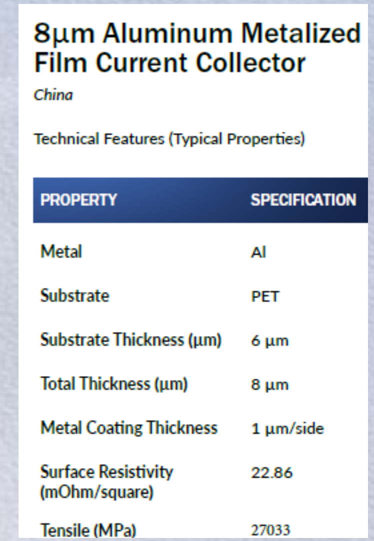
Metalized Plastic Current Collectors Isolating Internal Shorts in > 265 Wh/kg 21700 Cell Designs



8µm Aluminum Metalized Film Current Collector

China

Technical Features (Typical Properties)

PROPERTY	SPECIFICATION
Metal	Al
Substrate	PET
Substrate Thickness (µm)	6 µm
Total Thickness (µm)	8 µm
Metal Coating Thickness	1 µm/side
Surface Resistivity (mOhm/square)	22.86
Tensile (MPa)	27033

With beamtime at the European Synchrotron Radiation Facility

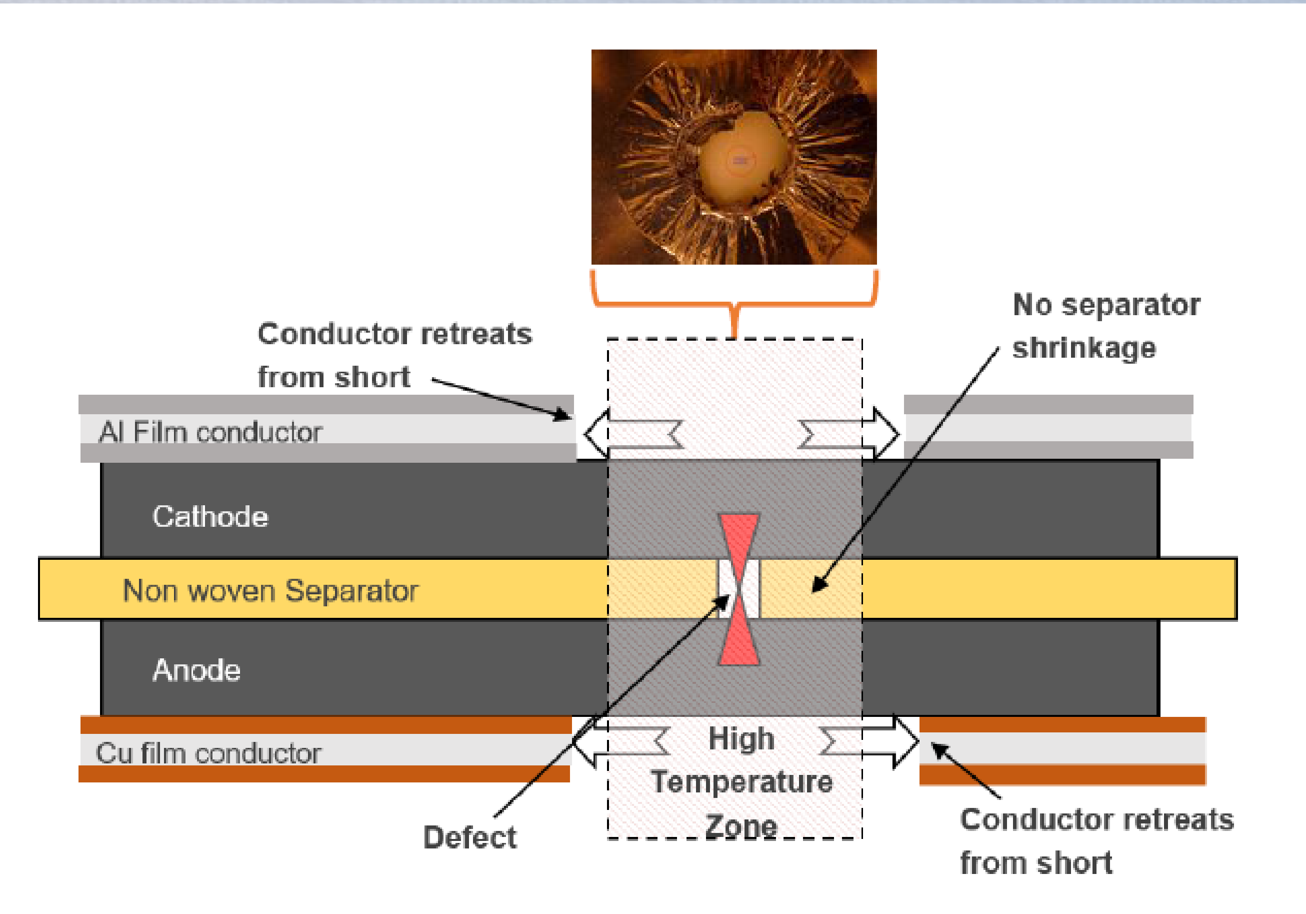
Presenter: Eric Darcy (NASA-JSC)

Advanced Automotive Battery Conference
Las Vegas, NV
9-11 Dec 2025

Contents

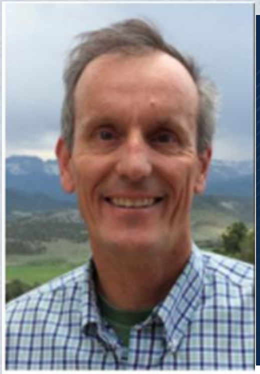
Motivation & Theory

- Motivation
  - What limits the effectiveness of Metallized Plastic Current Collectors (MPCCs) in isolating shorts?
  - Greatly reduce the design burden of achieving passive propagation resistance (PPR) batteries
- Theory
  - Plastic substrate of current collector thermally breaks down and isolates the electrochemically active materials from the defect within milliseconds



Graphics: B. Morin/Soteria

Team Effort



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- Alexander Rack/ESRF, Grenoble, France
- **Brian Morin and Joe Turner/SoteriaBIG, Greenville, SC, USA**
- **Forrest Gaskin and Ed Buiel/Coulometrics, Chattanooga, TN, USA**

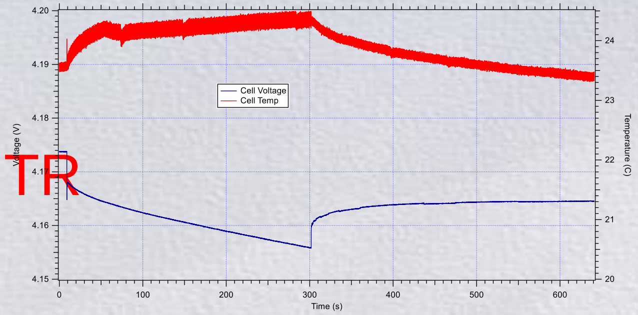
Acknowledgements

Thanks for the sponsors of our cell strategic reserve for funding this effort

- Orion, CCP, HLS, and NAVSEA

BAK 21700 4.6Ah Test Matrix and Results (Nail)

- Soteria metalized polyester (15)
  - PCC only on cathode (cell achieves 251 Wh/kg)
  - Cu foil on anode like all other features in control version
  - 14 of 15 cells tolerated nail penetration at 100% SoC
    - No fire, sparks, venting, or TR in those 14
    - Muted TR in 1 cell, generating ~50% kJ of control average
- Control cells (8)
  - Al and Cu foil CCs
  - All 8 cells went into TR



$\Delta t_{max} < 1°C$
$\Delta vmax < 19mV$

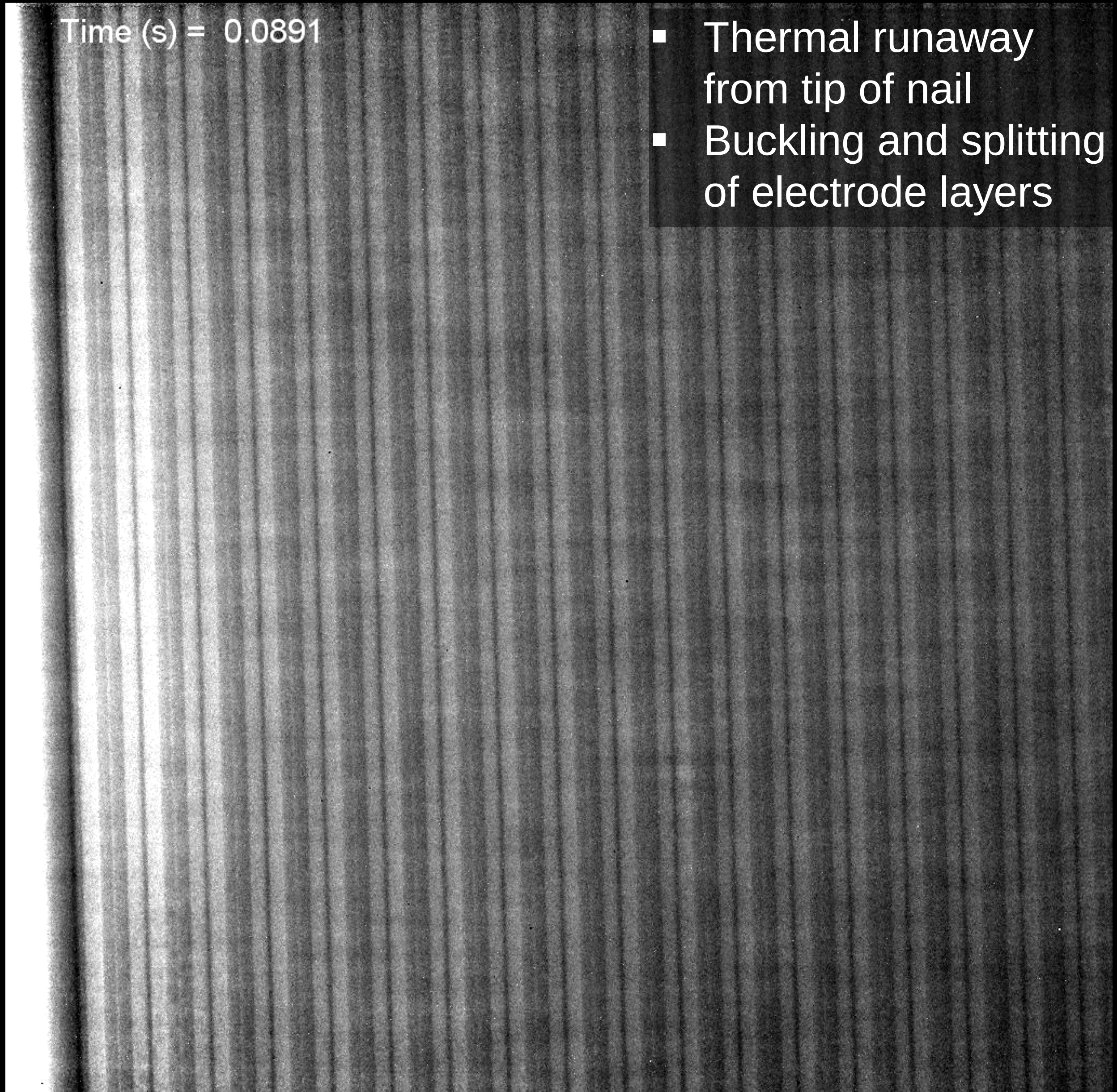
Tolerance demonstrated with near zero degradation of OCV!!!

Radiography at 3000 fps of 21700 cells

Dense material is dark (nail, can, NMC)

Control cell

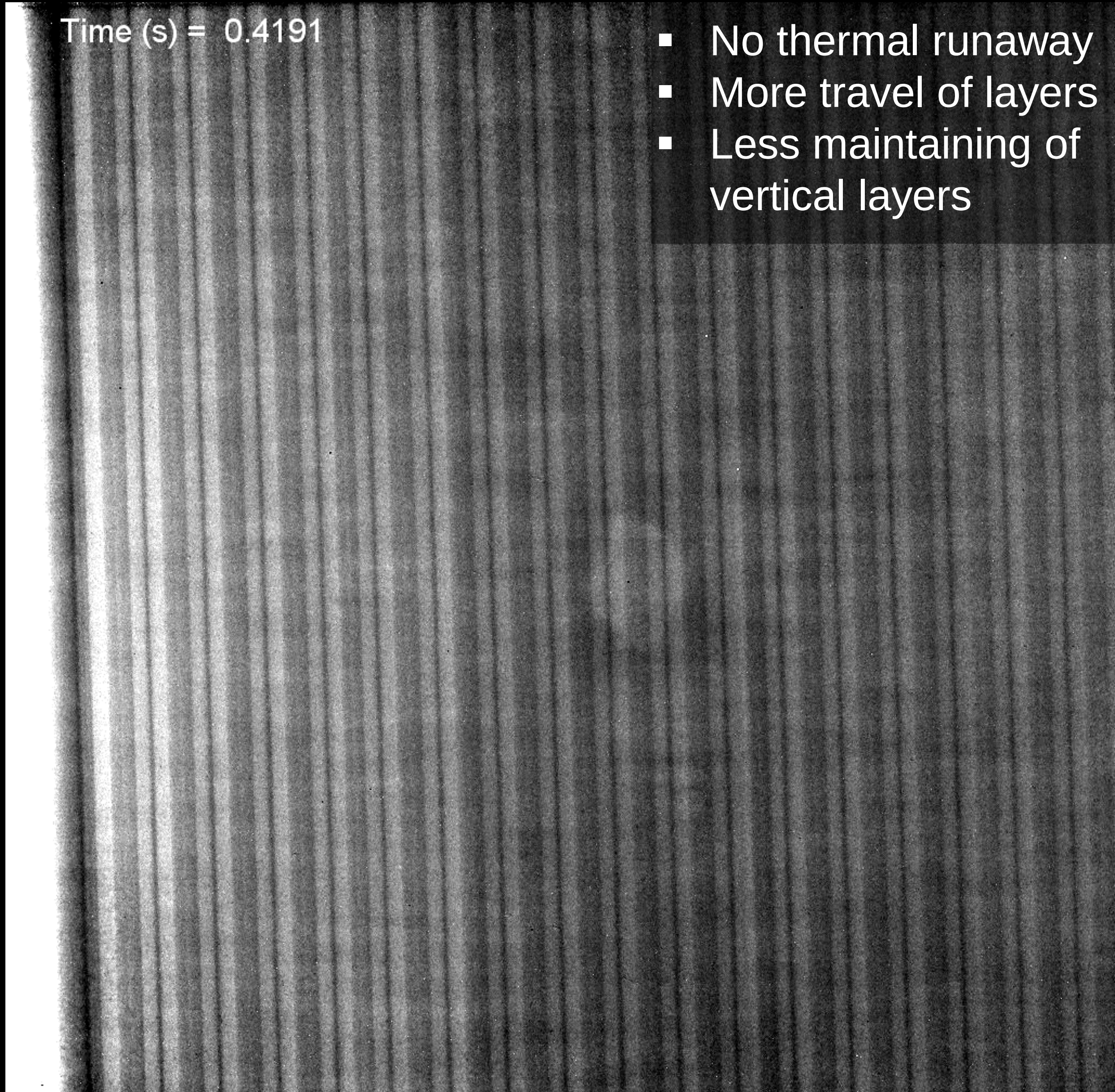
Run 025



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

Cell with PCC

Run 020

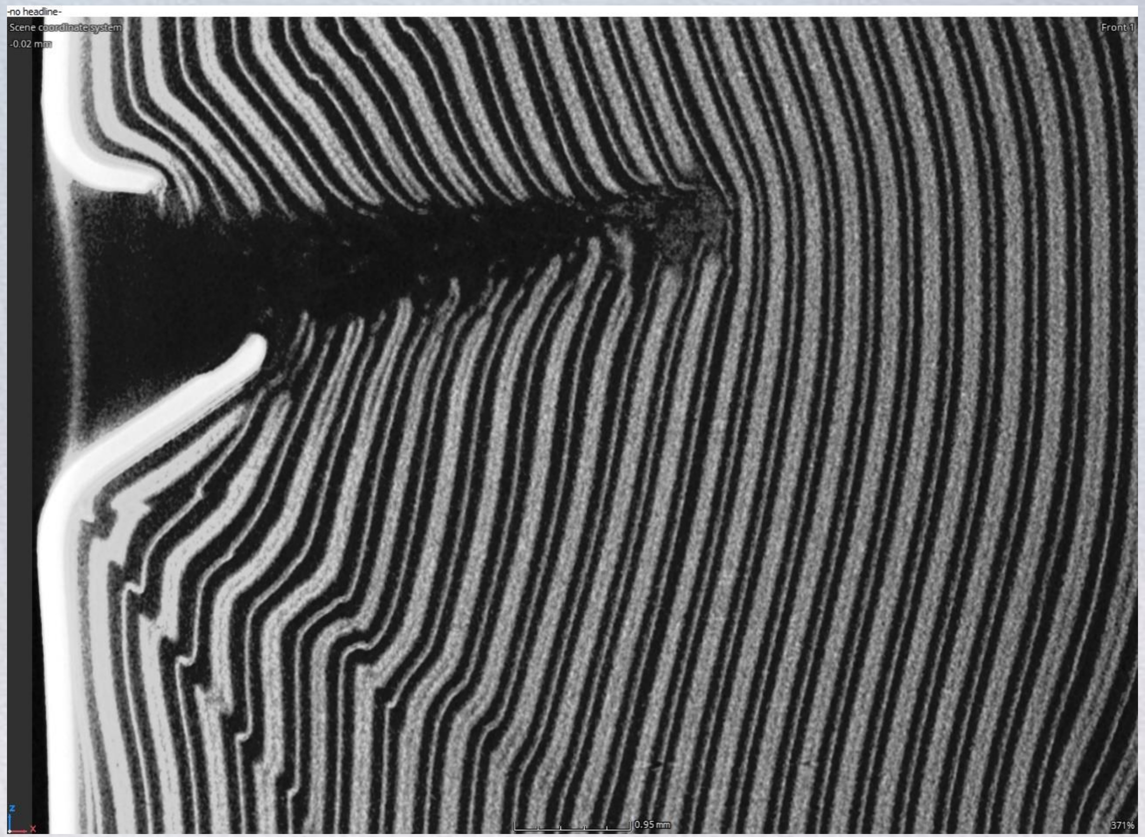


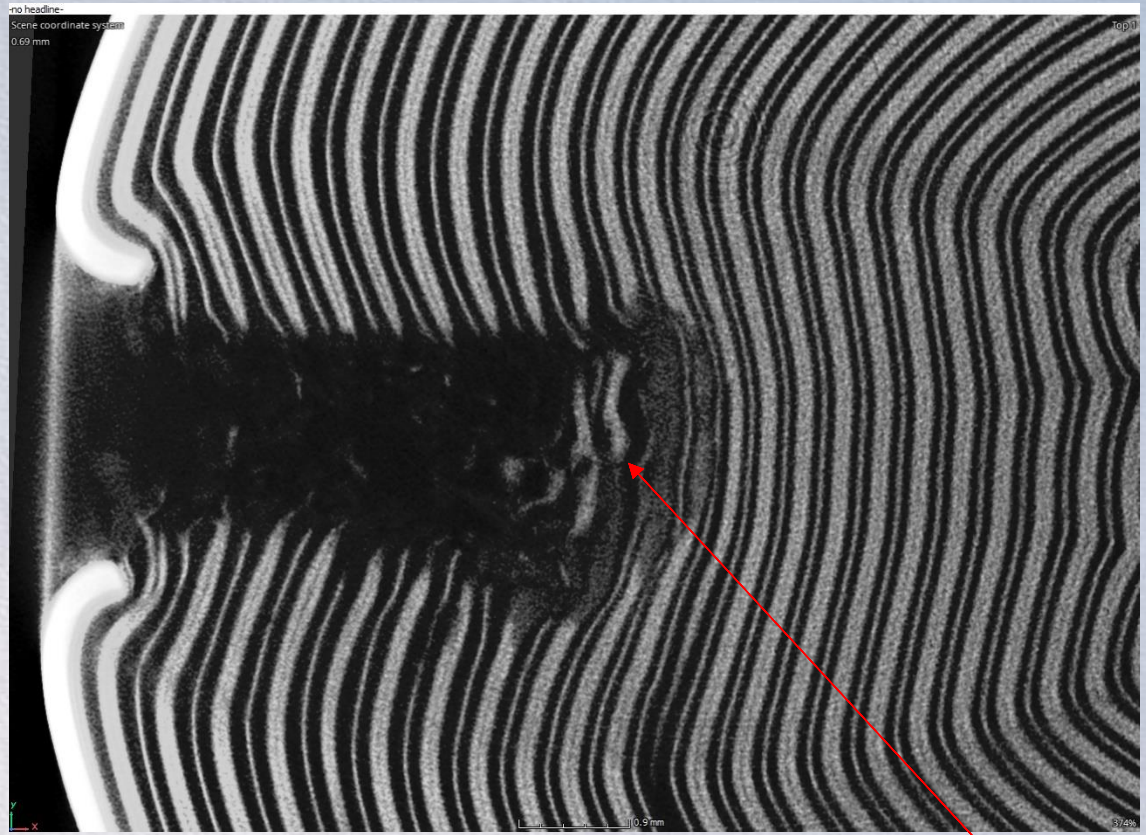
- No thermal runaway
- More travel of layers
- Less maintaining of vertical layers

CT Images of BAK 21700 with Cathode PCC

Axial view of nail penetration zone

Radial view of nail penetration zone





Stranded NMC

Reversing the image brightness from the video: Bright is most dense material, cell can, NMC
Al coated PCC for cathode is thin gray layer between NMC active material coatings.
Axial view shows cathode PCC is clearly missing at nail interface (split ends).

Pham et al., Cell Reports Physical Science, Volume 2, Issue 3, 100360, March 24, 2021

Higher Wh/kg Cell Designs & Test Matrix

Cell Format: 21700
Capacity: ~5.0Ah
Anode: Graphite
Cathode: Polycrystalline NMC811
Specific Energy: >265 Wh/kg
Made by Coulometrics in Chattanooga, TN

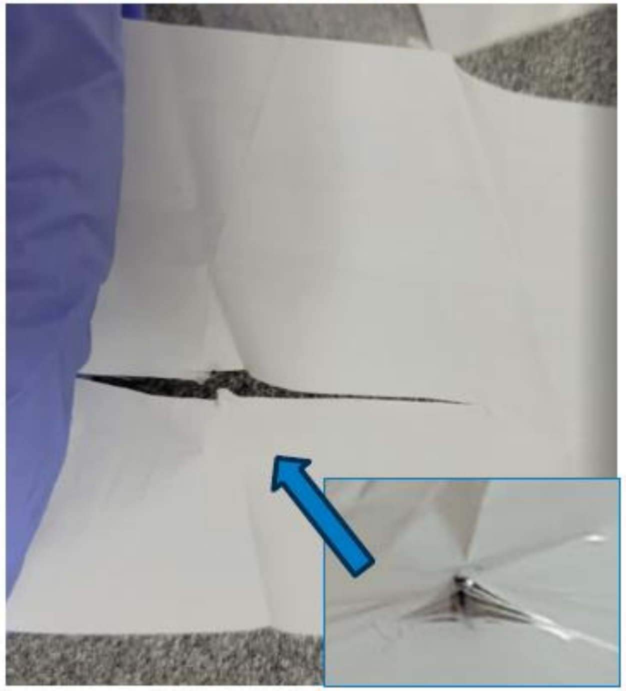
P/N	CC	Separator
N12	Al MPCC	All Ceramic (boehmite)
N13	Al MPCC	Ceramic coated polymer
N14	Metal foils	All Ceramic (Boehmite)
N15	Metal foils	Ceramic coated polymer

Run	Cell General Design	P/N	S/N
1	Coulometrics 4.95Ah with Al PCC and All Ceramic Sep	N12	19
2	Coulometrics 4.95Ah with Al PCC and All Ceramic Sep	N12	22
3	Coulometrics 4.95Ah with Al PCC and All Ceramic Sep	N12	25
4	Coulometrics 4.95Ah with Al PCC and All Ceramic Sep	N12	29
5	Coulometrics 4.95Ah with Al PCC and All Ceramic Sep	N12	30
6	Coulometrics 4.95Ah with Al PCC and All Ceramic Sep	N12	32
7	Coulometrics 4.95Ah with Al PCC and All Ceramic Sep	N12	35
8	Coulometrics 4.95Ah with Al PCC and All Ceramic Sep	N12	36
9	Coulometrics 4.95Ah with Al PCC and All Ceramic Sep	N12	40
10	Coulometrics 4.95Ah with Al PCC and All Ceramic Sep	N12	43
11	Coulometrics 4.95Ah with Al PCC and All Ceramic Sep	N12	46
12	Coulometrics 4.95Ah with Al PCC and All Ceramic Sep	N12	48
13	Coulometrics 5 Ah with Metal CC and All Ceramic Sep	N14	2
14	Coulometrics 5 Ah with Metal CC and All Ceramic Sep	N14	3
15	Coulometrics 5 Ah with Metal CC and All Ceramic Sep	N14	8
16	Coulometrics 5 Ah with Metal CC and All Ceramic Sep	N14	10
17	Coulometrics 4.95Ah with Al PCC and Ceramic Coated Sep	N13	1
18	Coulometrics 4.95Ah with Al PCC and Ceramic Coated Sep	N13	3
19	Coulometrics 4.95Ah with Al PCC and Ceramic Coated Sep	N13	4
20	Coulometrics 4.95Ah with Al PCC and Ceramic Coated Sep	N13	6
21	Coulometrics 4.95Ah with Al PCC and Ceramic Coated Sep	N13	7
22	Coulometrics 4.95Ah with Al PCC and Ceramic Coated Sep	N13	9
23	Coulometrics 4.95Ah with Al PCC and Ceramic Coated Sep	N13	10
24	Coulometrics 4.95Ah with Al PCC and Ceramic Coated Sep	N13	11
25	Coulometrics 4.95Ah with Al PCC and Ceramic Coated Sep	N13	12
26	Coulometrics 4.95Ah with Al PCC and Ceramic Coated Sep	N13	13
27	Coulometrics 4.95Ah with Al PCC and Ceramic Coated Sep	N13	16
28	Coulometrics 4.95Ah with Al PCC and Ceramic Coated Sep	N13	17
29	Coulometrics 4.95Ah with Al PCC and Ceramic Coated Sep	N13	19
30	Coulometrics 5 Ah with Metal CC and Ceramic Coated Sep	N15	3
31	Coulometrics 5 Ah with Metal CC and Ceramic Coated Sep	N15	4
32	Coulometrics 5 Ah with Metal CC and Ceramic Coated Sep	N15	6

Separator properties

Anisotropic

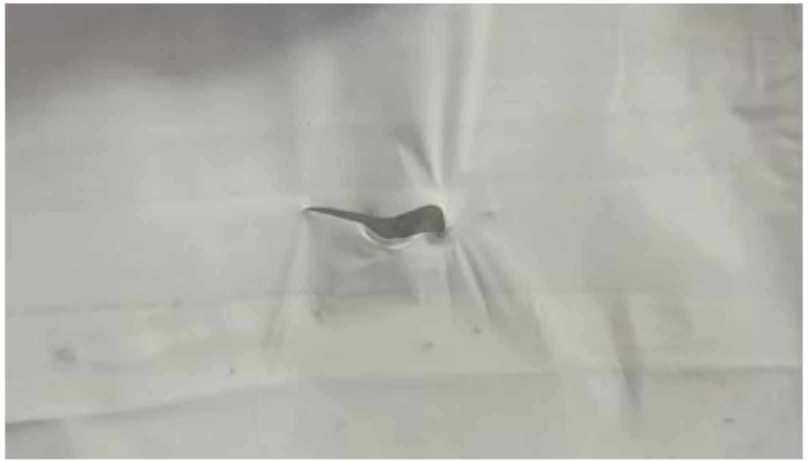
Ceramic-coated Celgard separator



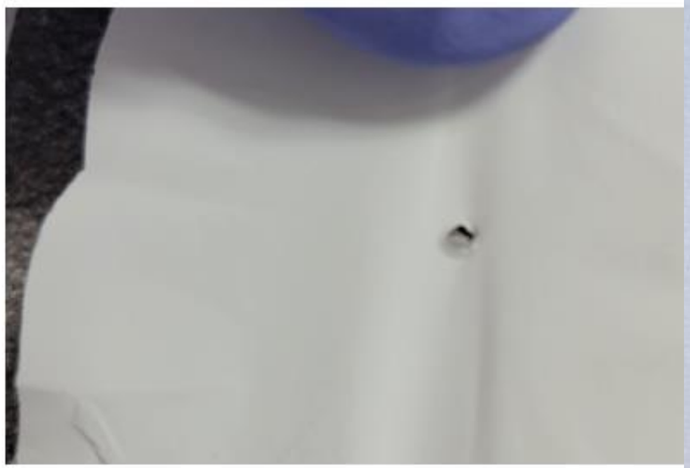
Anisotropic tensile strength incurs a large-area tear when deformed

Isotropic

BAK separator



All ceramic separator



Isotropic separators incur a symmetric small-area tear

The hypotheses

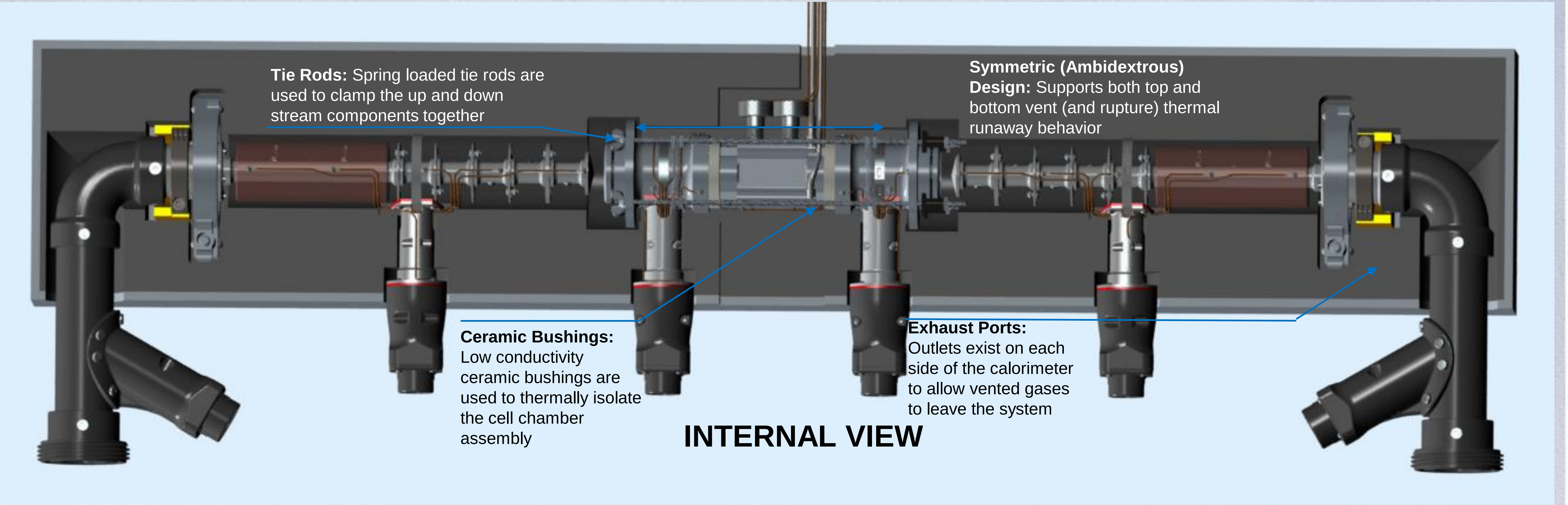
- The PCC prevents TR from the surface of the nail i.e. can isolate very localized high currents from small-area shorts
- The PCC cannot isolate wide-area shorts that arise from the separator splitting
- Preventing wide-area splitting requires changing the separator mechanical properties to be more ductile
- A combination of a PCC and a ductile, thermally-stable separator, may be the key combination to enhanced mechanical and thermal abuse tolerance

The challenges

- How to test localized small-area shorting if internal deformation leads to wide-area shorting?
- How to test the efficacy of separators in resisting splitting and wide-area shorting?

Fractional Thermal Runaway Calorimetry

- **The FTRC is designed to help characterize directional/fractional thermal runaway heat output:**
  - The cell chamber assembly is isolated from the remainder of the up and downstream calorimeter components with low conductivity ceramic bushings.
  - Maintaining thermal isolation is critical to our team's ability to discern the fraction of energy released through the cell casing vs. through the ejected material.
  - The ejecta mating segment is designed to capture and stop complete jellyroll ejections.

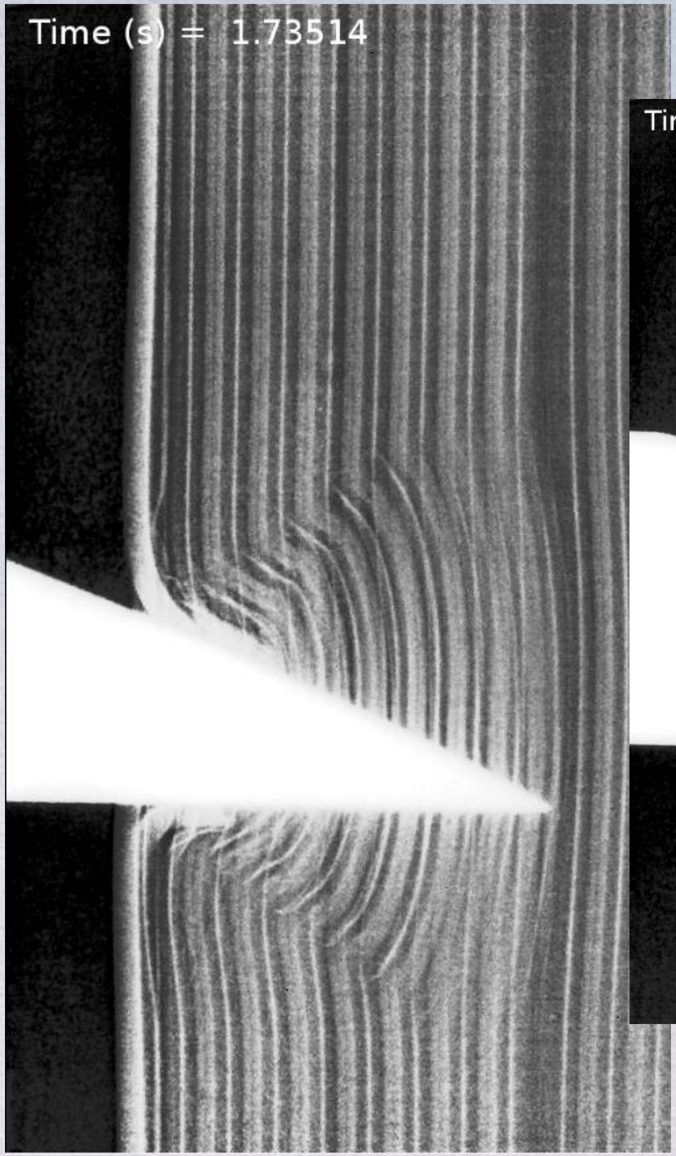


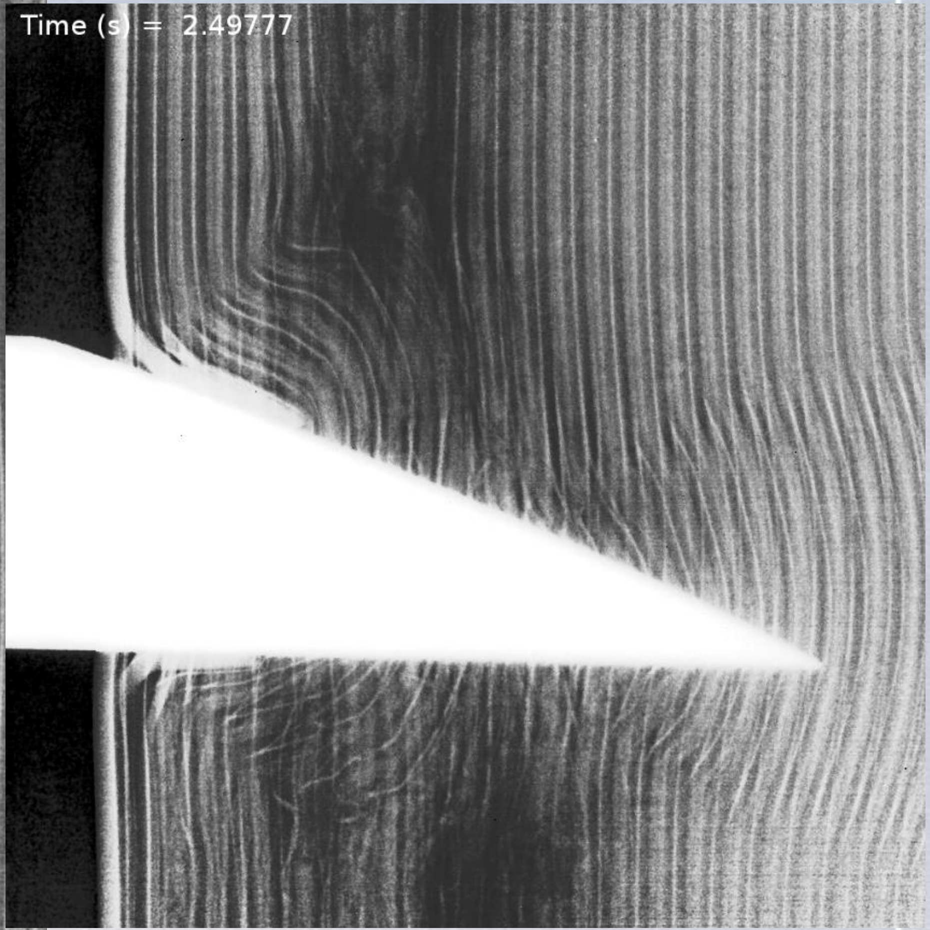
Chronological Summary

- N12 – MPCC & ACS - Started with 9mm slow nail
    - Runs 1-6: only 2 (#2 and #5) had no TR, the rest had delayed TR
    - Runs 7 & 8: Tried to make the nail more shallow, but not successfully (delayed TR)
    - Runs 9-11: Successfully reduced nail depth to 3-4 mm (No TR)
    - Run 12: Followed up shallow nail with a 9mm penetration in same spot (No TR)
- N14 – Metal CCs & ACS started with shallow, slow nail
    - 2 (#14 & #16) of 3 cells survived shallow nail
    - All went into TR with 2nd deeper penetration in same spot
- N13 – MPCC & CCS – Shallow nail for first 6 runs
    - No TR in all 6 runs (#17 to #22)
    - Deep nail resulted in No TR in 5 of 7 (#24 and #27) runs
- N15 – Metal CCs & CCS – Shallow nail resulted immediate TR in all 3 runs

Findings with Metal CCs

- Polymer ceramic coated separator
  - Immediate TR with slow, shallow nail (3 of 3)
- All ceramic separator (Boehmite)
  - 2 of 3 tolerated slow, shallow nail
  - 3 of 3 TRs after slow, deep nail



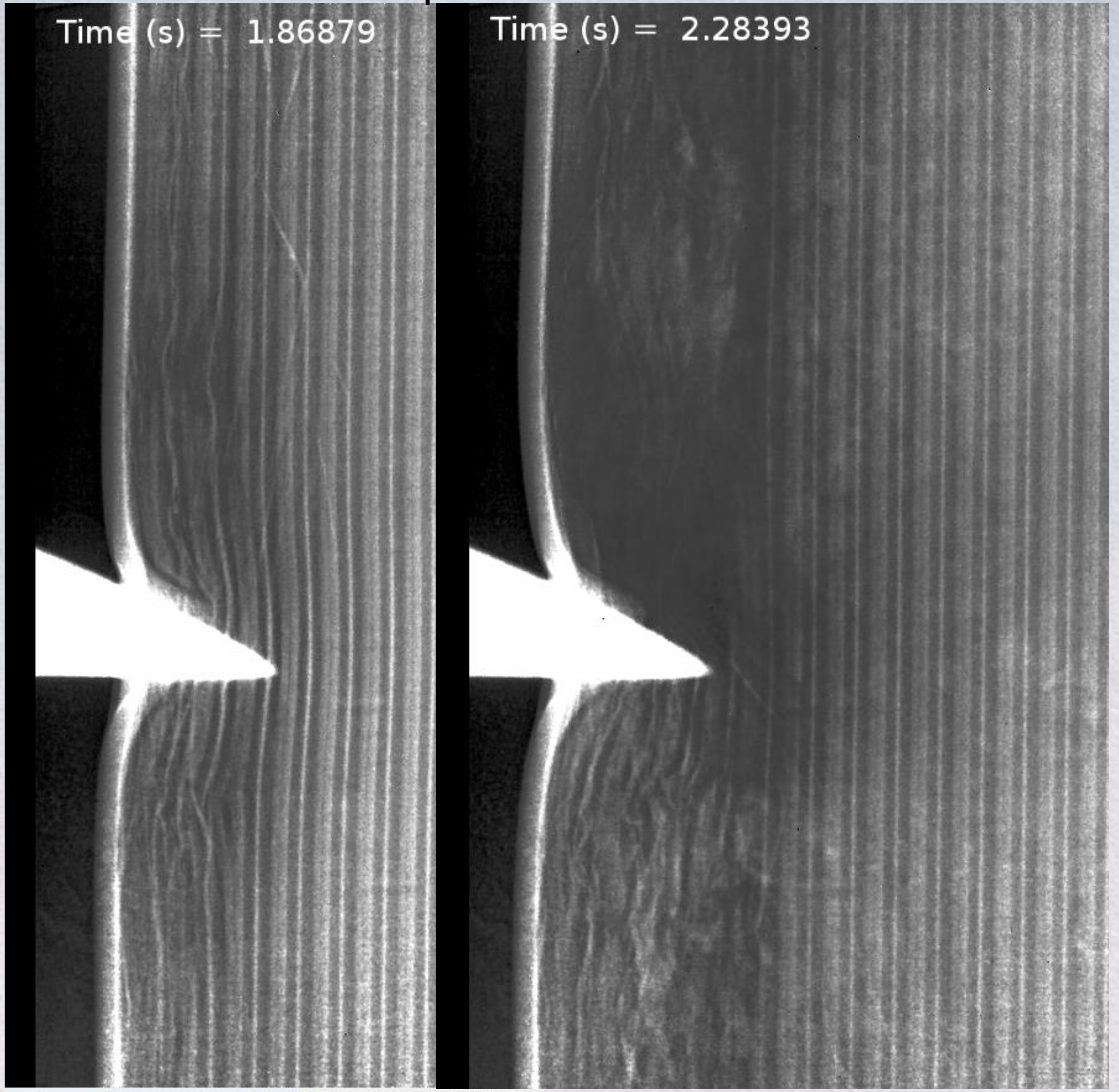


Delayed TR with All Ceramic Separator

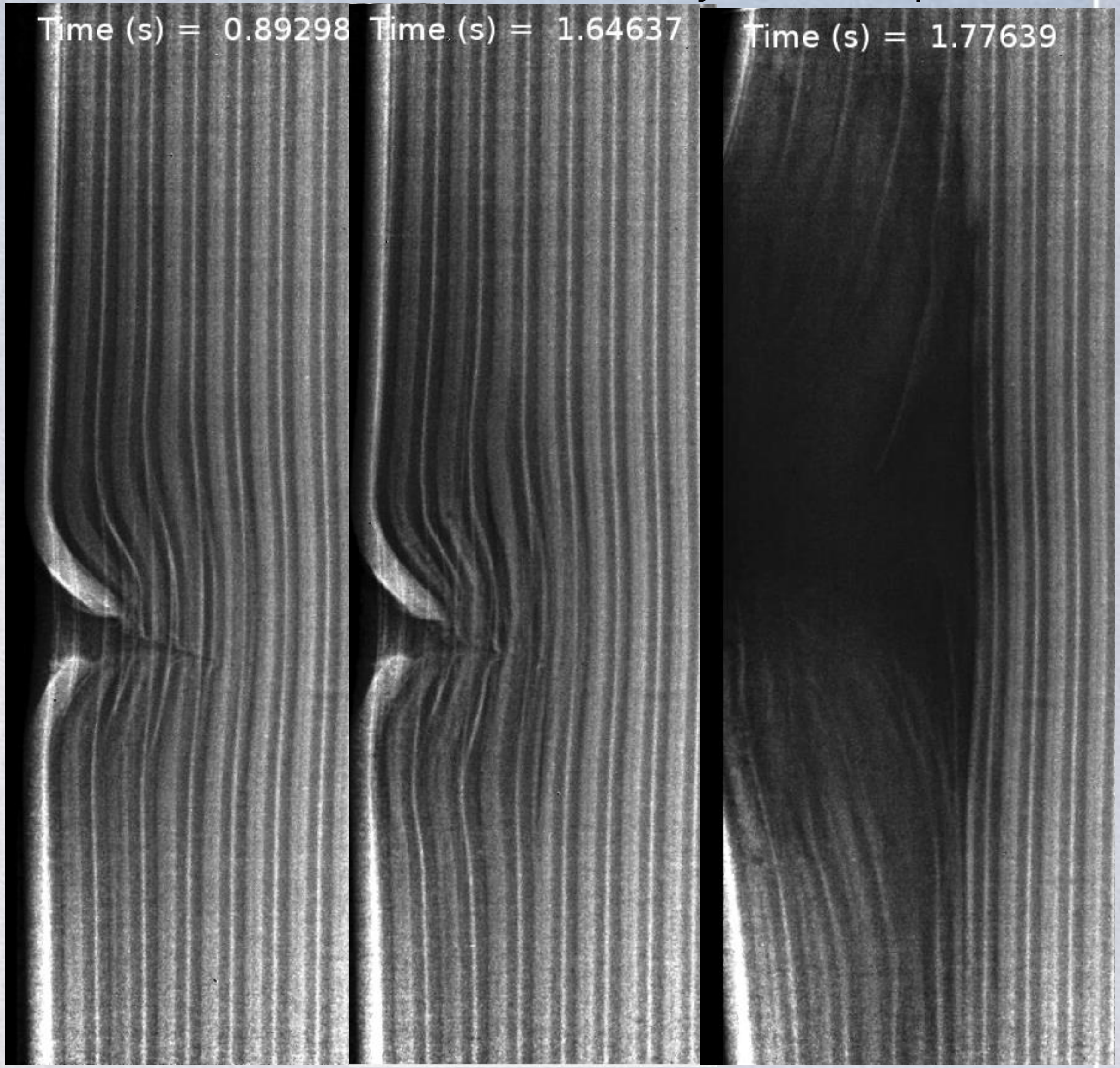
Ceramic Coated Polymer vs All Ceramic Separator

Both Cells with Metal Foil CCs and shallow nail

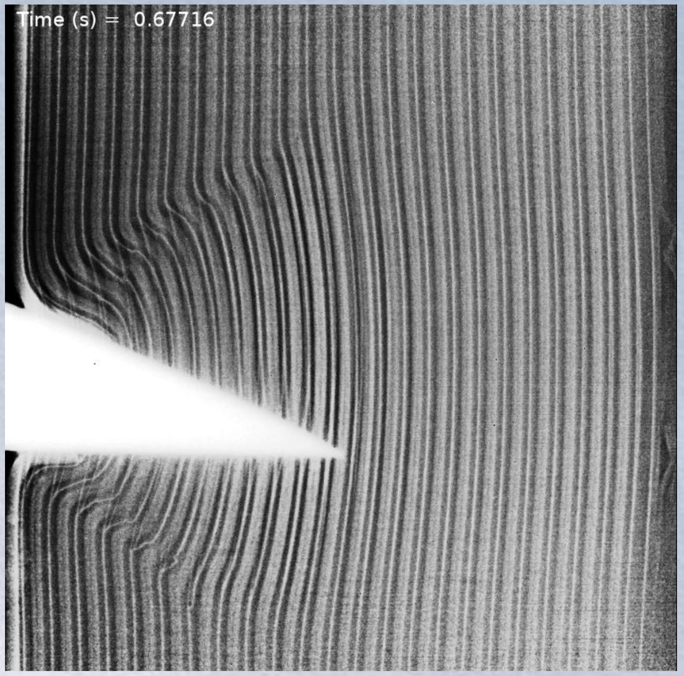
Immediate TR response

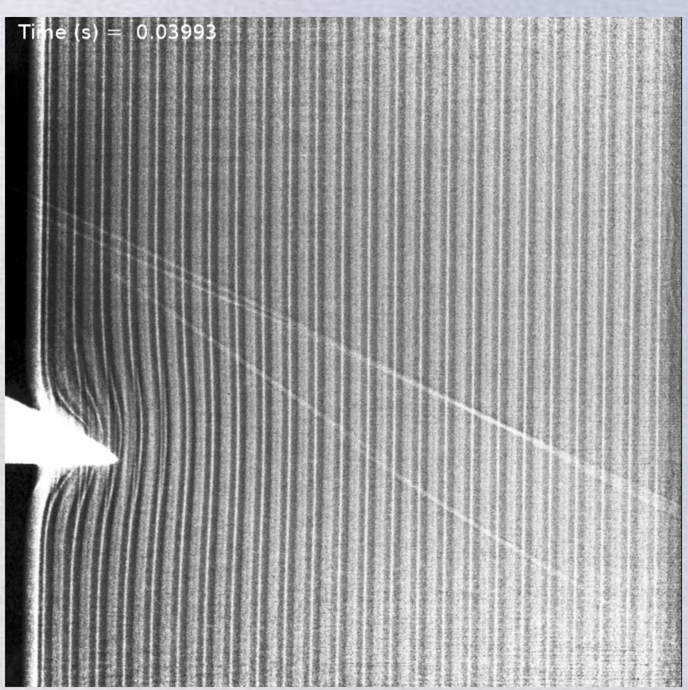


Delayed TR response



MPCC Findings





With All Ceramic Sep

- Delayed or no TR in all 12 runs
  - No TR in 2 of 8 runs with deep, slow nail
  - No TR in 4 of 4 runs with shallow, slow nail
    - 1 was followed up with deep nail in same spot

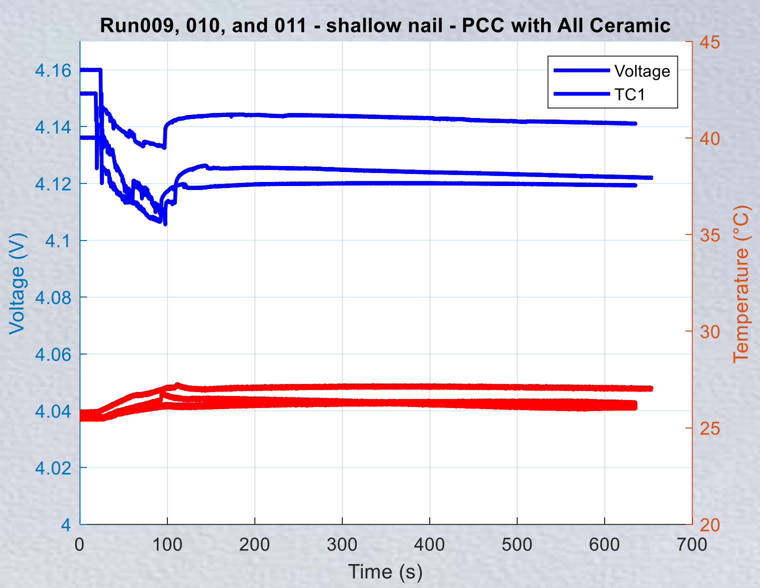
With Ceramic Coated Polymer Sep

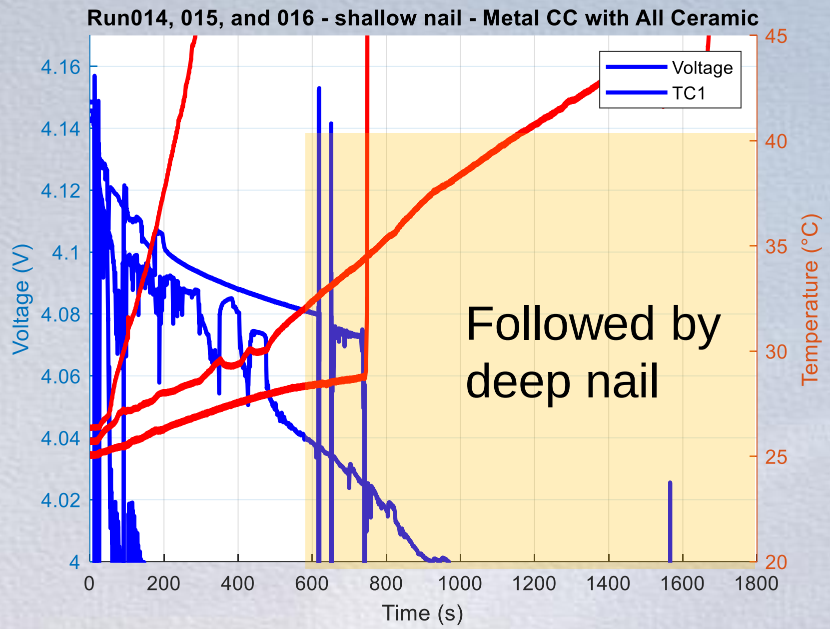
- Delayed or no TR in 11 of 13 runs
  - No TR in 6 of 6 with slow, shallow nail only
  - No TR in 4 of 7 with slow, deep nail
    - 2 (Runs 24, 27) immediate TR out of 13 runs

Shallow nail tests for Coulometric cells

PCC and all-ceramic

- Prevents TR
- Encounters a soft short while nail is in place
- Leads to isolated shoft after nail removed
- Minor self heating



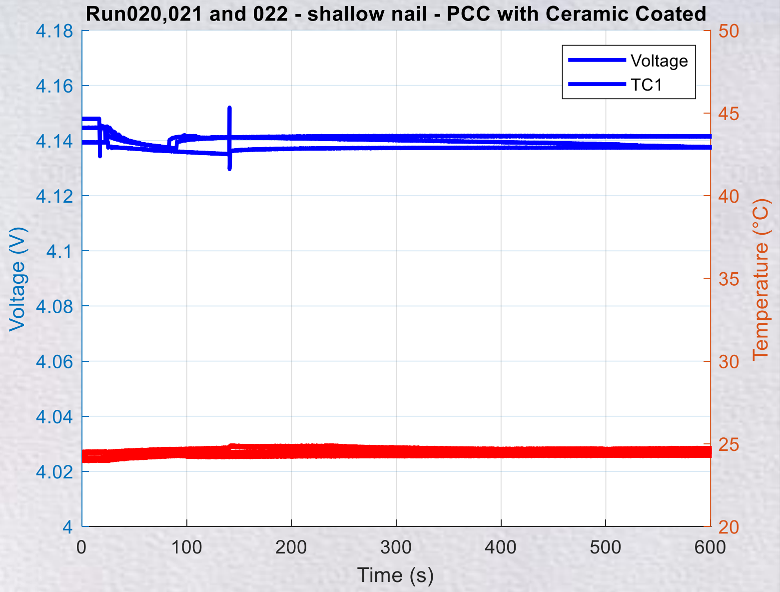


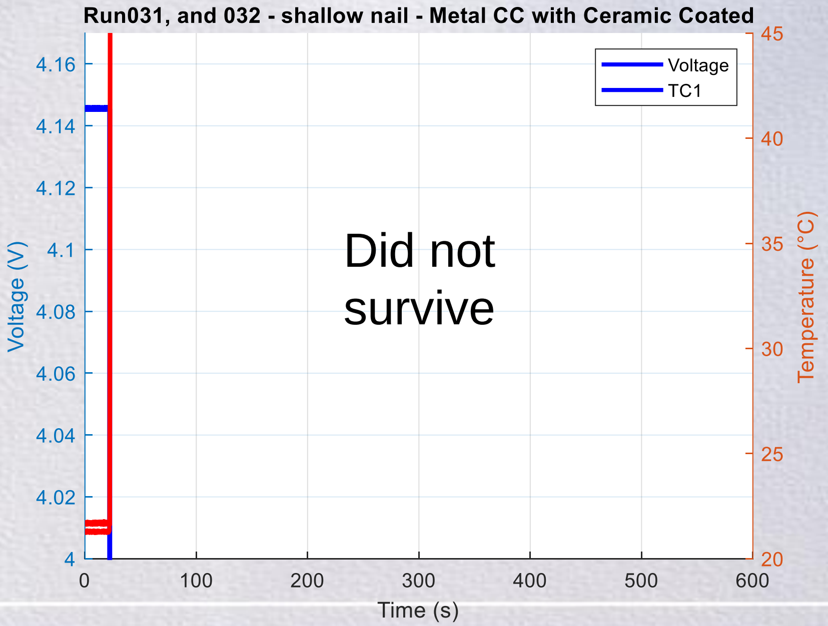
Metal CC and all-ceramic

- Soft- and hard-short while nail is inserted
- Significant self-heating
- Some improvement over the baseline cell by softening the short and self heating

PCC and ceramic-coated

- Prevents TR
- Soft short while nail is inserted
- Isolated short when nail is removed.
- Insignificant self heating





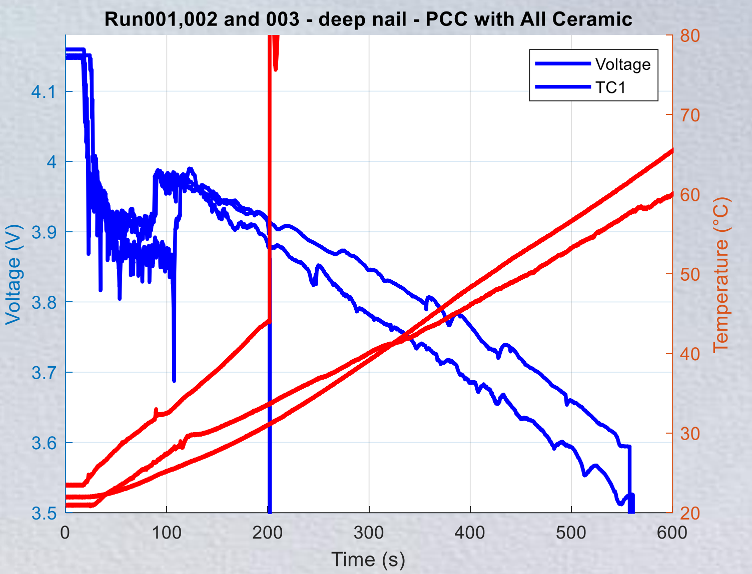
Metal CC and ceramic coated

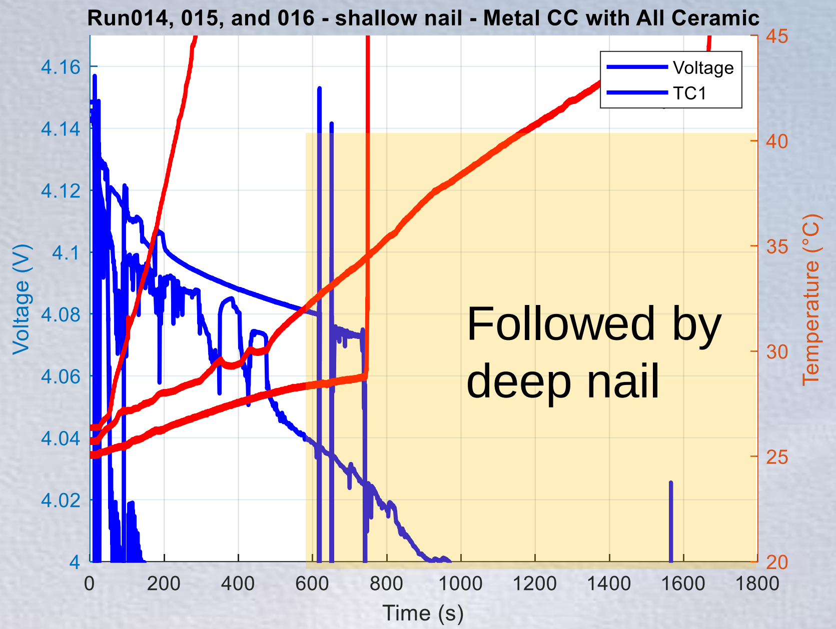
- TR immediately

Deep nail tests for Coulometric cells

PCC and all-ceramic

- All cells encountered a medium-short until they went into TR
- TR mostly happened within 5 mins, with one cell happening 15 mins later
- Still, some improvement over baseline





Metal CC and all-ceramic

- Soft- and hard-short while nail is inserted
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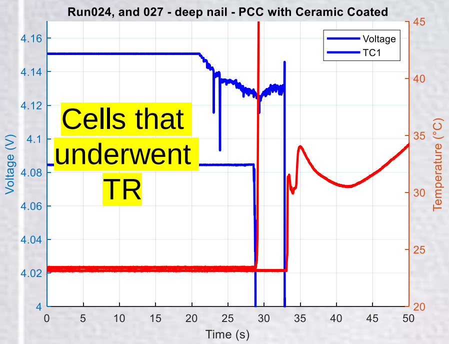
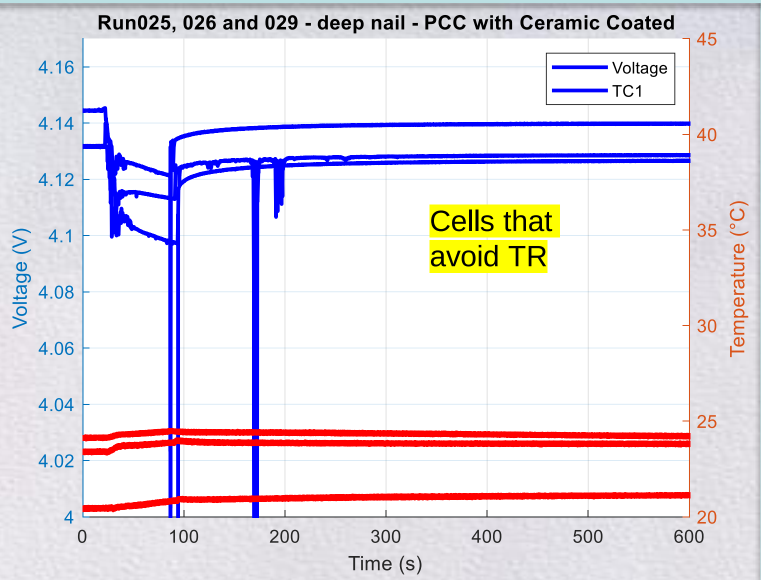
- Some improvement over the baseline cell by softening the short and self heating





PCC and ceramic-coated

- 2 cells went into TR
- Radiographs showed that one hit the tab and the other had a burr

Metal CC with ceramic coated
None survived past shallow nail

Metal CC and ceramic coated

- TR immediately

Overall Findings

Al MPCC in 21700 > 265 Wh/kg

- Delayed or No TR in 24 of 25 Runs
  - 1 immediate TR with CCS
  - 1 TR in delayed by 10s with CCS
- 10 for 10 in tolerating slow, shallow nail (with ACS & CCS)
- 6 for 14 in tolerating slow, deep nail (with ACS & CCS)

Nail parameters are important

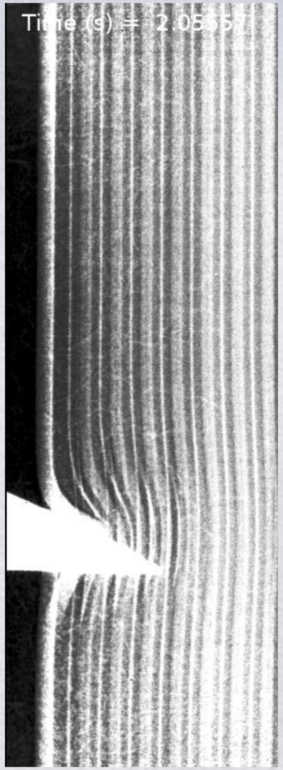
- Depth and speed of nail is important factor

Separator is critical

- ACS delayed TR even with metal foil CCs
  - But couldn’t prevent TR with deep nail
- Immediate TR with metal foil CCs and ceramic coated separator and slow, shallow nail
- BAK cells (<250Wh/kg) with Al MPCC & isotropic strength ceramic coated PE separator consistently prevented TR or shorts
  - Fast, deep nail at 100% SoC
  - Slow, deep indentations at 0% SoC

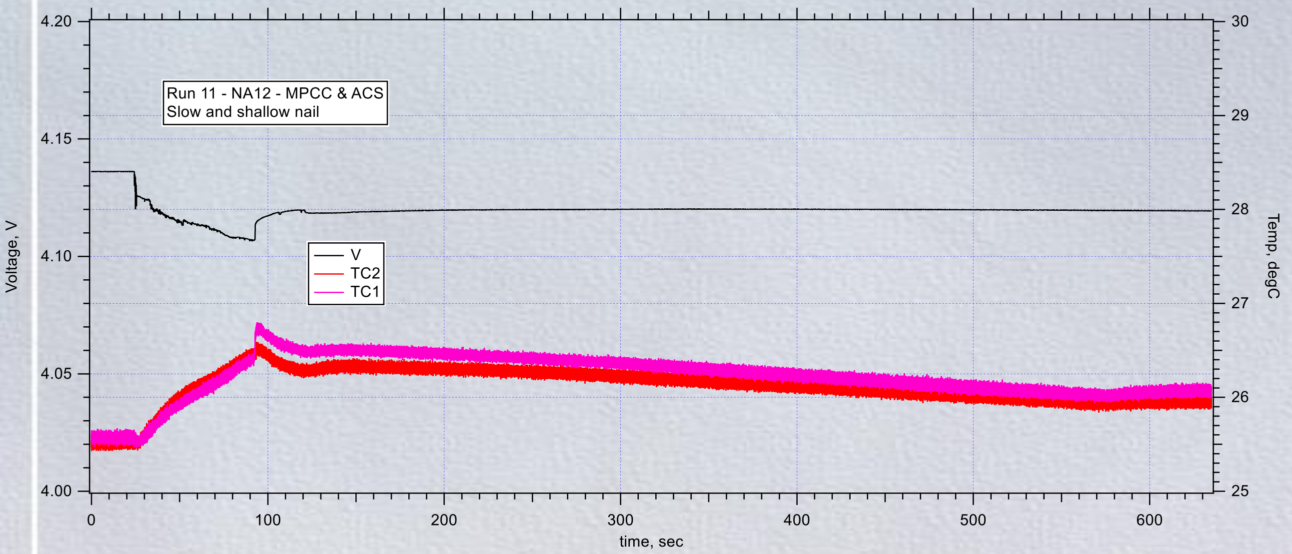
Shallow nail is more representative of a defect internal short

- Shallow nail attempts to short circuit 2-3 electrode pairs, while deep nail shorts 10-14 pairs and often impacts the positive tab.



Al MPCC with All Ceramic Separator
Shallow nail penetration
4 for 4 in nail tolerance

Run 11 – MPCC & ACS



Conclusions and Future Work

Conclusions

- Shallow nail tolerance demonstrated 10 of 10 times with Al MPCC and both separators
  - Show consistency and good promise for tolerating defect induced cell internal shorts

Future Work

- Combination of Al PCC and a strong isotropically stretchy separator is expected to lead to a robust mechanically-abuse tolerant cell design
  - New cell trials in work
- All Ceramic Separator is too fragile for high throughput cell winding
  - Need to improve its robustness