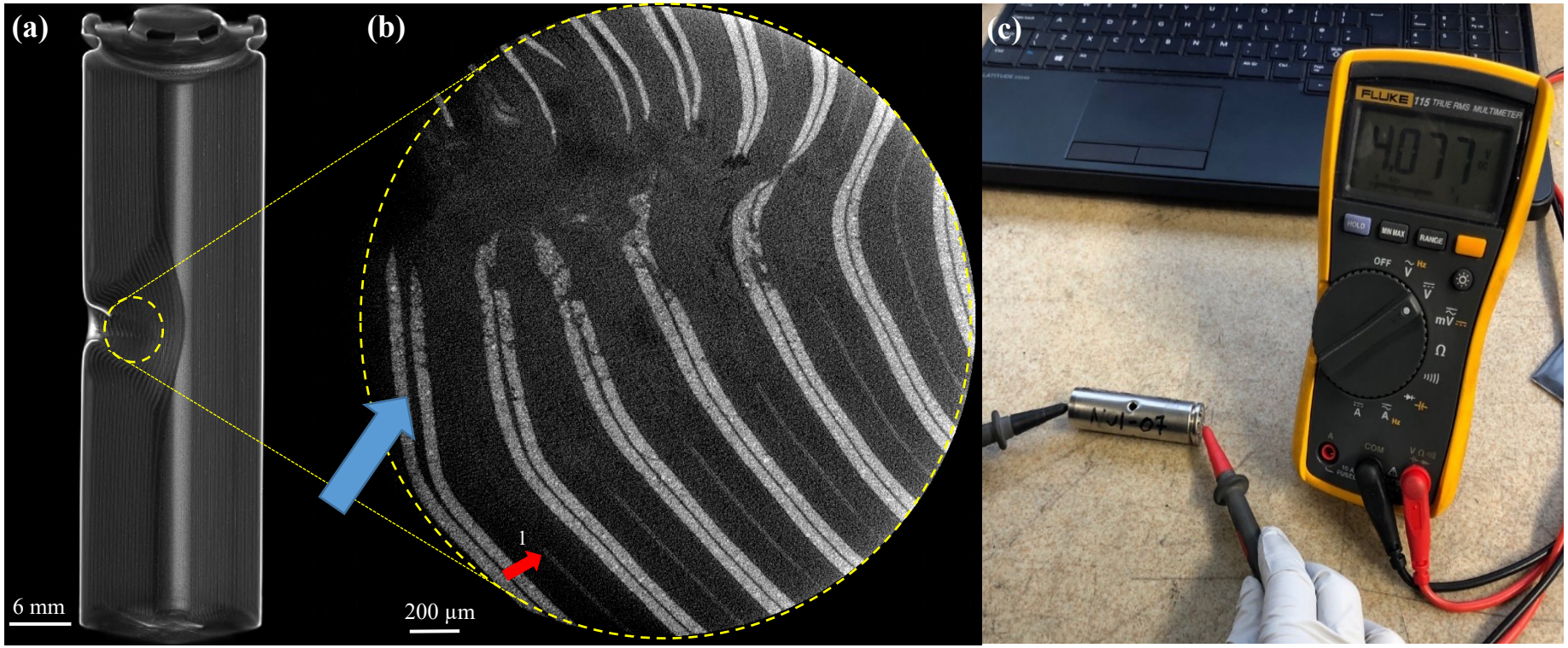



**Electrode layers adjacent to nail splitting**

# Results: Thermal Effect

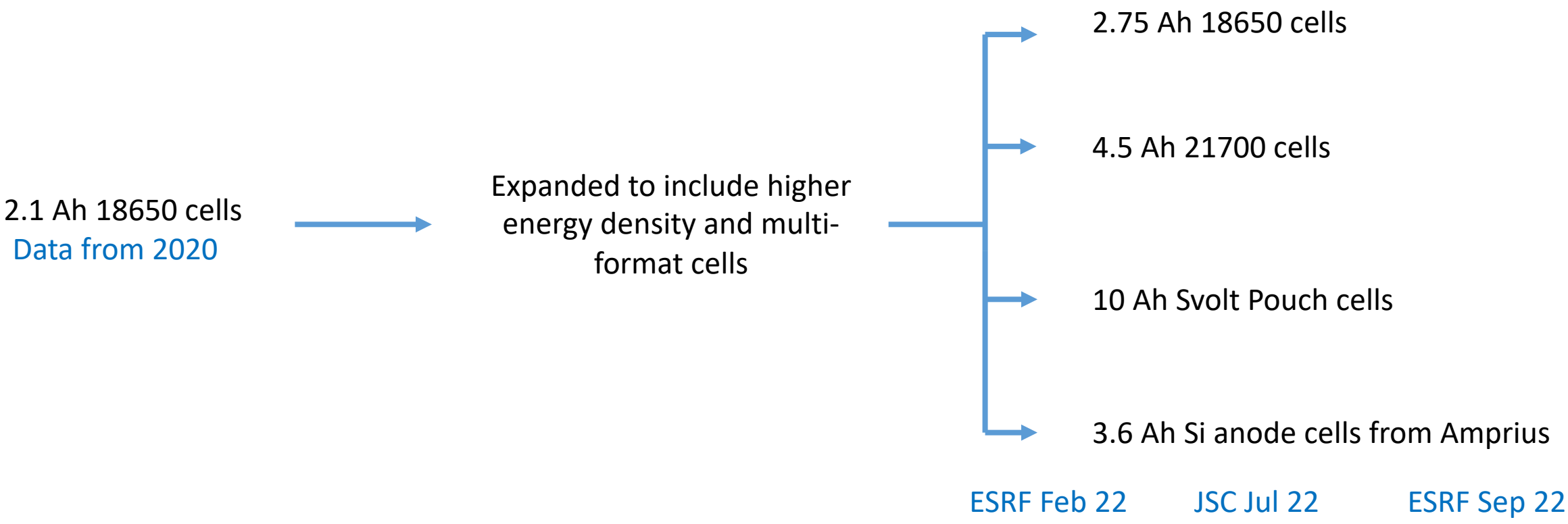
## Data from 2020

**PCC cell**




X-ray CT reveal Al and Cu PCCs withdrawn from the nail, thus reducing further short-circuiting. OCV measurement showed 4.07 V; cells retained voltage for over 10 months.

# Expanding Test Matrix

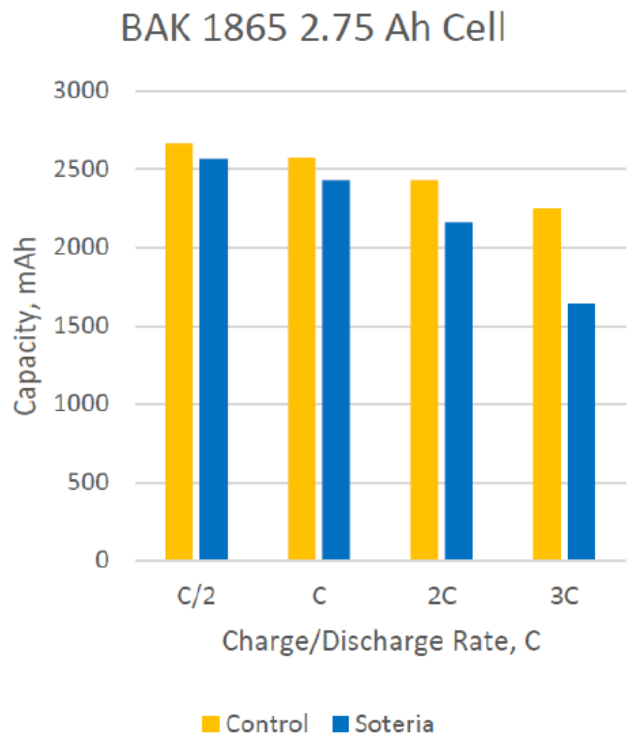


BAK
2.75 Ah 18650 cells

# BAK 18650 Cell Specifications

| Control Cell Preliminary Specifications | |
|---|---|
| Manufacturer | BAK Power Battery |
| Separator | Polyolefin Film |
| Current Collector | Standard Foils |
| Nominal Voltage | 3.6V |
| Capacity | 2.75Ah |
| AC impedance | 34 mΩ |
| Weight | 45 g |
| Energy Density | 209 Wh/kg |
| Voltage Range | 2.5V-4.2V |

| Soteria Cell Preliminary Specifications | |
|---|---|
| Manufacturer | BAK Power Battery |
| Separator | Polyolefin Film |
| Current Collector | Soteria Al, Standard Cu |
| Nominal Voltage | 3.6V |
| Capacity | 2.75Ah |
| AC impedance | 51 mΩ |
| Weight | 44 g |
| Energy Density | 200 Wh/kg |
| Voltage Range | 2.5V-4.2V |



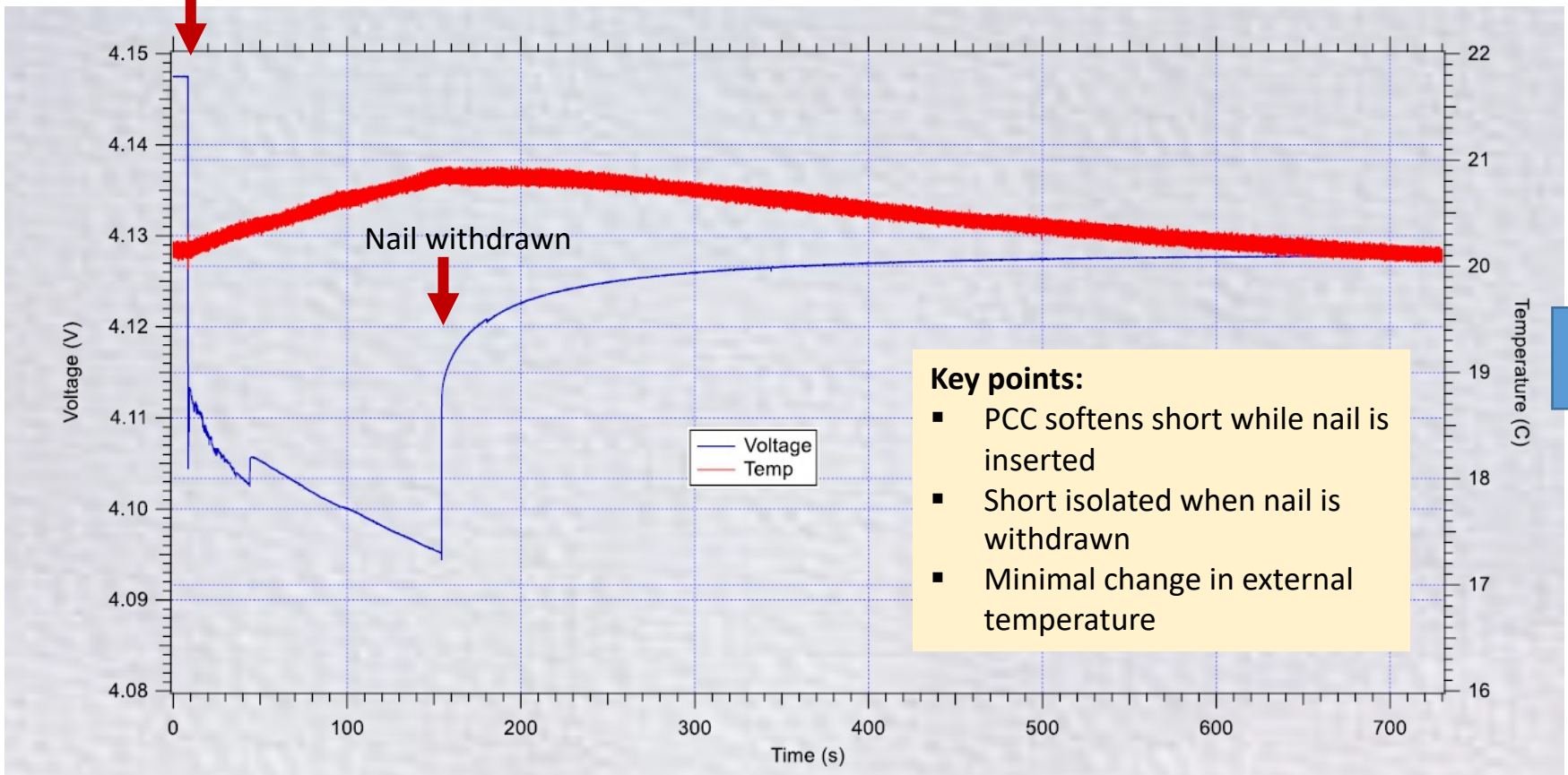
# Summary of Results for BAK 2.75 Ah 18650 Cells

## Soteria PCC cells

- 4 with cathode PCC (no TRs)
- 4 with anode & cathode PCCs (no TRs)
- 3 control cells with metal CCs (all TRs)

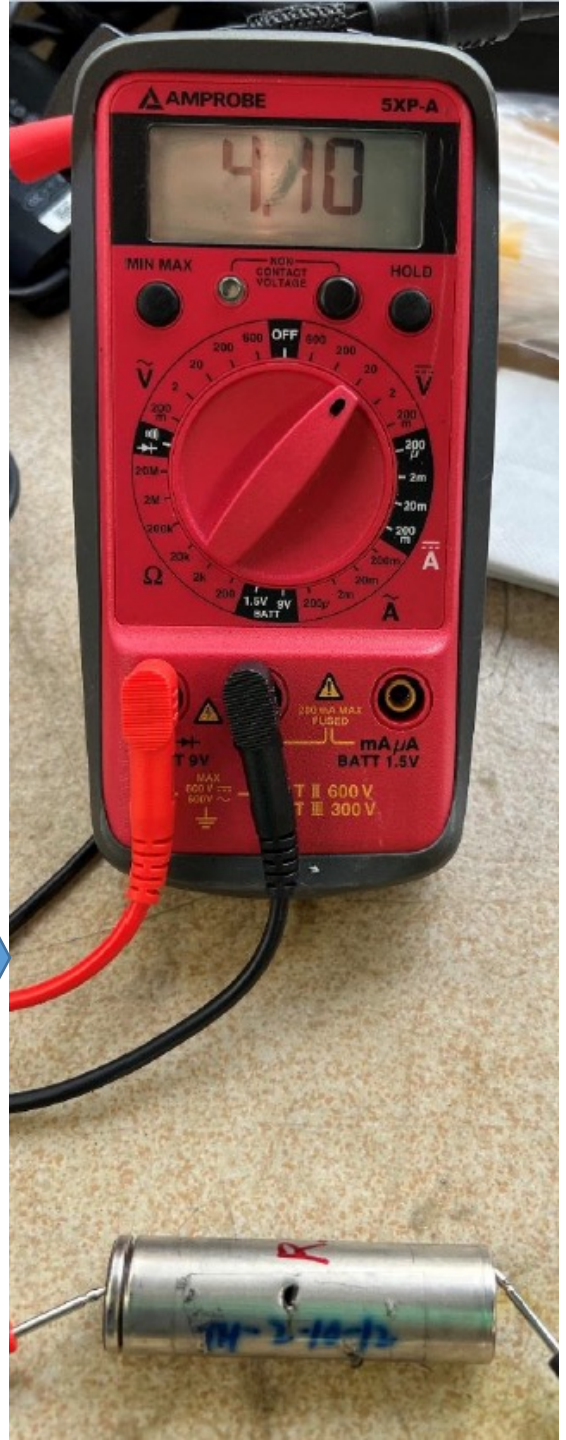
Time of nail insertion

Example voltage response during nail penetration of PCC cell




**Key points:**

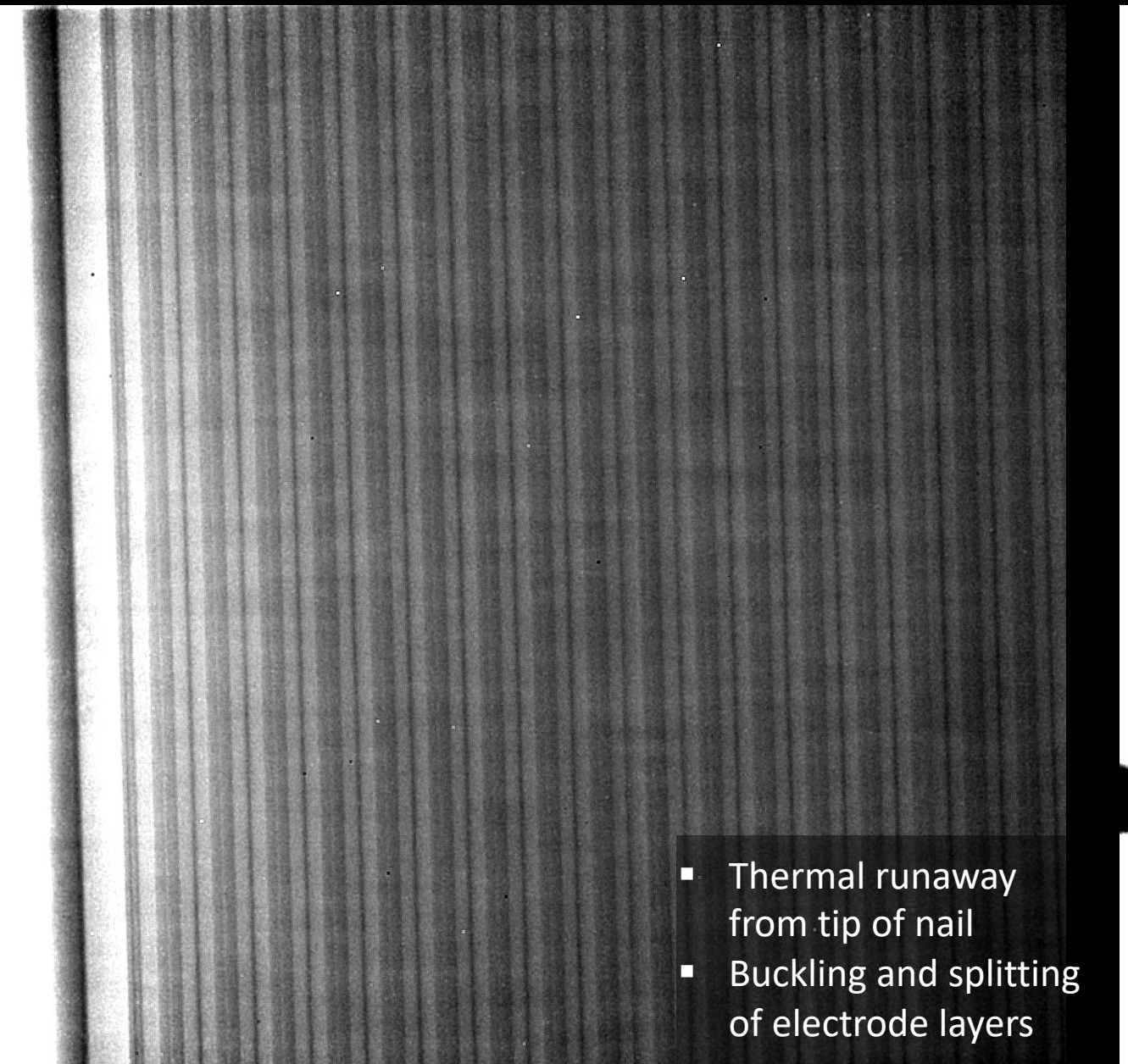
- PCC softens short while nail is inserted
- Short isolated when nail is withdrawn
- Minimal change in external temperature



# Radiography at 3000 fps of 18650 cells

## Control cell

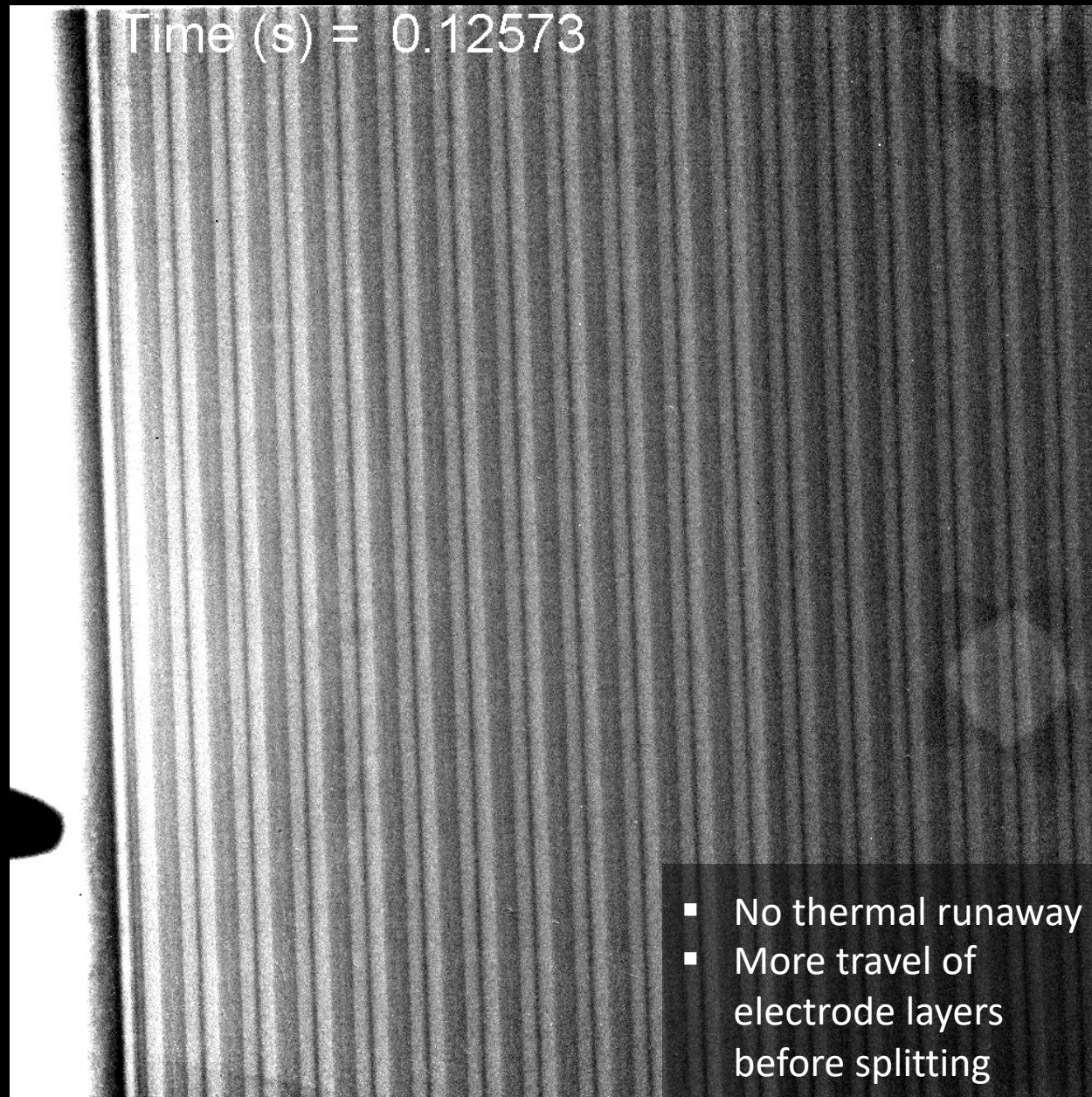
Run 034



- Thermal runaway from tip of nail
- Buckling and splitting of electrode layers

## Cell with PCC

Run 031



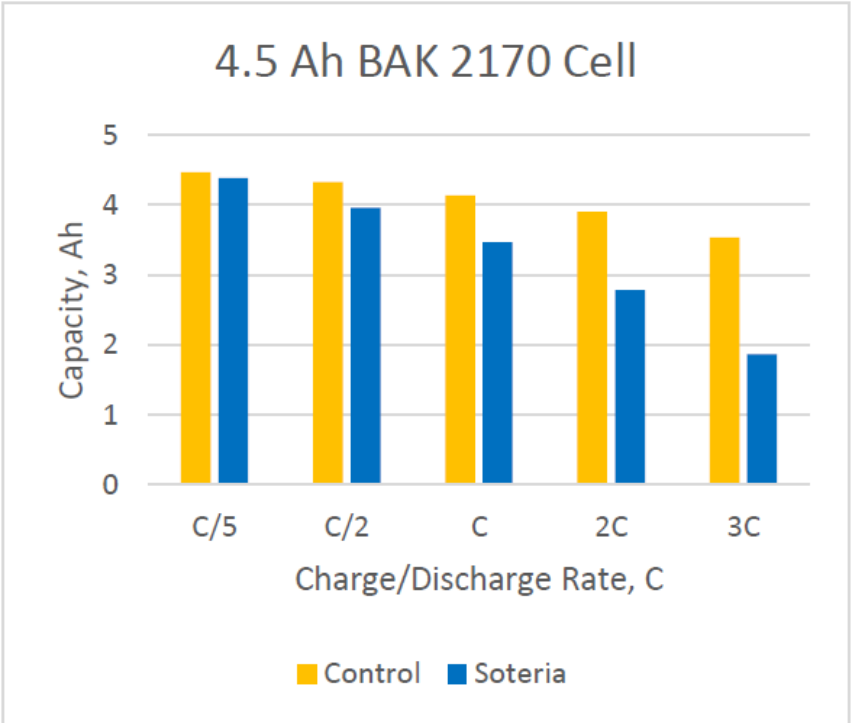

- No thermal runaway
- More travel of electrode layers before splitting

# BAK
# 4.5 Ah 21700 cells

# BAK 21700 Cell Specifications

| Soteria Cell Preliminary Specifications | |
|---|---|
| Manufacturer | BAK Power Battery |
| Separator | Polyolefin Film |
| Current Collector | Soteria Al, Standard Cu |
| Nominal Voltage | 3.6V |
| Capacity | 4.5Ah |
| AC impedance | 42 mΩ |
| Weight | 66 g |
| Energy Density | 205 Wh/kg |
| Voltage Range | 2.5V-4.2V |

| Control Cell Preliminary Specifications | |
|---|---|
| Manufacturer | BAK Power Battery |
| Separator | Polyolefin Film |
| Current Collector | Standard Foils |
| Nominal Voltage | 3.6V |
| Capacity | 4.5Ah |
| AC impedance | 20 mΩ |
| Weight | 67 g |
| Energy Density | 227 Wh/kg |
| Voltage Range | 2.5V-4.2V |



# Summary of Results for BAK 4.5 Ah 21700 Cells

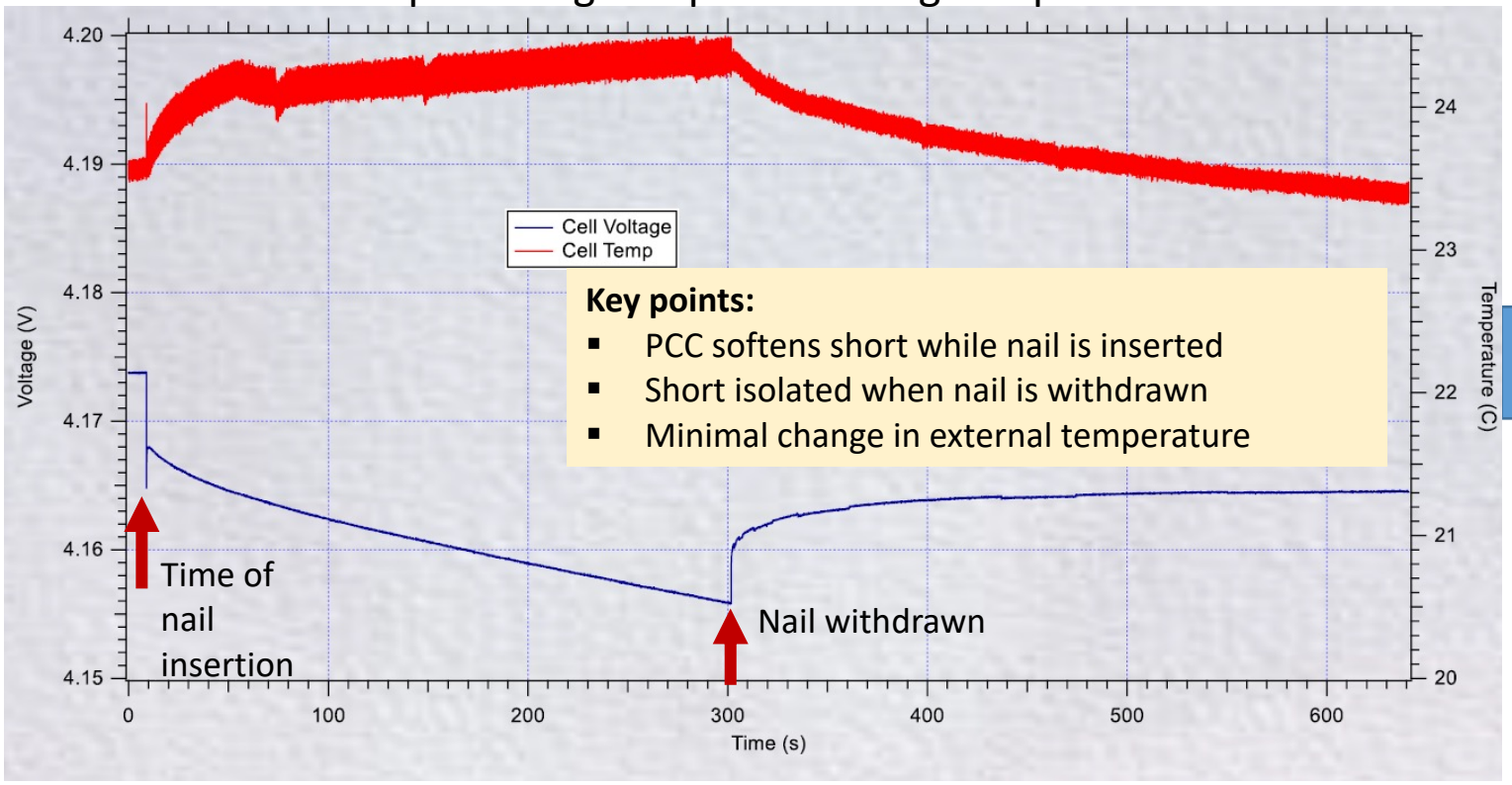
**Soteria metalized polyester (3)**

- PCC only on cathode
- Cu foil on anode like all other features in control version
- All 3 cells tolerated nail penetration
- No fire, sparks, venting, or TR

**Control cells (3)**

- Al and Cu foil CCs
- All 3 cells went into TR

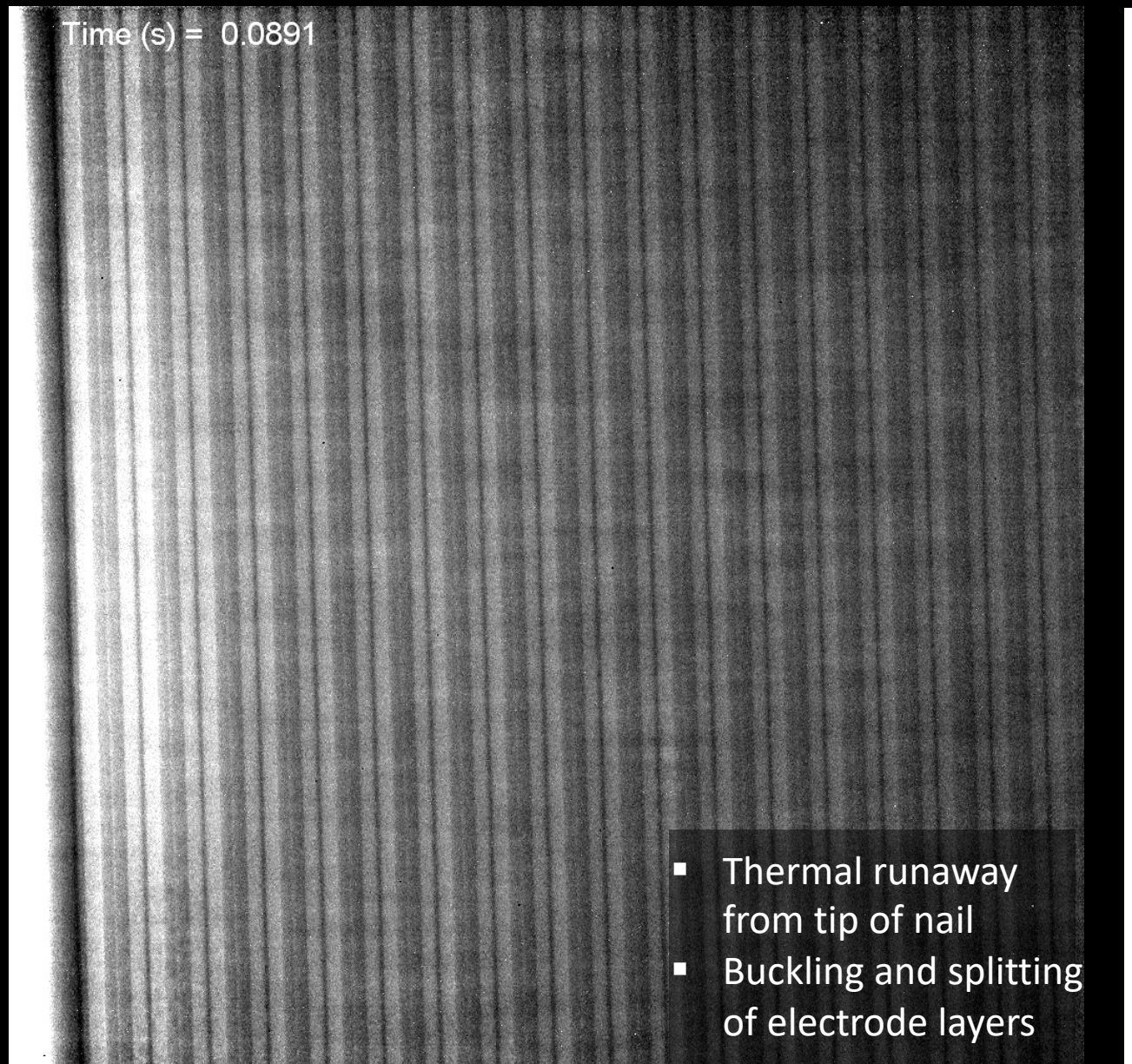
Example voltage response during nail penetration of PCC cell




# Radiography at 3000 fps of 21700 cells

## Control cell

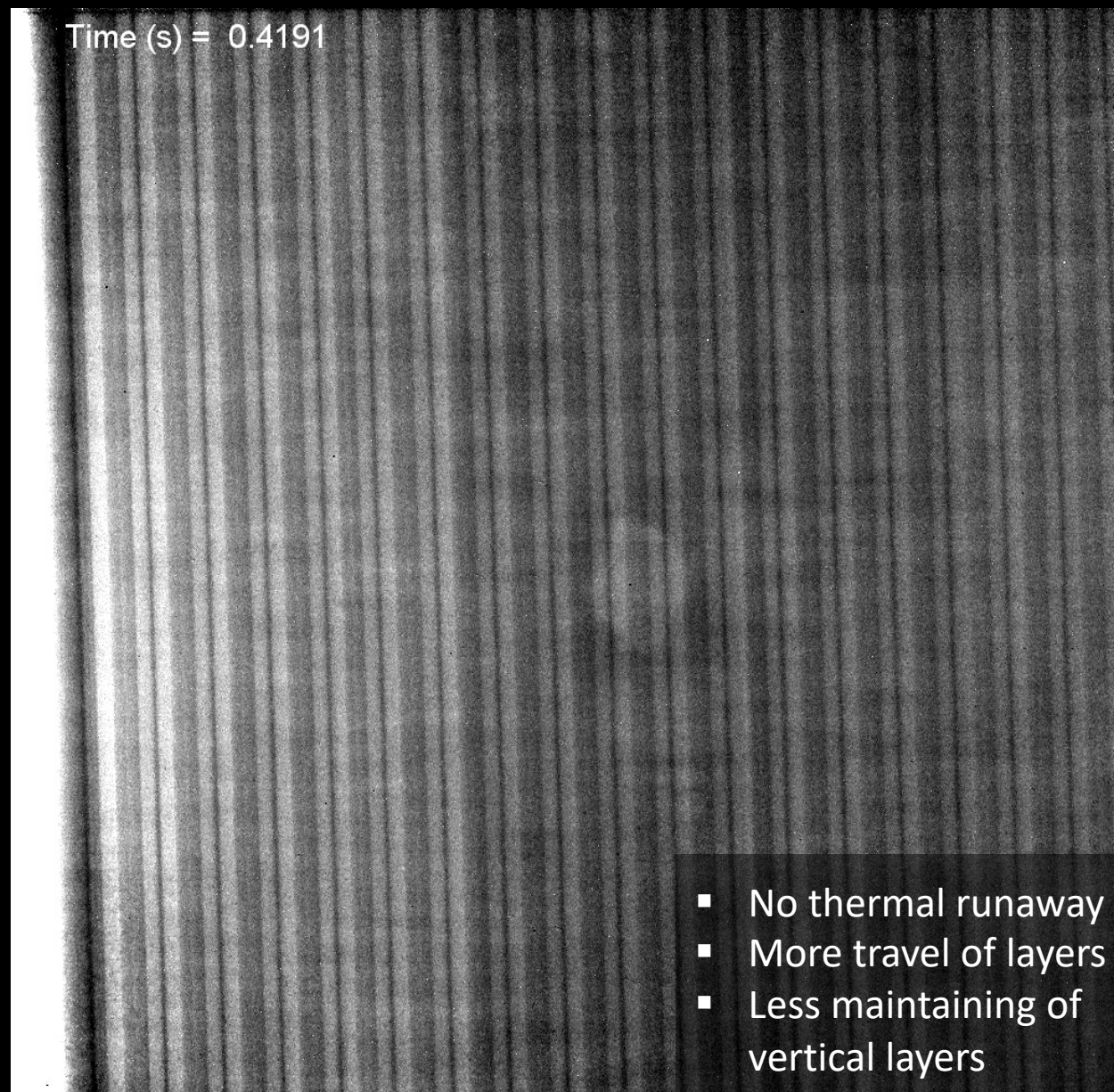
Run 025




- Thermal runaway from tip of nail
- Buckling and splitting of electrode layers

## Cell with PCC

Run 020

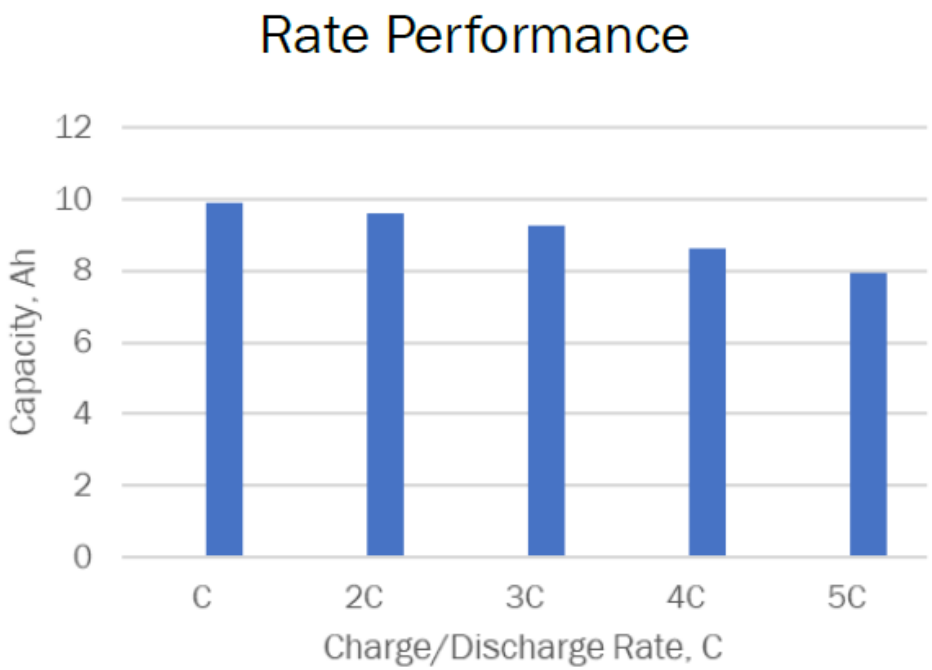



- No thermal runaway
- More travel of layers
- Less maintaining of vertical layers

# SVolt
# 10 Ah Pouch Cells

# Svolt 10Ah Pouch Cell Specifications

| Cell Specifications | |
|---|---|
| Manufacturer | SVolt Energy |
| Separator | Polyethylene w/ ceramic coating |
| Current Collector | Soteria Al<br>Standard Cu |
| Cathode Material | NCM 811 |
| Anode Material | Synthetic Graphite |
| Capacity | 10Ah |
| Voltage Range | 3.0-4.2V |
| Energy Density | 240 Wh/kg |



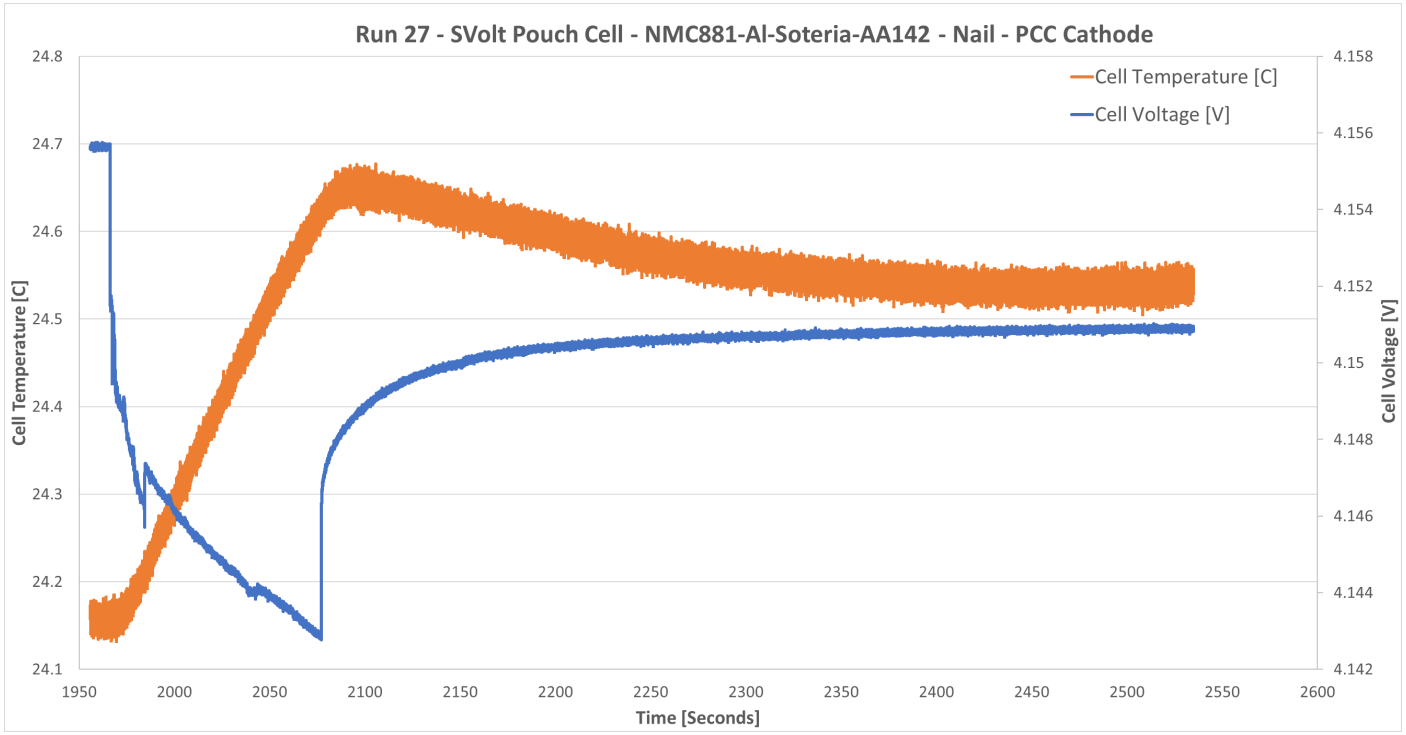
# Summary of Results For Svolt 10Ah Pouch Cells

**Soteria metalized polyester (4)**

- PCC only on cathode
- Cu foil on anode like all other features in control version
- All 4 cells tolerated nail penetration
- No fire, sparks, venting, or TR

**Control cells (4)**

- Al and Cu foil CCs
- All 4 cells went into TR




# Radiography at 3000 fps of SVolt cells

Control cell

Run030

Time (s) = 0.0904

- Thermal runaway

X-ray direction

Cell with PCC

Run033

Snapshot taken after 3 mins

- No thermal runaway

# Amprius
# 3.6 Ah Si Anode Pouch Cells

# Summary of Results for Amprius 3.6Ah Si Anode with LCO (Nail)

## Control Amprius cells (3)

- Al collector on cathode & Si anode

### Results (one of each)

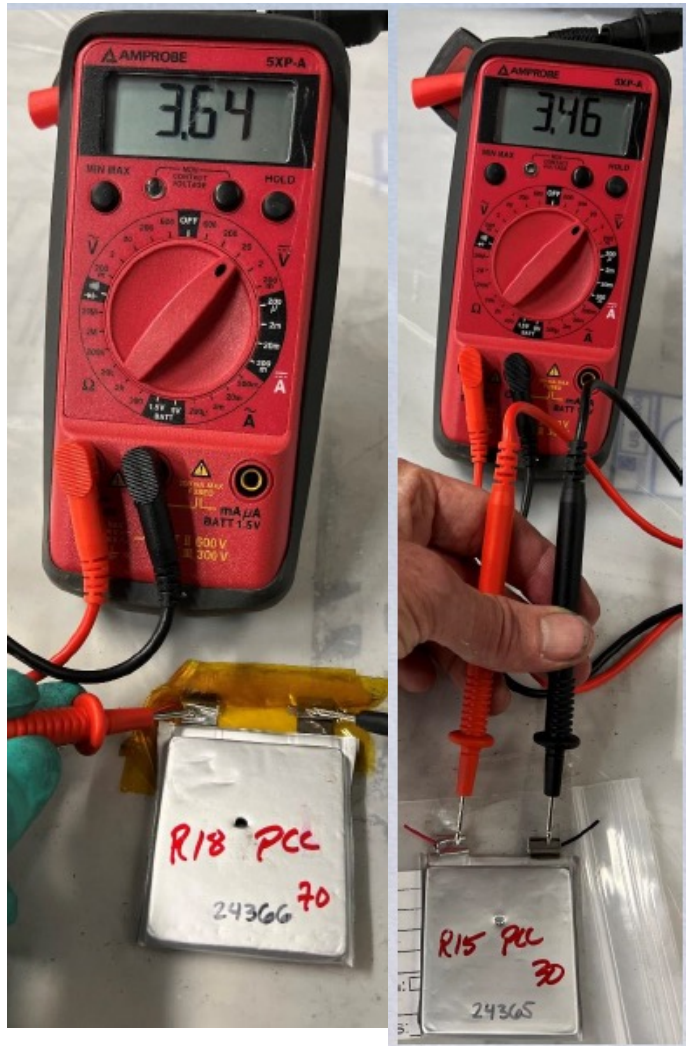
- 100% SoC went into TR
- 70% SoC went into TR
- 30% SoC went into TR

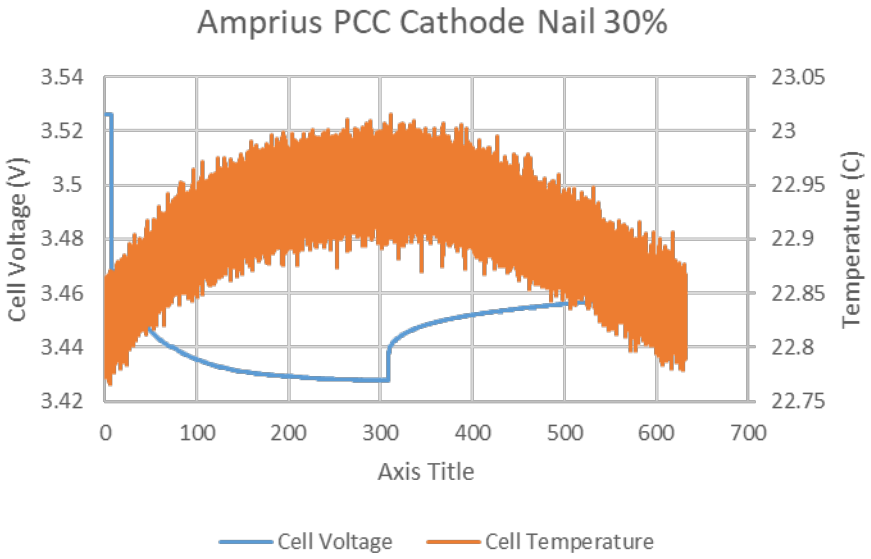
## Soteria PCC cells (3)

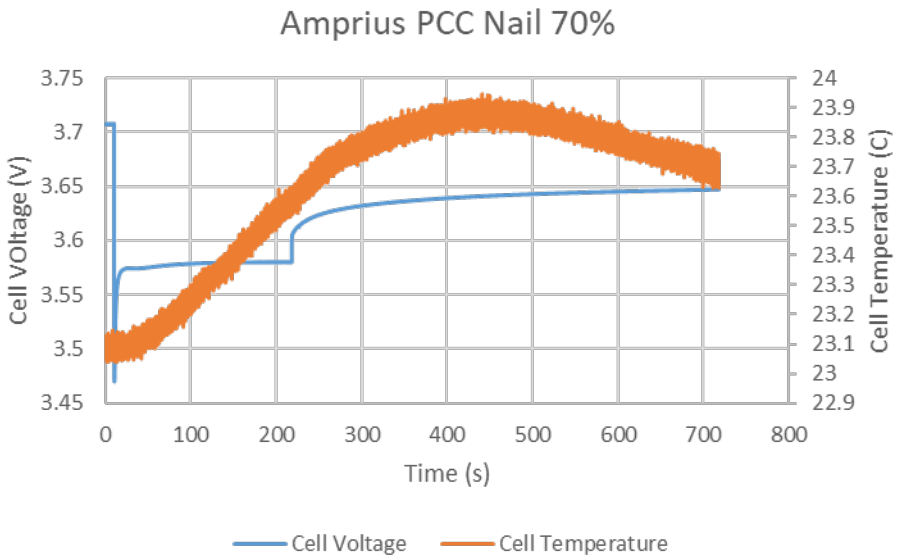
- PCC on cathode only
- 100% Si anode with Ti collector

### Results (one of each)

- 100% SoC went into TR
- 70% SoC experienced no TR
- 30% SoC experienced no TR

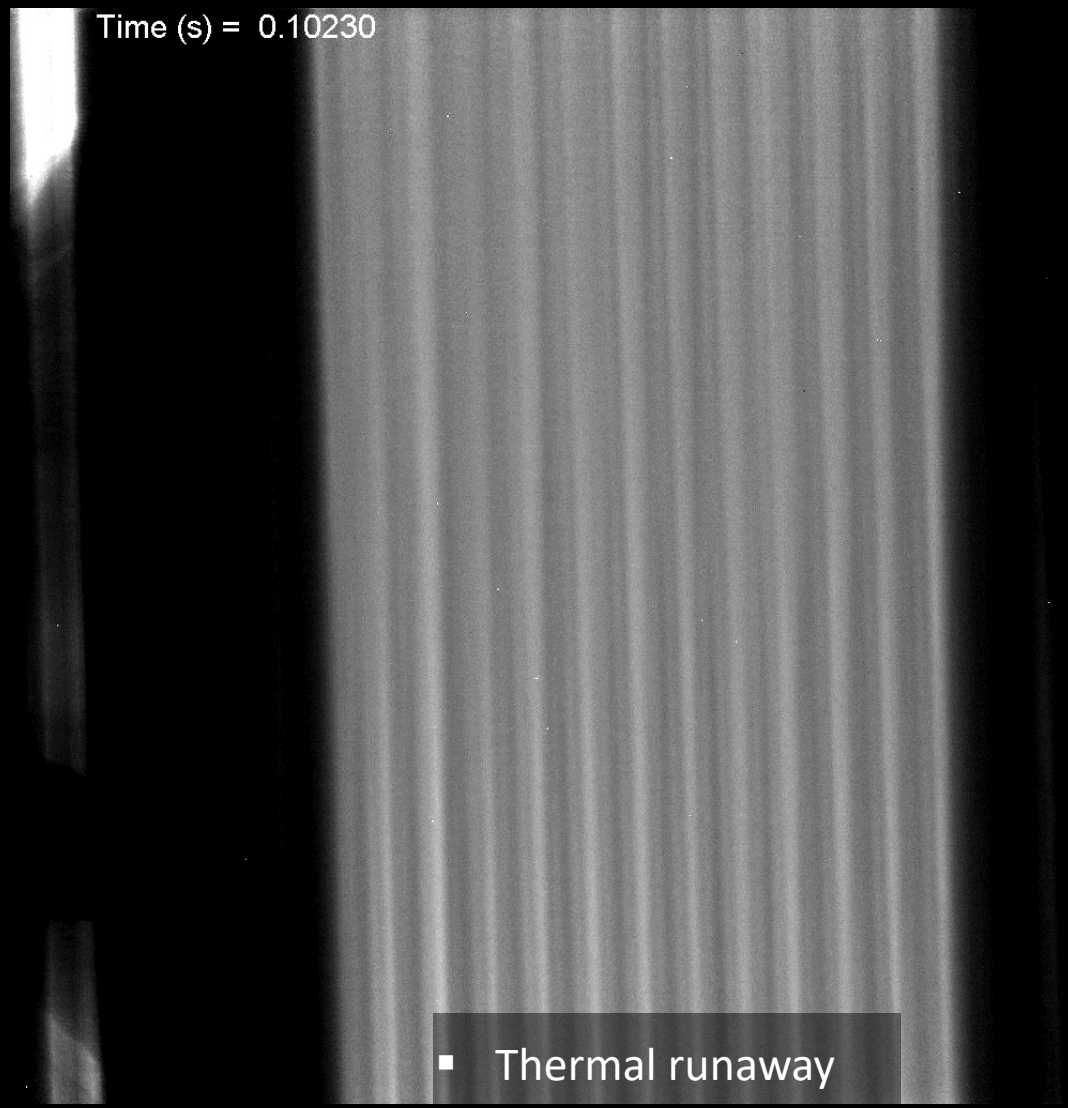


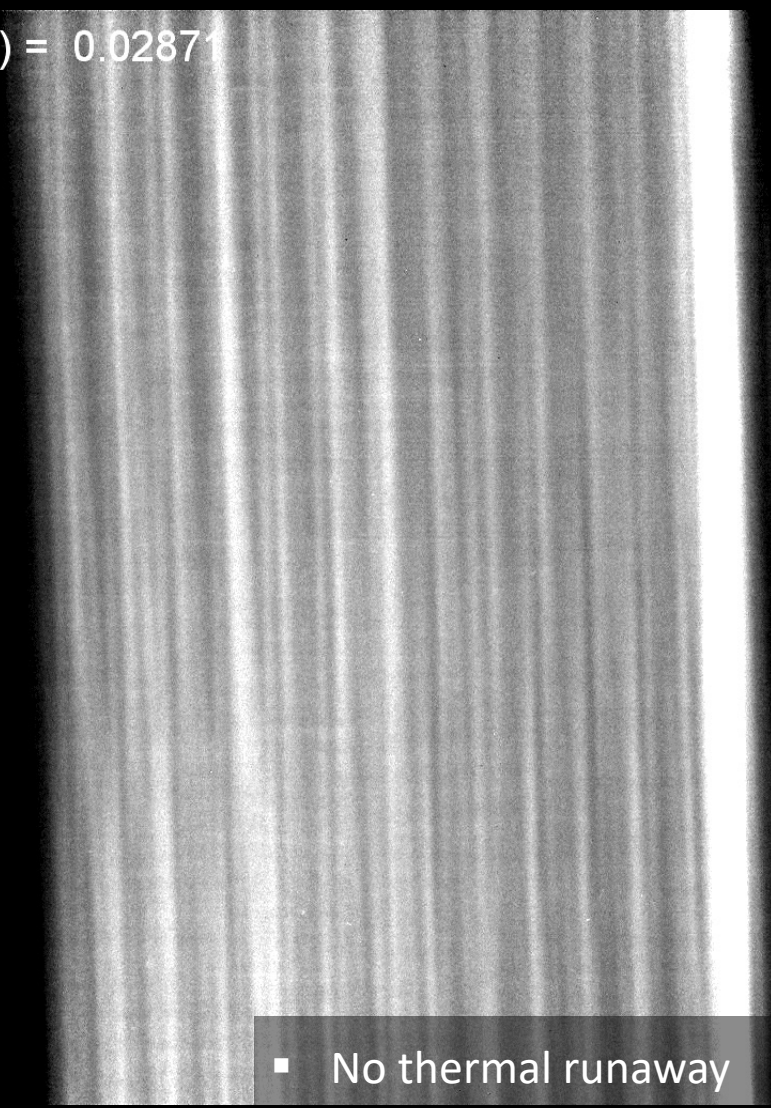
# Radiography at 3000 fps of Amprius cells

Control cell at 70% SOC




- Thermal runaway

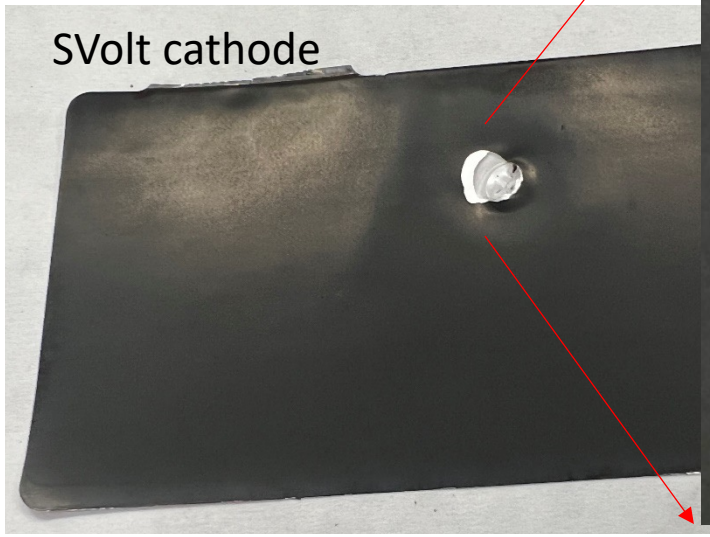
Cell with PCC at 70% SOC

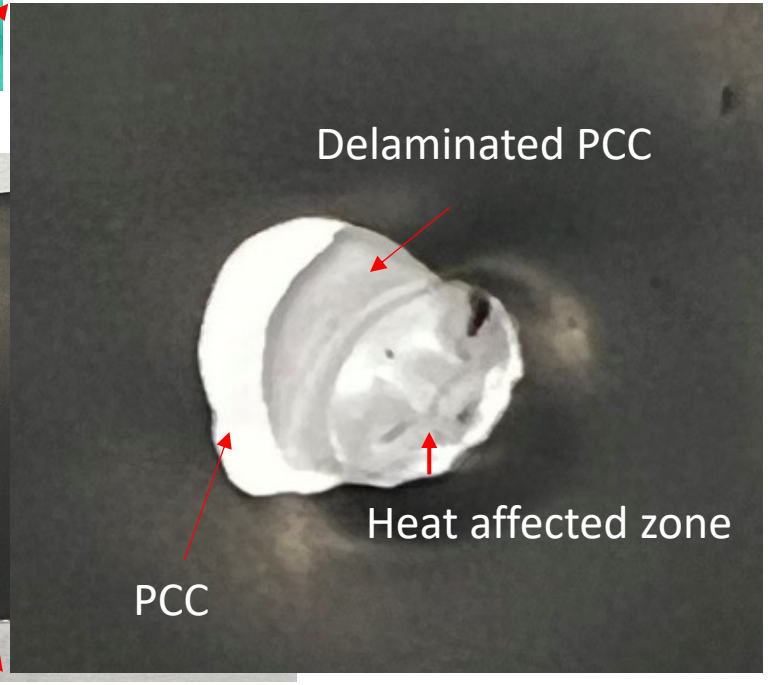



- No thermal runaway

# DPA Post PCC Response





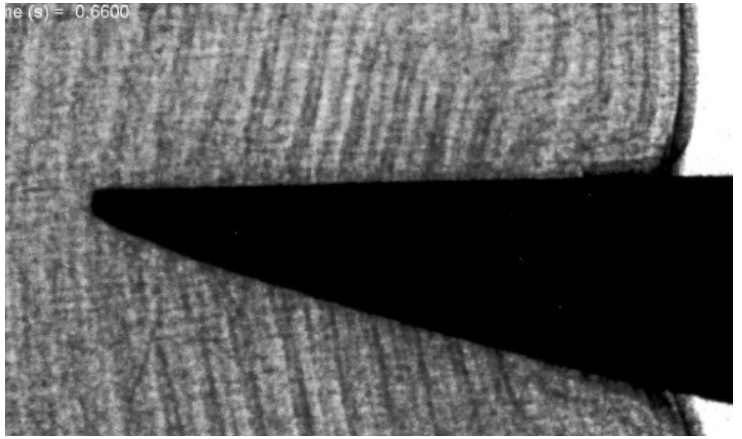

- Difficult unwinding due to melting of polyester
- CC and polyolefin separator ending glued together at nail interface
- Nail hole reveals thermally stressed PCC

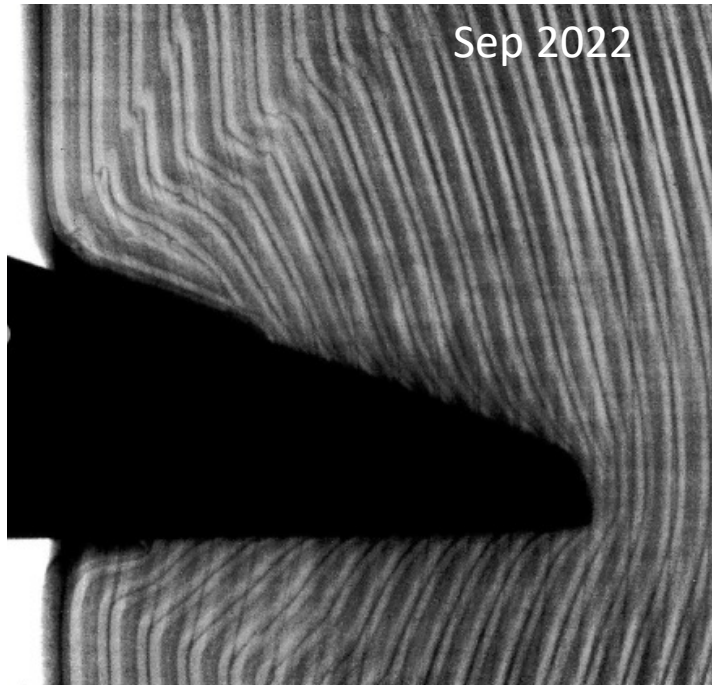
# Recap of our 2022 Effort

**Soteria polyester PCC reliable in tolerating nail penetration in 37 of 38 Li-ion cells tested in 2022**

- 2.1 Ah Coulometric 18650s (18 for 18)
- 2.75 Ah BAK 18650s (6 for 6)
- 4.5 Ah BAK 21700s (5 for 6)
- 10 Ah SVolt Pouch Cells (8 for 8)
- 3.6 Ah Amprius cells survived at 70% SOC or less

Feb 2022





# Conclusions

- The technology for plastic current collectors is improving, and cell manufacturers are becoming more skilled in its use.
- The PCC shows extremely strong resistance to TR from nail penetration, and provides compelling mechanical properties / mass savings.
- Al PCC seems sufficient, Cu PCC not necessary to prevent TR.
- Welding is still an issue for PCCs, but the technique is improving.
- Power capability is still lower than metal foils, but is approaching parity at slower rates.
- The PCC is now proven to be applicable to a wider range of cell formats and manufacturers, helping demonstrate usefulness to a broader market.

# Forward Work

- Use new radiography data to gain greater insight into fundamental mechanism of action  of plastic current collectors.
- Use new Fractional Thermal Runaway Calorimetry (FTRC) data to determine the effect of PCC on total output thermal energy for each format tested.
- Cross-Section and DPA cell carcasses further to attempt to see an “activated” Internal Short Circuiting Device (ISCD).
- Further develop ISCD thermal triggering method and collect more data.

# Thank you for listening

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