# SIDEWALL RUPTURE CHARACTERIZATION

## Molicel P45B with Thicker Spin Groove

**Jesus E. Trillo** [1], David Petrushenko [1], Zoran Bilc [2], Nicklas G. Owens [3], Eric Darcy [1]

[1] NASA Johnson Space Center
[2] S&K Engineering and Research
[3] Amentum Services, Inc

Trade names and trademarks are used in this report for identification only. Their usage does not constitute an official endorsement, either expressed or implied, by the National Aeronautics and Space Administration.

# ACRONYMS DEFINITION

| | |
|---|---|
| BR | Bottom Rupture |
| CB | Collar Breach |
| HR | Header Release |
| JRE | Jelly Roll Ejection |
| NTV | Nominal Top Vent |
| PPR | Passive Propagation Resistant |
| SGR | Spin Groove Rupture |
| SWR | Sidewall Rupture |
| TR | Top Rupture |

# GUIDELINES FOR PASSIVE PROPAGATION RESISTANT (PPR) BATTERIES

1. **Reduce the risk of cell can sidewall breaches (Sidewall and Spin Groove Ruptures)**
2. Provide adequate cell spacing and heat rejection
3. Individually fuse parallel cells
4. Protect the adjacent cells from the hot thermal runaway ejecta
5. Prevent flames and sparks from exiting the battery

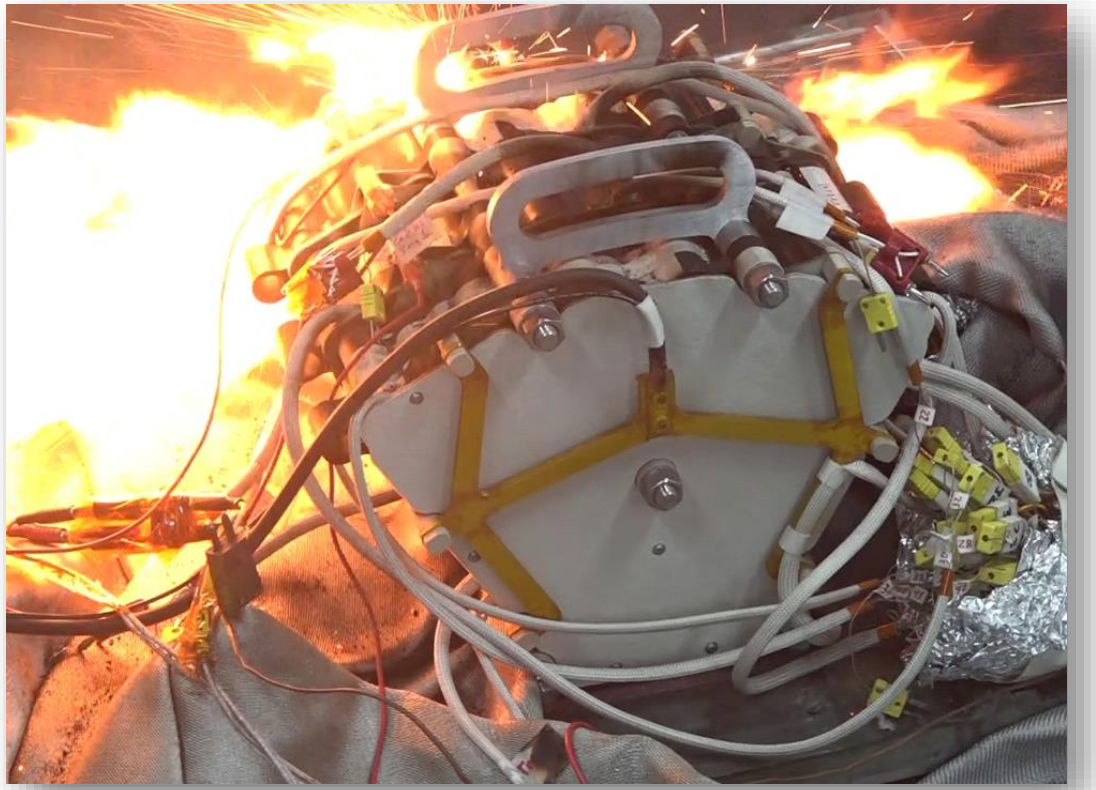


**Figure**: 134P-3S PPR battery pack developed by NASA successfully sustained 12 single trigger events without propagating thermal runaway

# THERMAL RUNAWAY (TR) SWR VIDEO



# SWR CHARACTERIZATION WITH **UNSUPPORTED** CELLS

## PROBLEM

Unsupported cell-level testing

=

False sense of low risk of SWR/SGR

Panasonic NCR A&B = 10% SWR/SGR

Samsung 30Q = 7% SWR/SGR

=

Costly PPR test failures (under-design)



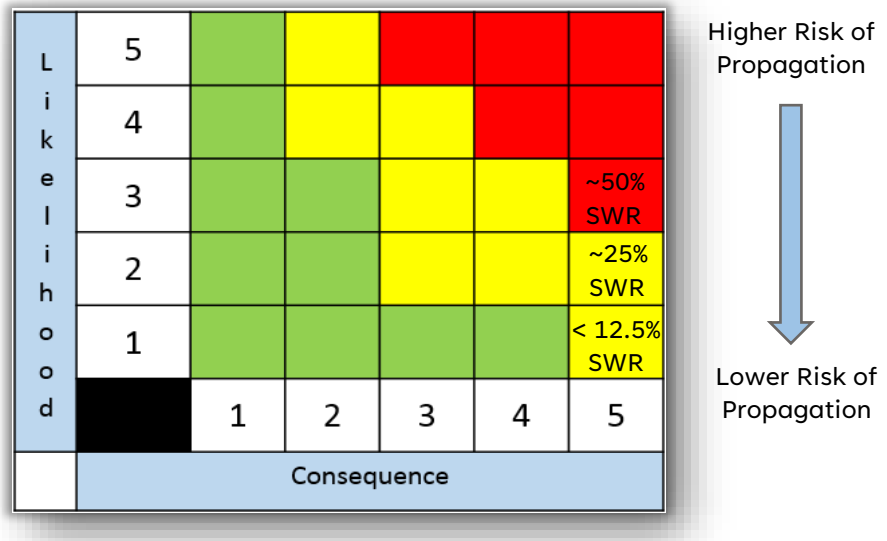



**Figure**: Likelihood versus consequence matrix

# SWR CHARACTERIZATION WITH **UNSUPPORTED** CELLS

## SOLUTION

1. Design a test article that includes battery specific cell constraints and features
2. Test enough cells to obtain statistically defendable results
   - [1] Assuming a lot of 60,000 cells, 5% margin of error and 70% estimated proportion- test 270 cells to achieve 93% confidence level

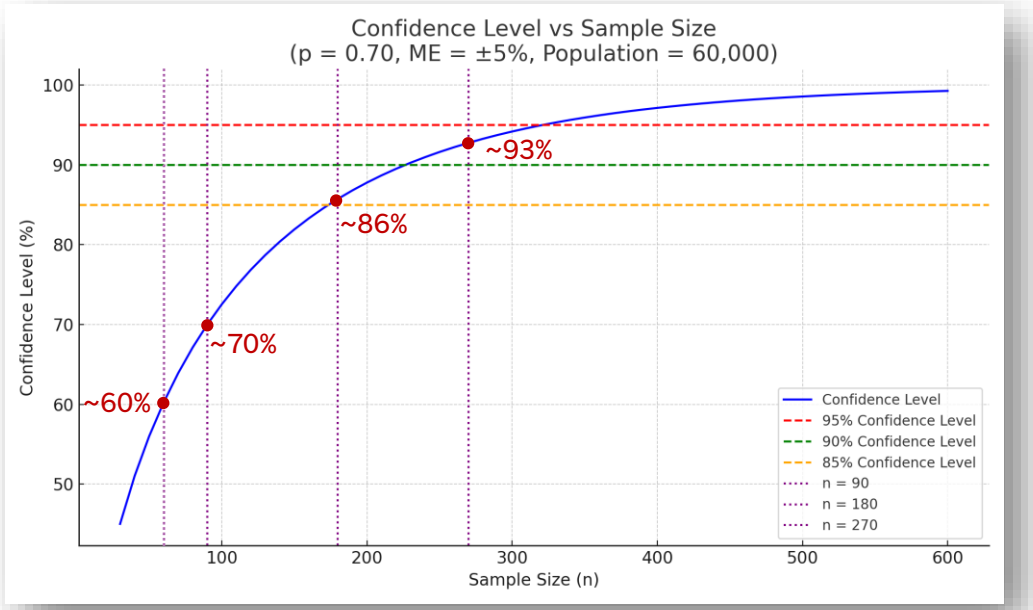



**Figure**: Confidence level vs. Sample size

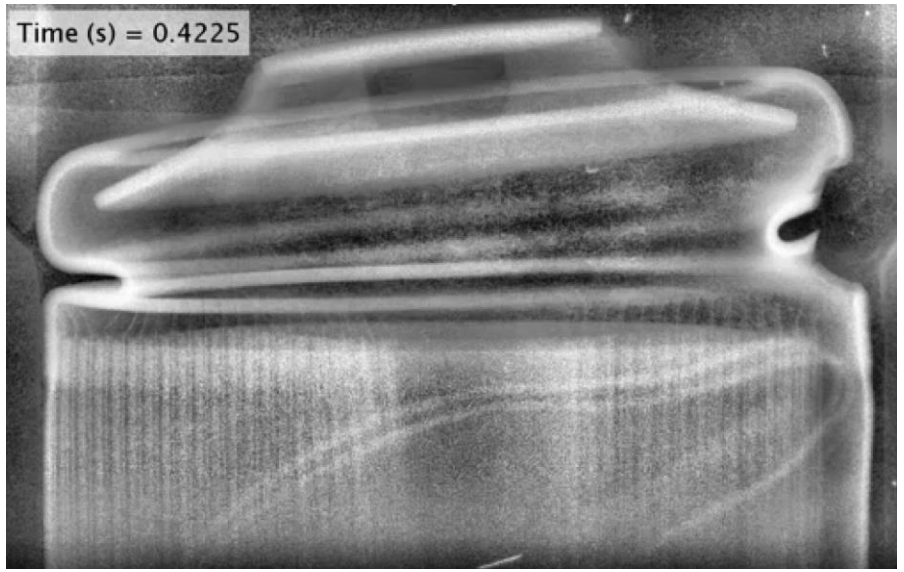


[1]Daniel, W. W., & Cross, C. L. (2018). Biostatistics: a foundation for analysis in the health sciences. Wiley.

# BENEFITS OF SWR CHARACTERIZATION

SWR characterization provides the baseline understanding needed to evaluate and mitigate rupture risks in lithium-ion cells and battery packs, key benefits include:

- Safer cell selection
- Informed pack design trade-offs (protection vs weight/volume)
- Quantitative input for Probability Risk Assessment (PRA)
- Objective cell manufacturer communication




- Note: No cell will ever be 100% free of sidewall and spin groove rupture risk, but knowledge is power.



[1]Daniel, W. W., & Cross, C. L. (2018). Biostatistics: a foundation for analysis in the health sciences. Wiley.

# TEST ARTICLE AND SET UP

# 21700 SIDEWALL RUPTURE TEST ARTICLE

- 10 cell test article designed to evaluate the propensity of 21700 cylindrical cells to sidewall/spin groove rupture during thermal runaway (TR)
- Test article designed to separates neighboring cells to prevent pre-TR biasing
- Test article captures pertinent features of the battery pack design:
  - Heat sink material and cell-to-cell wall thickness
  - Cell preparation and installation
  - Heat rejection path
  - Bus plate and blast plate features

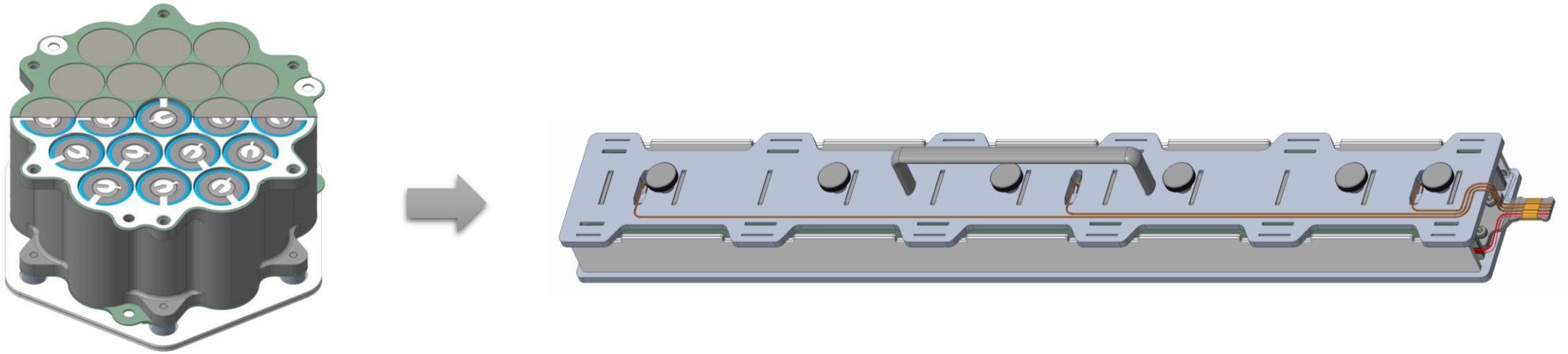
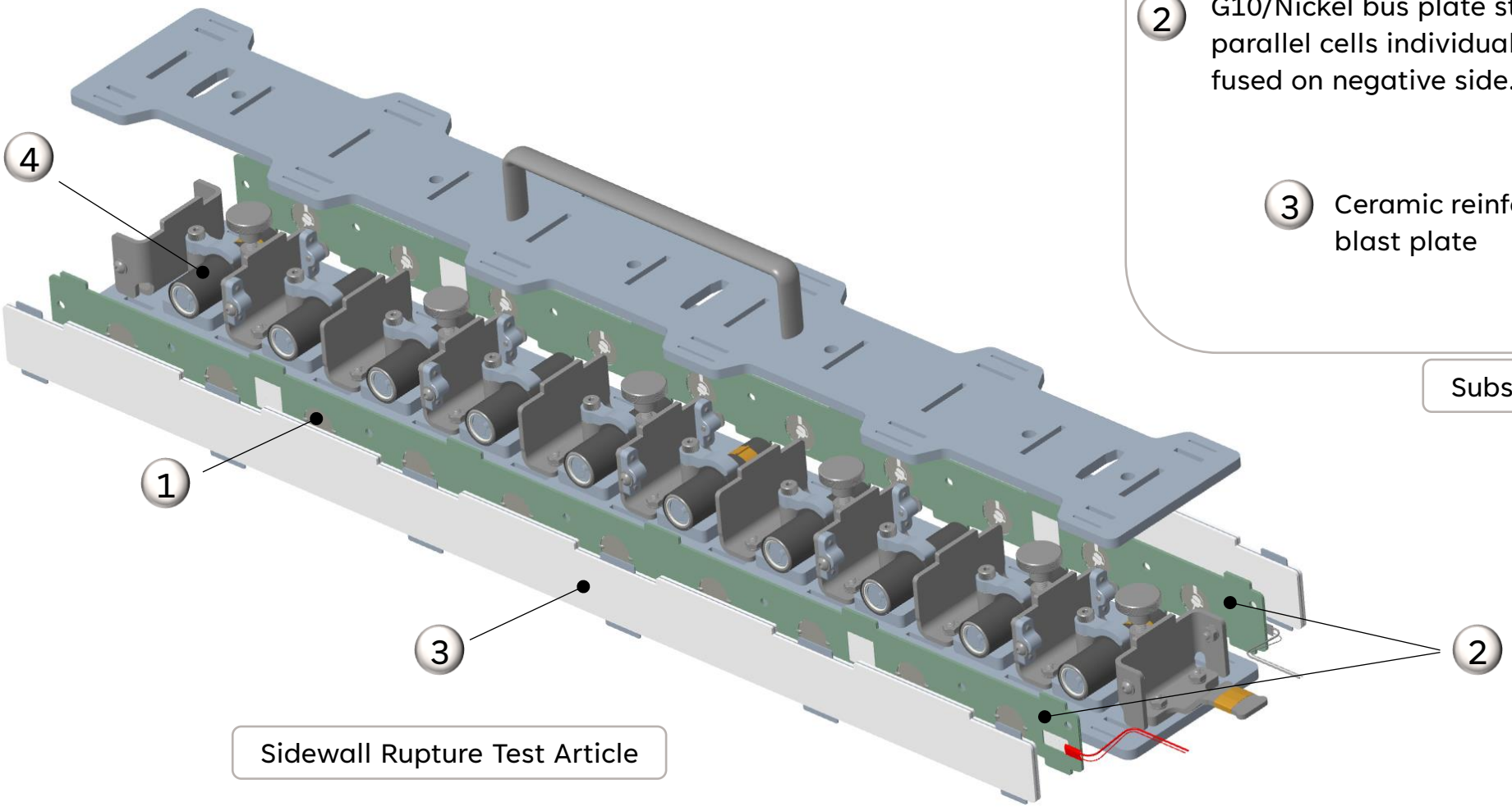


**Figure:** 21700 Sidewall rupture test article (right) designed to capture pertinent features of 21700 battery pack (left – subscale pack shown)

# TEST ARTICLE DESCRIPTION



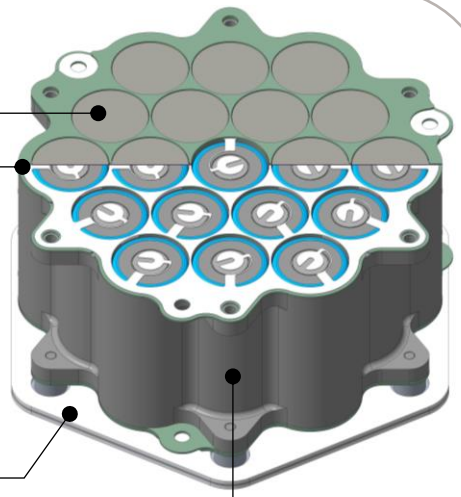

Sidewall Rupture Test Article

1 Mica covers protect adjacent cells from ejecta.

2 G10/Nickel bus plate stack, parallel cells individually fused on negative side.

3 Ceramic reinforced blast plate

4 Heat path through heat sink/cell body.

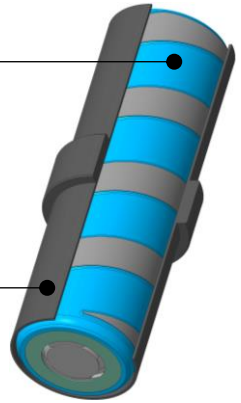


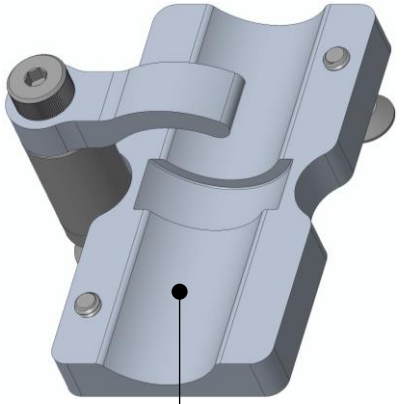
Subscale Battery Pack

# CELL PREPARATION

Cells are prepared the same as battery pack with mica ribbon and shrink tube.

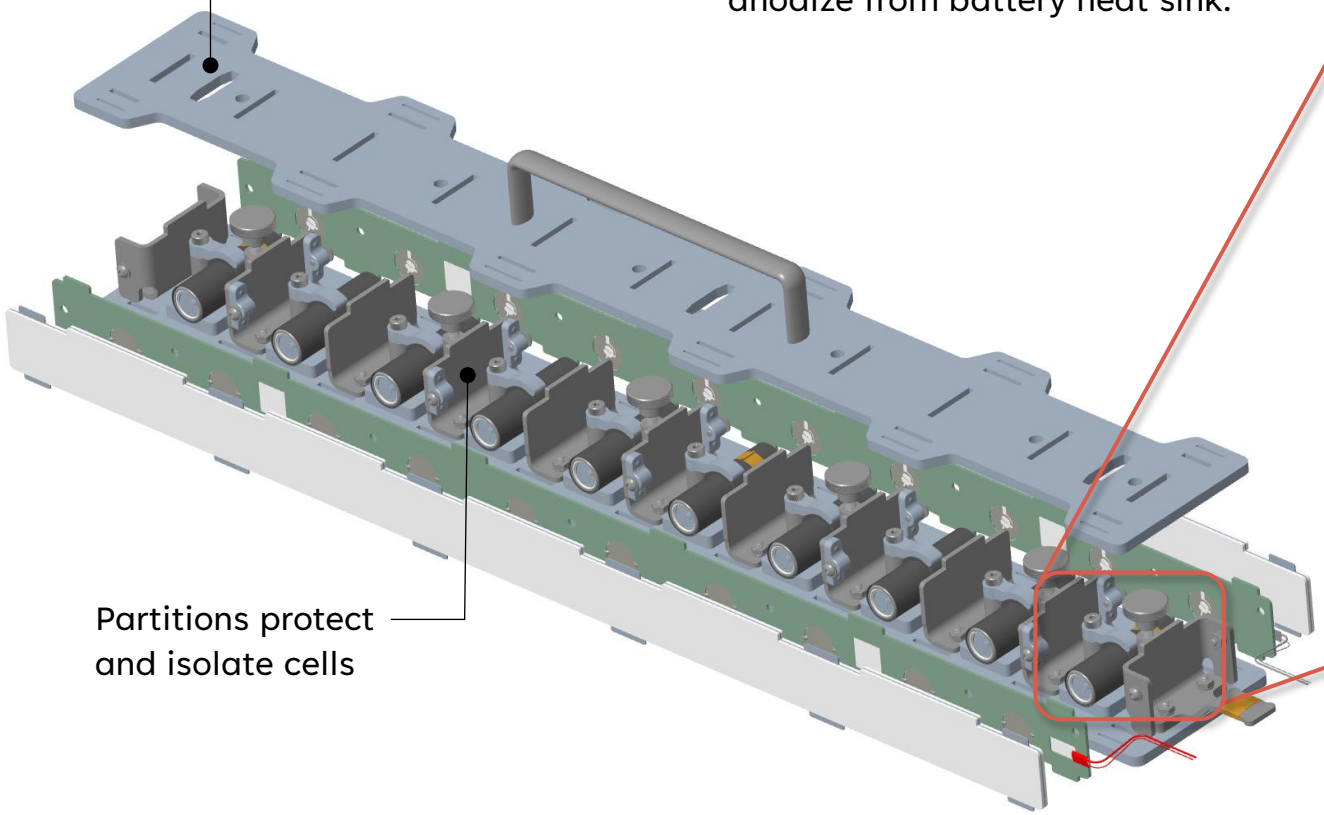
Aluminum cell tube replicates wall thickness (0.020”) and anodize from battery heat sink.





Cradle secures cell in place.

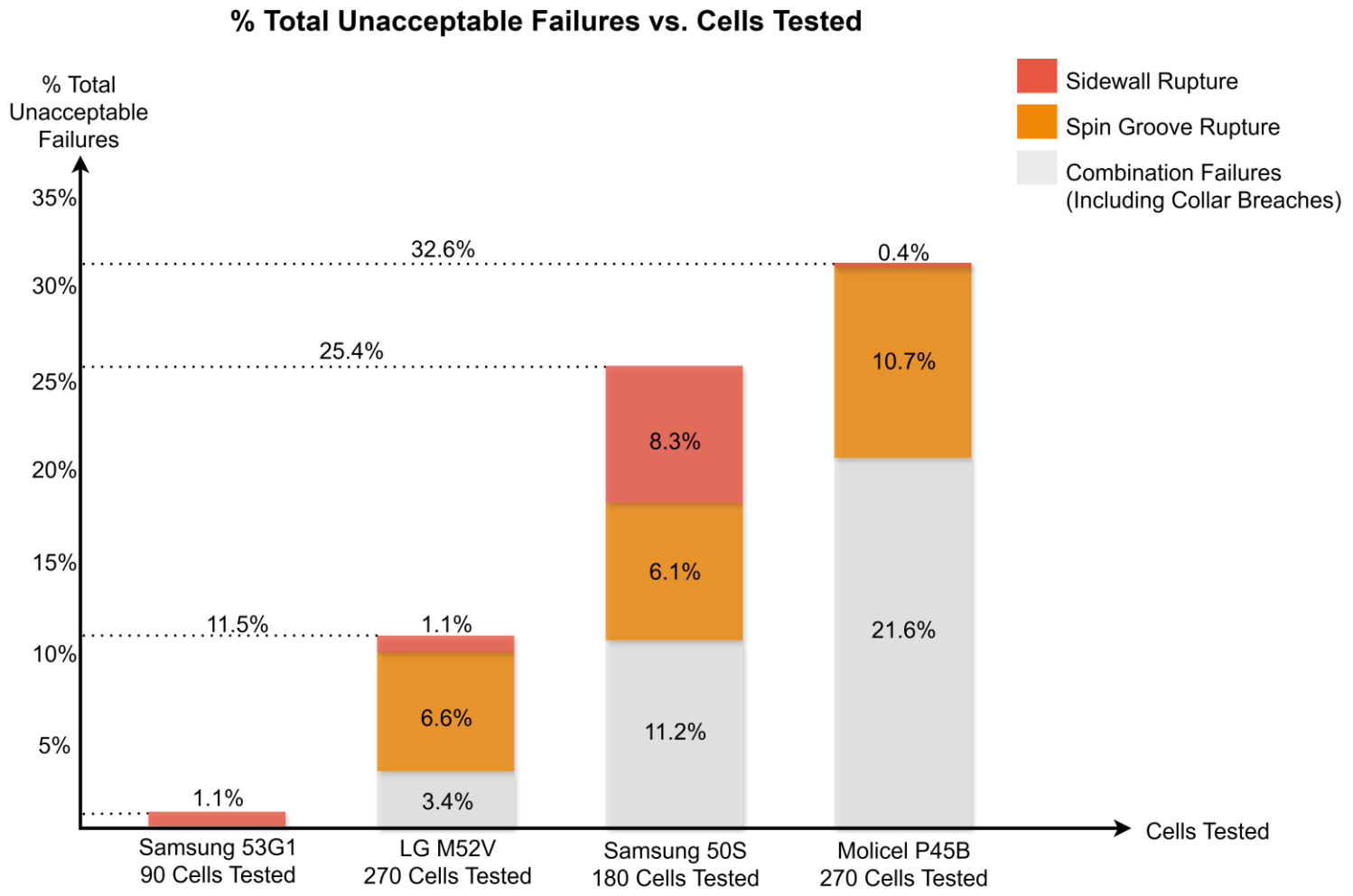
Protective cover.



Partitions protect and isolate cells

# SUMMARY OF PREVIOUS 21700 SWR CHARACTERIZATION

In December 2023, different commercial 21700 cylindrical cells were tested for propensity of sidewall rupture/spin groove rupture using the test article described and using heat as trigger method, the results are summarized below:



# DEFINITION CRITERIA

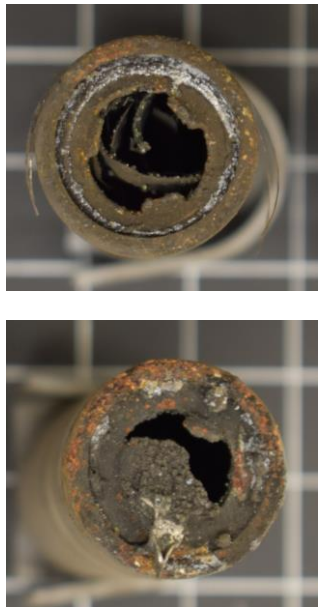
## ACCEPTABLE FAILURES



**Nominal Top Vent**

**(NTV)**

Cell vented only, no breach through the header.



**Top Rupture**

**(TR)**

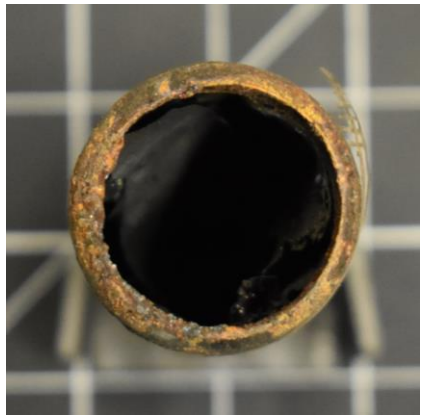
Header gets breached but some part still remains.



**Header Release**

**(HR)**

Header gets ejected in its entirety. Usually spin grooves unfolds.



**Jelly Roll Ejection**

**(JRE)**

The majority (>85%) of the jelly roll gets ejected.



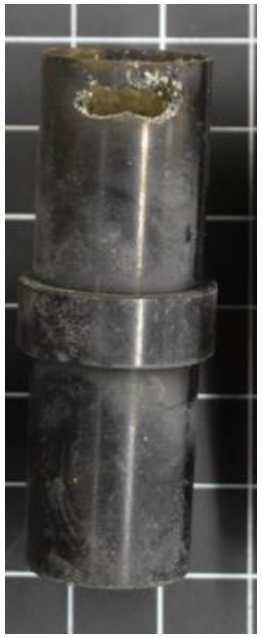
**Bottom Rupture**

**(BR)**

Breach through the bottom of the cell.

# DEFINITION CRITERIA

## UNACCEPTABLE FAILURES



**Collar Breach (CB)**

Breach of the aluminum cell tube.



**Spin Groove Rupture (SGR)**

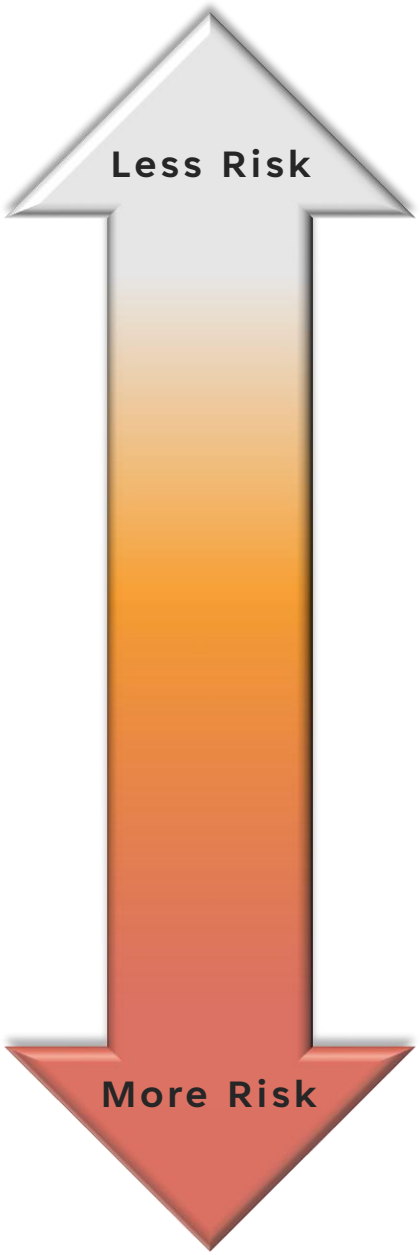
Breach through the spin groove only. Anything above or below the spin groove is considered a Sidewall Rupture.



**Sidewall Rupture (SWR)**

Breach through the sidewall of the cell can below and above the spin groove.

# FAILURE RISK SCALE




Nominal Top Vent

Header Release

Top Rupture

Jelly Roll Ejection

Bottom Rupture

Sidewall Rupture

Spin Groove Rupture

Collar Breach

Unacceptable Failures

# SWR/SGR VS CAN WALL THICKNESS

| | Samsung 53G1 (1.1%) | LG M52V (11.5%) | Samsung 50S (25.6%) | Molicel P45B (32.6%) |
|---|---|---|---|---|
| SWR/SGR Robustness | More Robust | | | Less Robust |
| | ✓ | ✗ | ✗ | ✗ |
| Avg. Can Wall Thickness | Thicker | | | Thinner |
| | Samsung 53G1 (237 µm) | Molicel P45B (225 µm) | LG M52V (213 µm) | Samsung 50S (200 µm) |

# SWR/SGR VS SPIN GROOVE THICKNESS

| | Samsung 53G1 (1.1%) | LG M52V (11.5%) | Samsung 50S (25.6%) | Molicel P45B (32.6%) |
|---|---|---|---|---|
| SWR/SGR Robustness | More Robust | | | Less Robust |
| | ✓ | ✓ | ✓ | ✓ |
| Avg. Spin Groove Thickness | Thicker | | | Thinner |
| | Samsung 53G1 (324 µm) | LG M52V (321 µm) | Samsung 50S (271 µm) | Molicel P45B (269 µm) |

# MOLICEL P45B SIDEWALL RUPTURE TEST CAMPAIGN

Motivated by the results obtained in 2023, Molicel agreed to provide variants of the P45B with a thicker spin groove and tooling change with the goal of achieving a SWR/SGR robust cell. 60 cells of each variant were tested.

| P45B Cells Test Matrix | | | | | | |
|---|---|---|---|---|---|---|
| Base Thickness (µm) | | 300 | | | | |
| Wall Thickness (µm) | | 220 | | | | |
| Cell Version | | V1 | V2 | V3 | V4 | V5 |
| Spin Groove Thickness (µm) | Measured Max | 292 | 289 | 286 | 334 | 332 |
| | Measured Min | 201 | 232 | 235 | 248 | 248 |
| | Measured Avg | 269 | 260 | 261 | 300 | 295 |
| Description | | Production cell made in original plant. Original standard can. | Production cell made in alternate plant. Original standard can. | Production Cell w/ Tooling change made in alternate plant. Original standard can. | Production cell made in alternate plant. Thicker can. | Production Cell w/ Tooling change made in alternate plant. Thicker can. |

# TEST SETUP

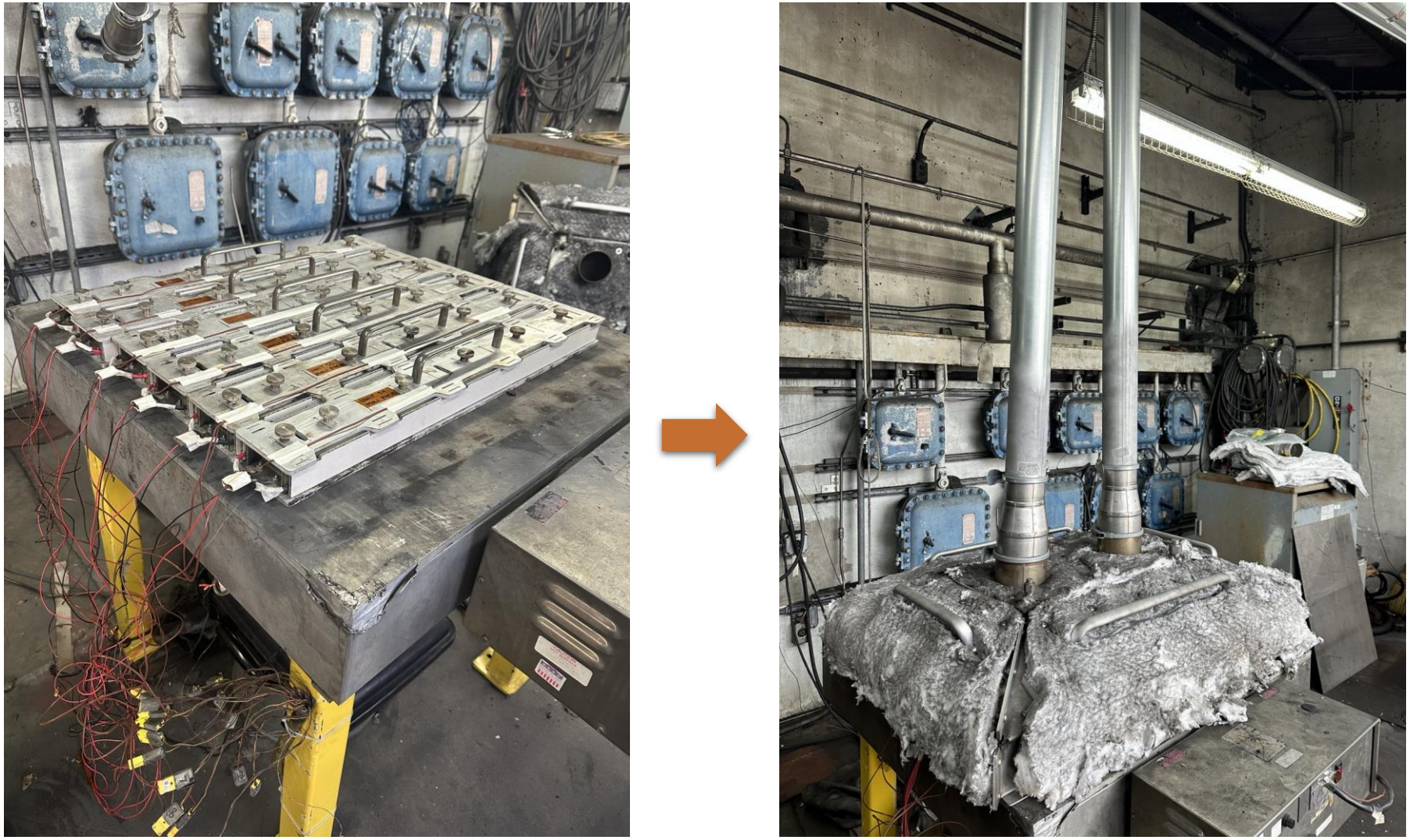
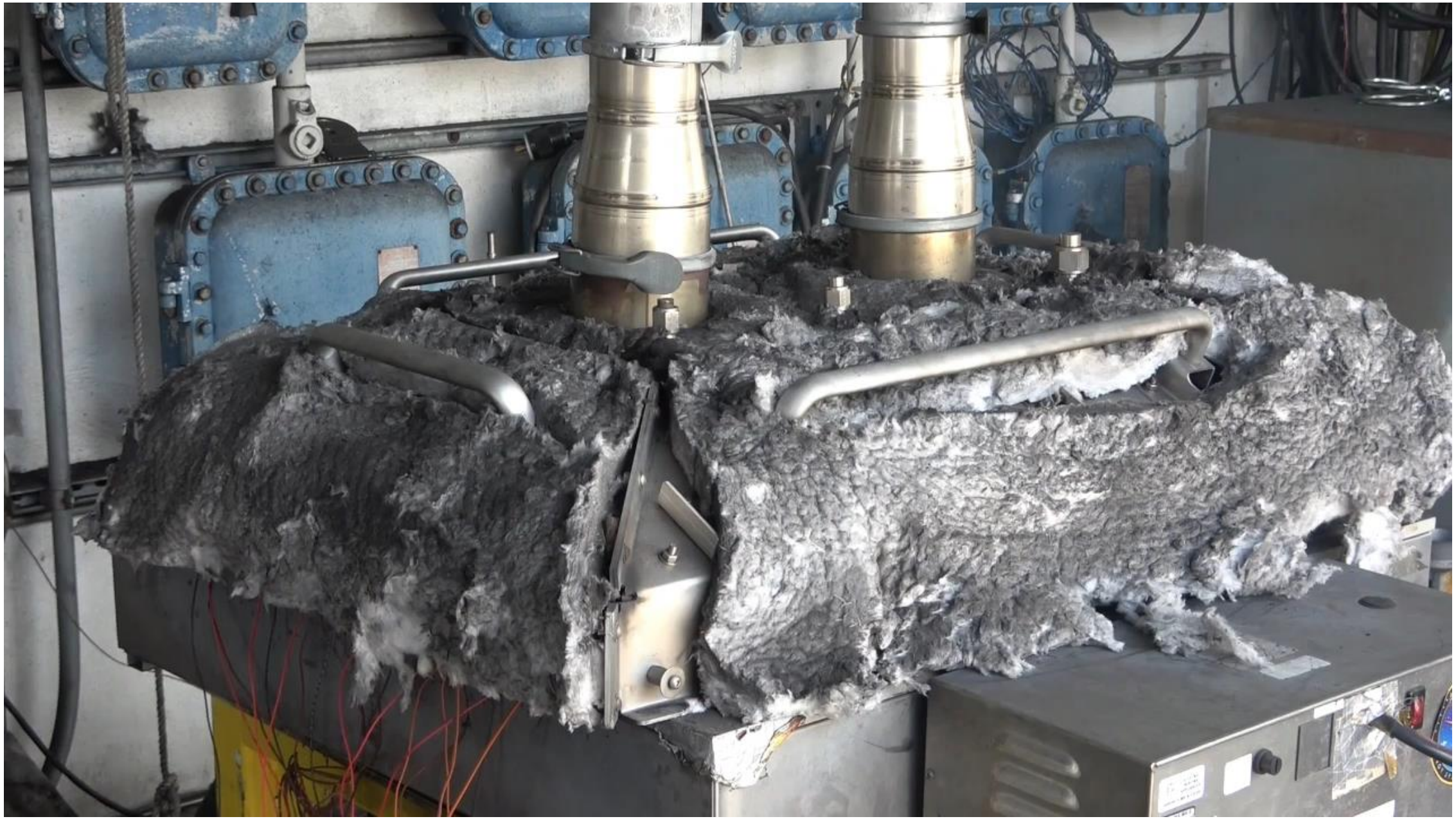


**Figure:** A 36” X 36” hot plate is used to heat 6 test articles at a time to trigger 60 cells into thermal runaway.

# TEST SAMPLE VIDEO



# POST TEST SEQUENCE







**Figure:** After testing, test articles are disassembled, and cells inspected and tallied individually.

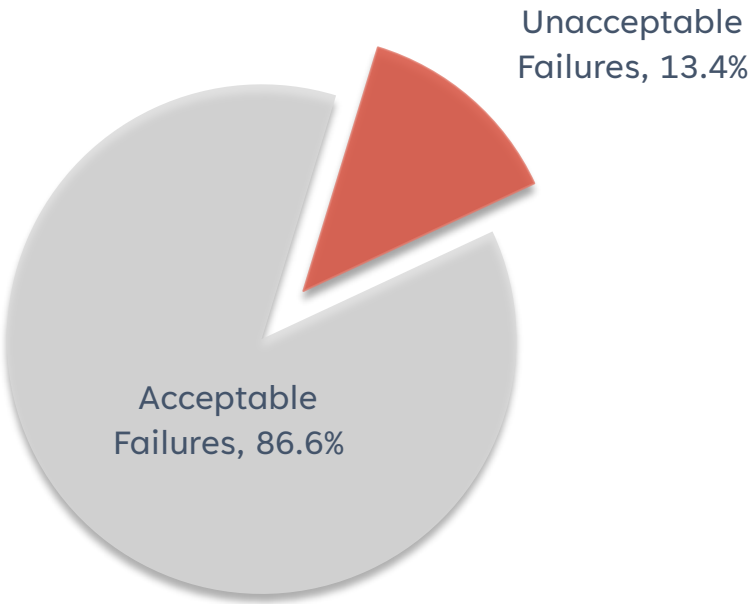
# TEST RESULTS

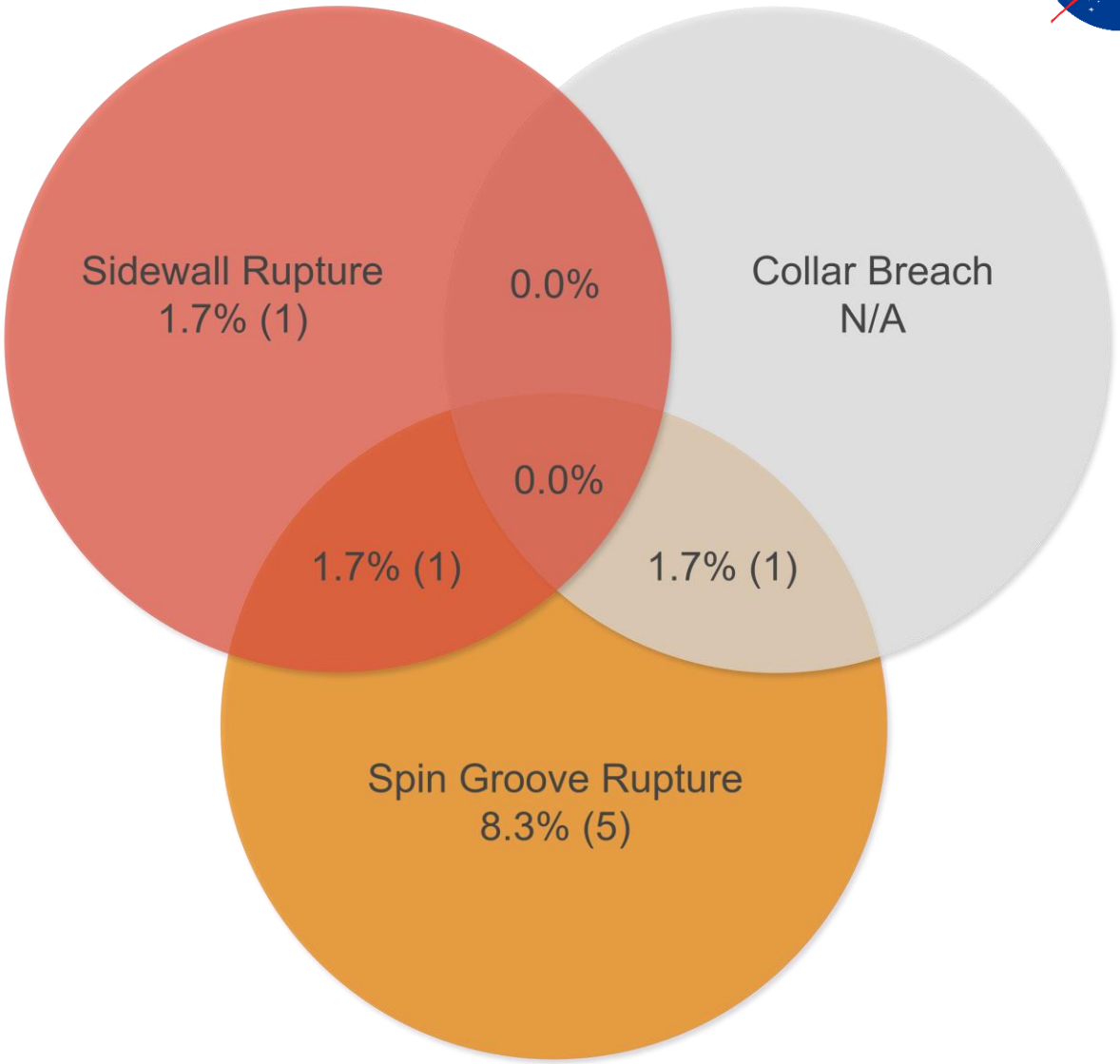
TEST RESULTS

**P45B V1**

**ORIGINAL PRODUCTION CELL**

**60** CELLS TESTED, **100%** SOC



# PHOTOGRAPHIC EVIDENCE
# P45B V1







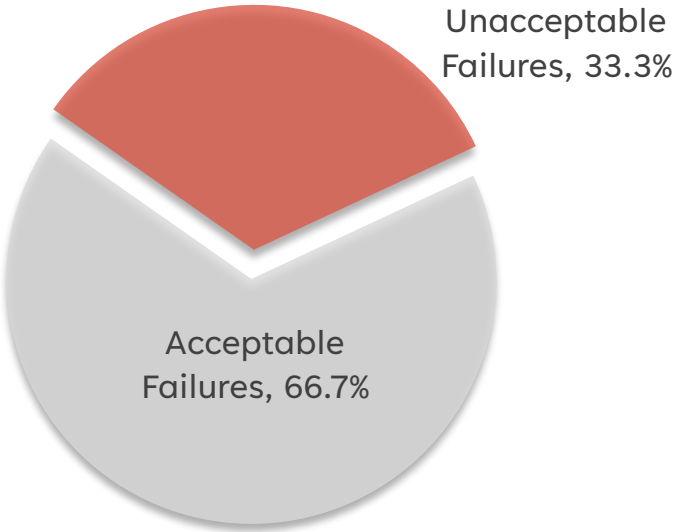


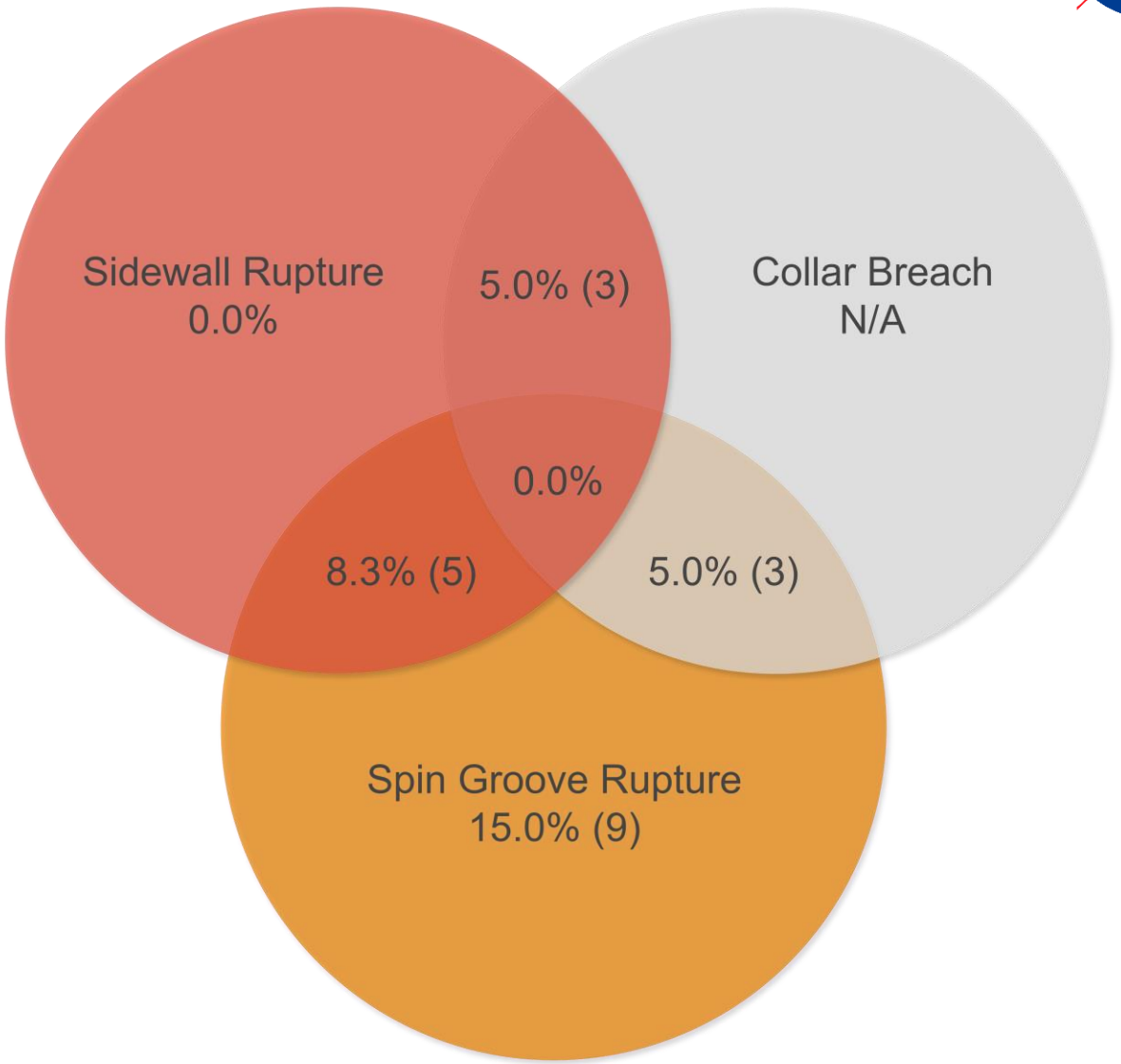
TEST RESULTS

**P45B V2**

**PRODUCTION CELL, ALT. PLANT**

**60** CELLS TESTED, **100%** SOC



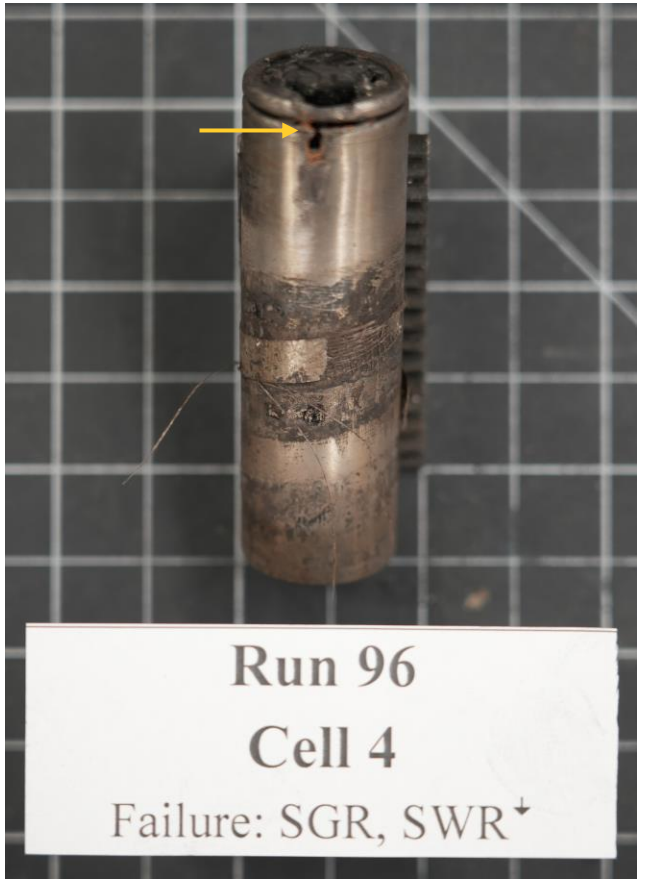



# PHOTOGRAPHIC EVIDENCE
# P45B V2







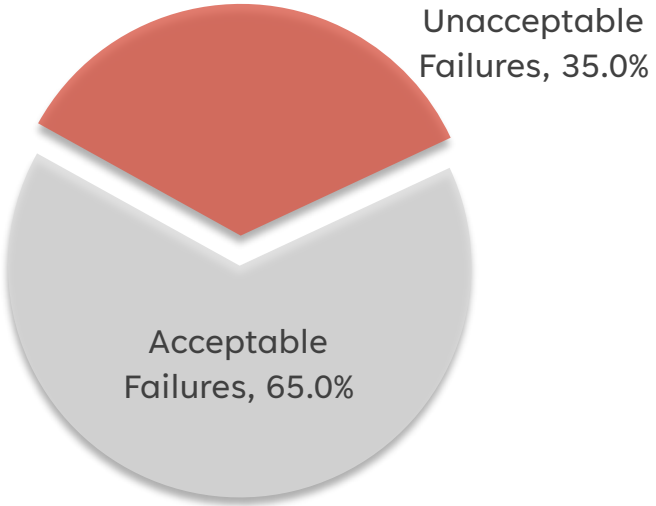


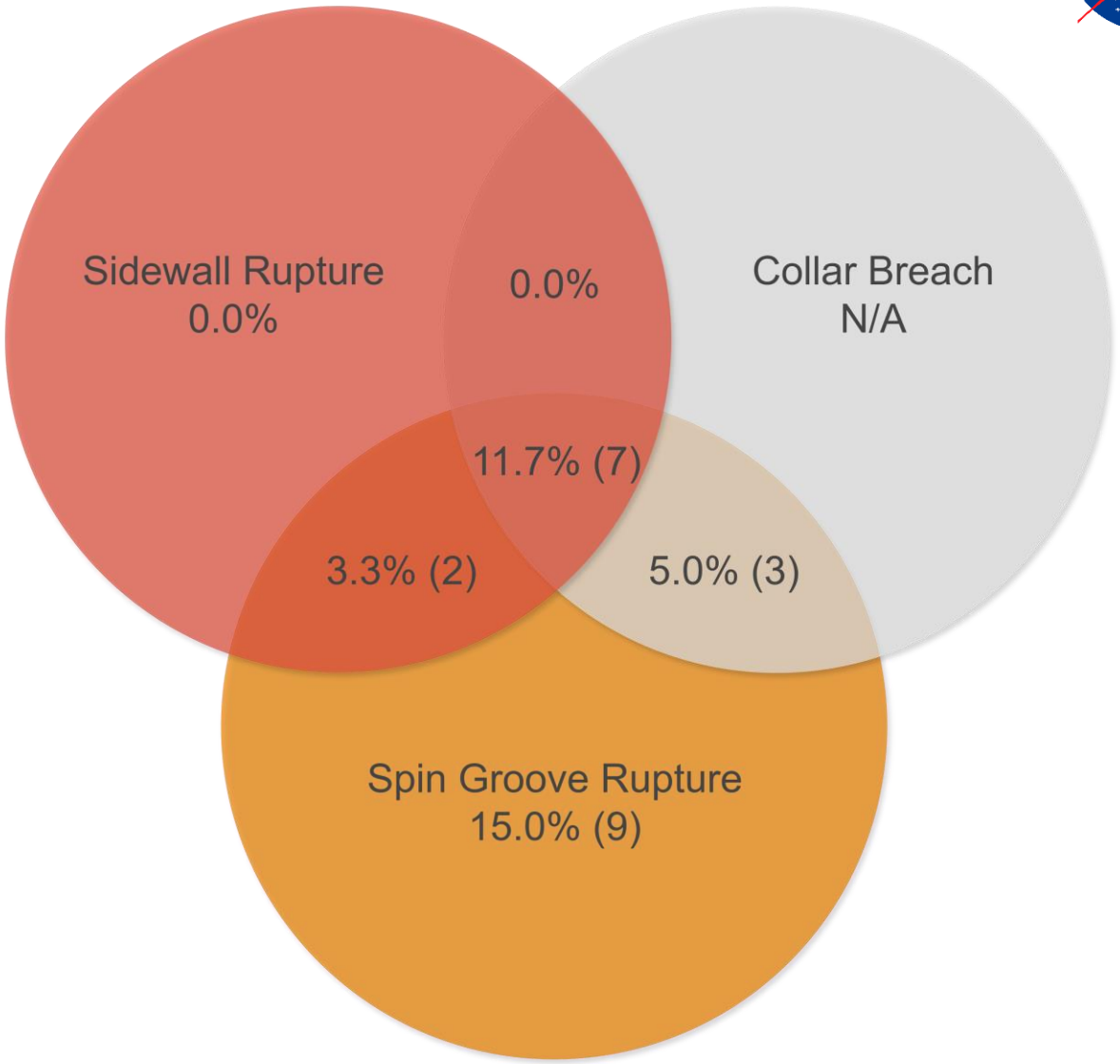
TEST RESULTS

**P45B V3**

**PRODUCTION CELL, ALT. PLANT, TOOLING CHANGE**

**60** CELLS TESTED, **100%** SOC



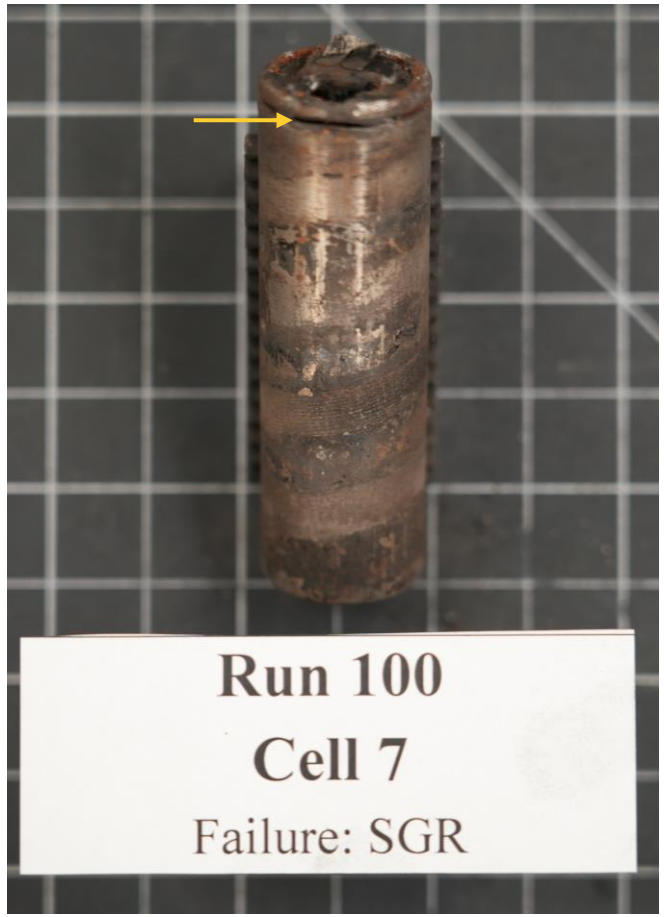



# PHOTOGRAPHIC EVIDENCE
# P45B V3







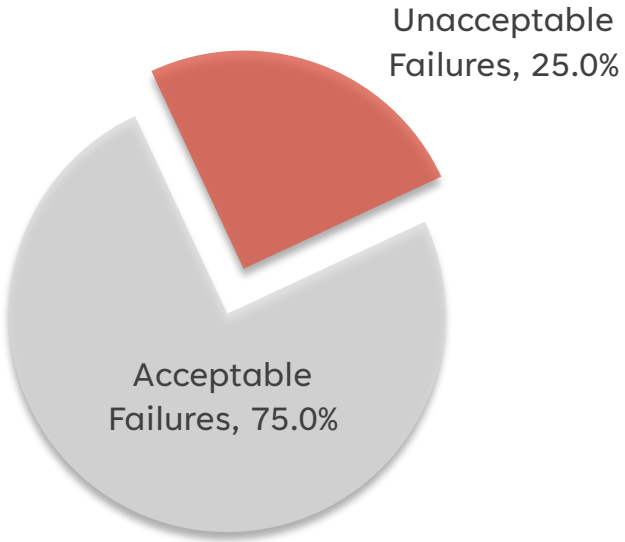


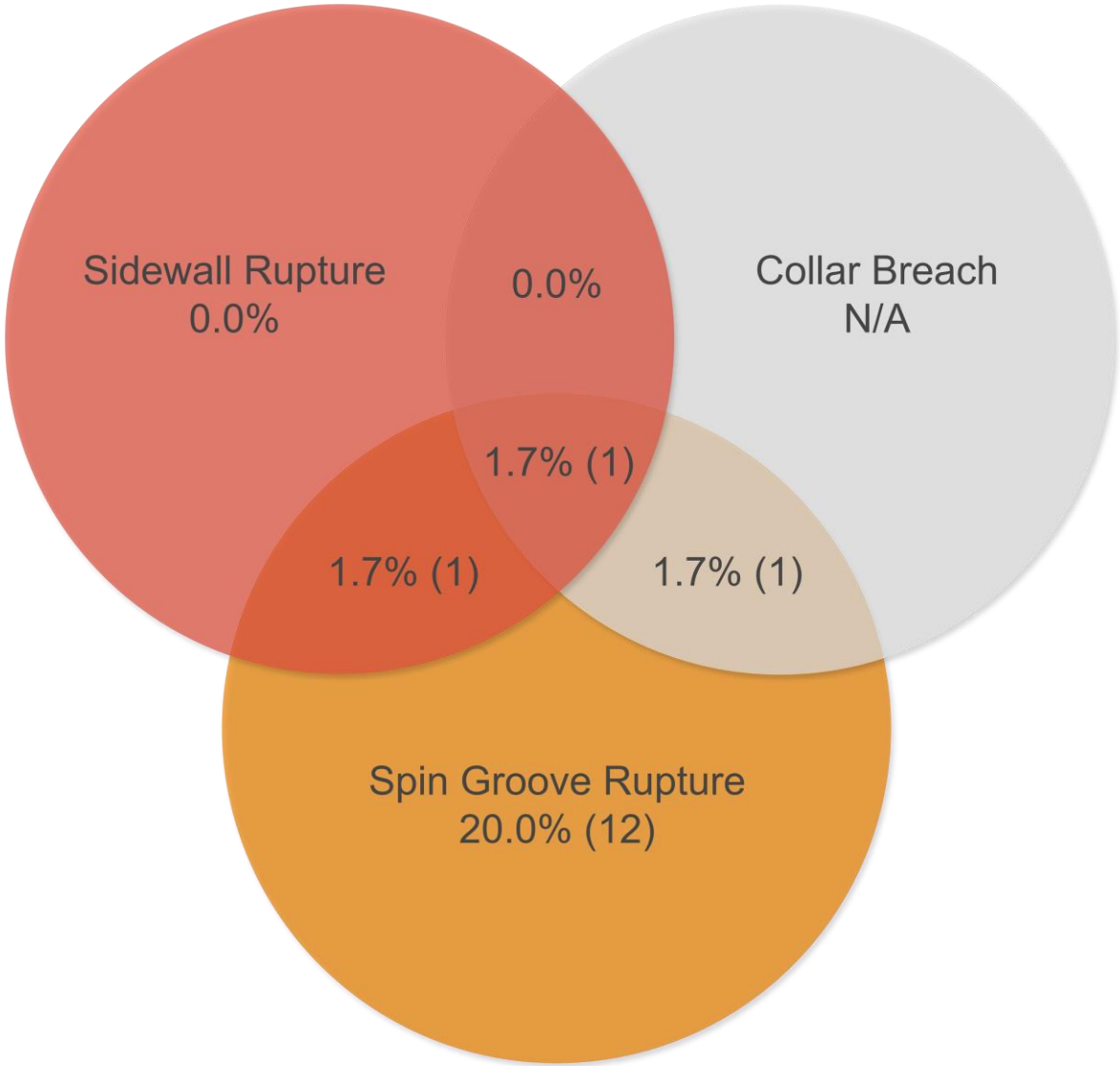
TEST RESULTS

**P45B V4**

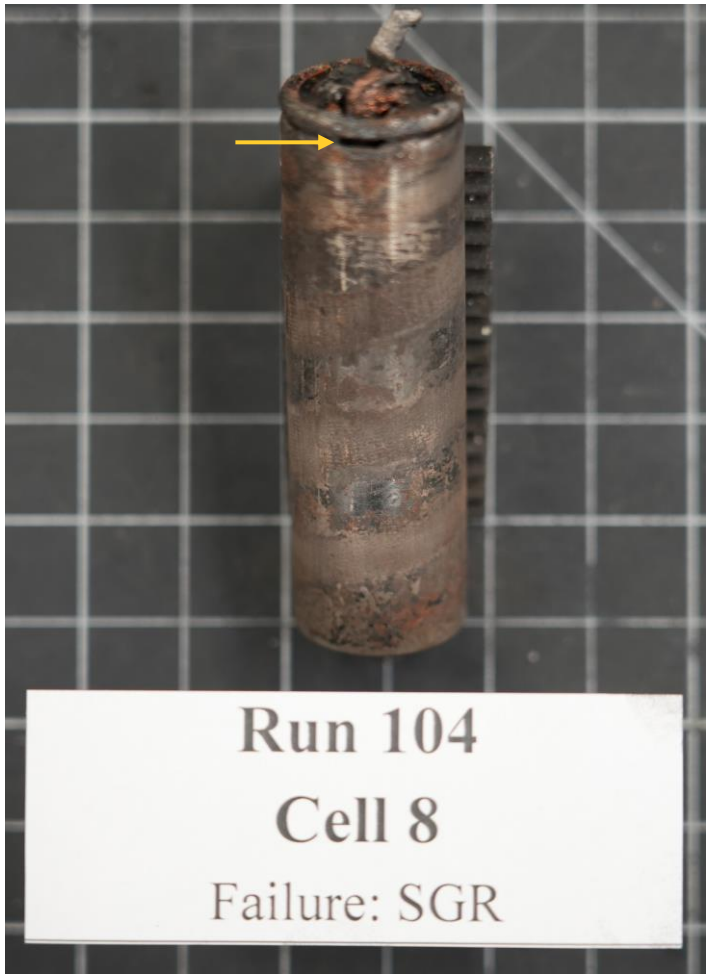
**PRODUCTION CELL, ALT. PLANT, THICKER CAN**

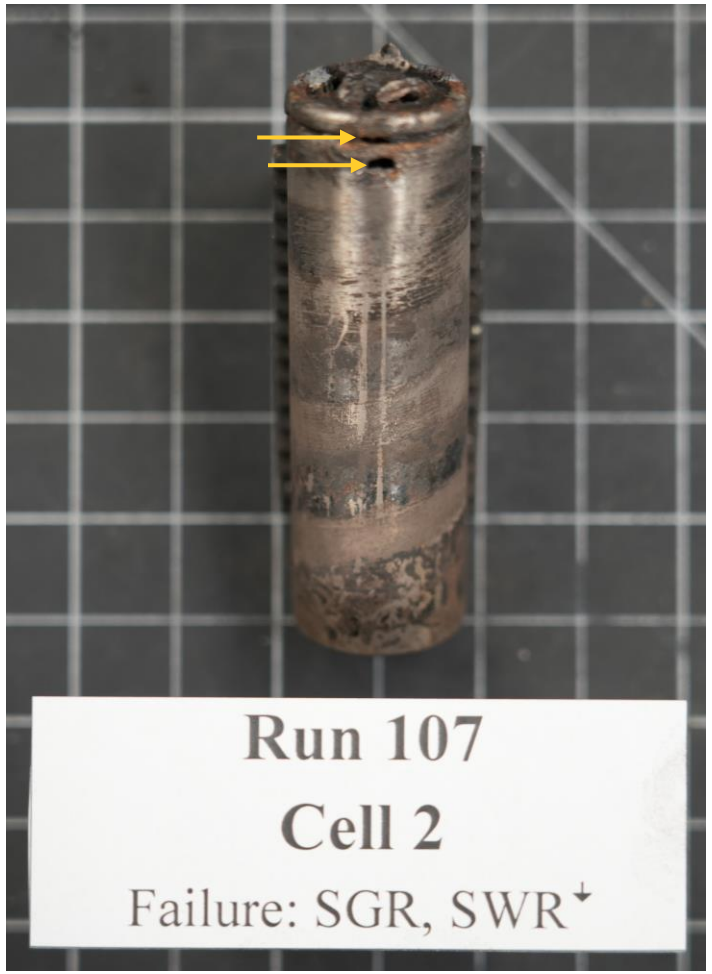
**60** CELLS TESTED, **100%** SOC



# PHOTOGRAPHIC EVIDENCE
# P45B V4



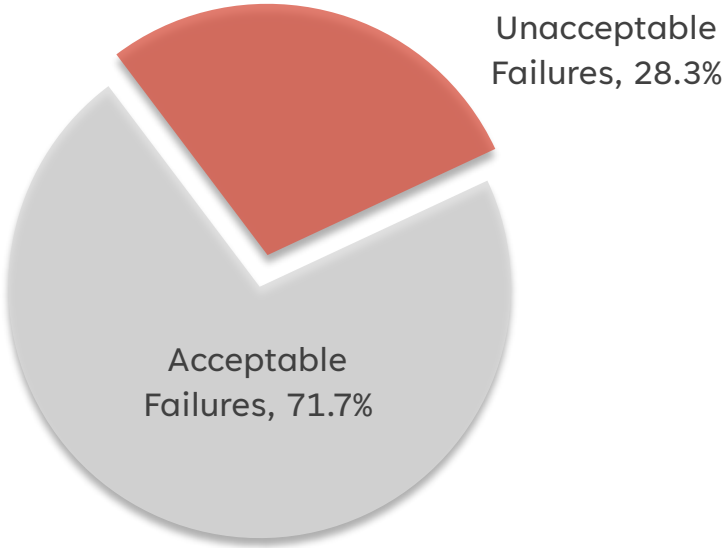


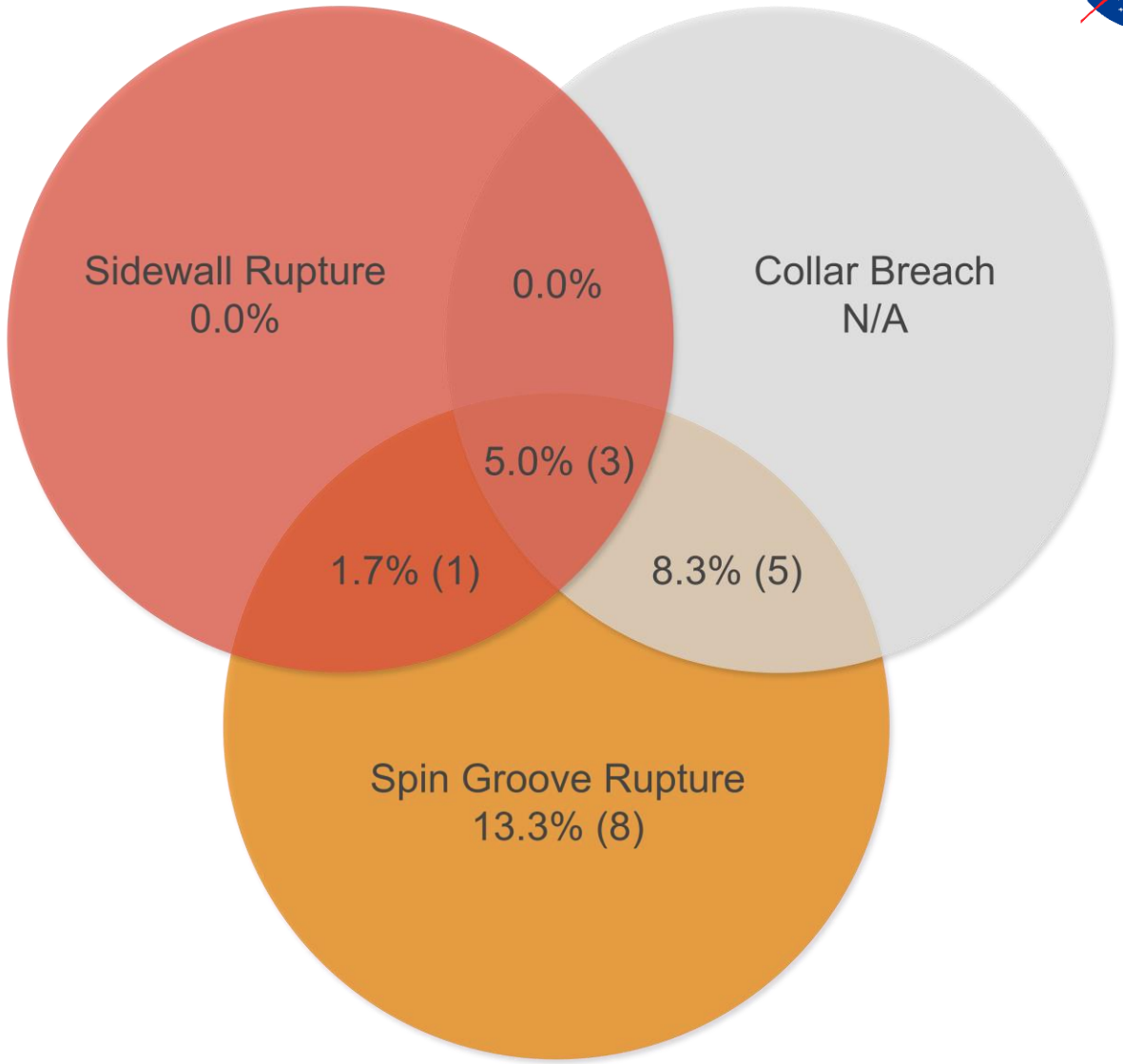

TEST RESULTS

**P45B V5**

**PRODUCTION CELL, ALT. PLANT, THICKER CAN, TOOLING CHANGE**

**60** CELLS TESTED, **100%** SOC



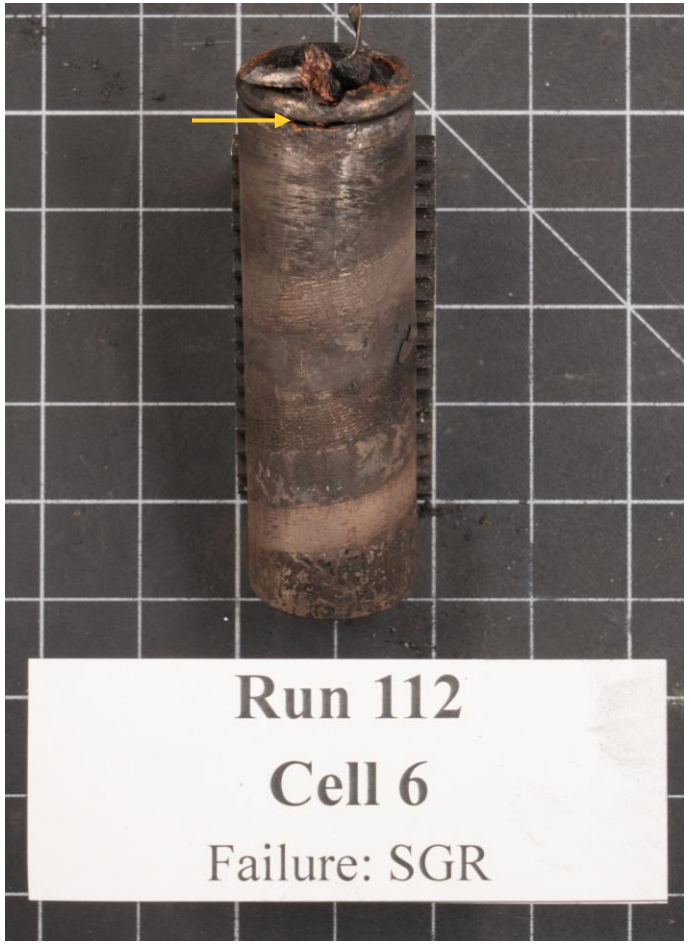



# PHOTOGRAPHIC EVIDENCE
# P45B V5

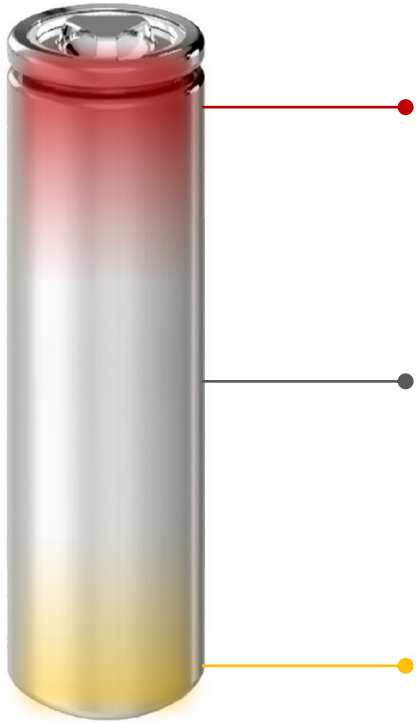








# CELL CRITICAL FAILURE AREAS



**Highest Risk:** Most of the failures are spin groove ruptures (SGR). Individual sidewall ruptures (SWR) are less common, most are in conjuction with a SGR. Most collar breaches are associated with SGR.

**Lowest Risk:** Very rare to see a sidewall rupture in the middle section of the cell body.

**Moderate Risk:** Some bottom ruptures happen close to the edge of the can and a few slightly breach through the sidewall.

# SUMMARY OF RESULTS- MOLI P45B




- **P45B V1 – Production cell with standard can**
  - 13.3% unacceptable failures, 11.7% spin groove ruptures total
    - Bottom Ruptures: 20.0% (12)
  - Significant improvement from 2023 production cell (13.3% vs. 32.6%)




- **P45b V4 – Production cell made in alt. plant with thicker can**
  - 25.0% unacceptable failures, all had a spin groove rupture
    - Bottom Ruptures: 31.7% (19)
  - Improvement from the Canada production cell with the thinner spin groove, but less robust than the Taiwan production cell with the thinner spin groove




- **P45B V5 – Production cell made in alt. plant with thicker can and tooling change**
  - 28.3% unacceptable failures, all had a spin groove rupture
    - Bottom Ruptures: 13.3% (8)
  - Improvement from the Canada production cell with the thinner spin groove, but less robust than the Taiwan production cell with the thinner spin groove
  - Tooling change did not improve the robustness of the cell based on test data

# SUMMARY OF RESULTS- MOLI P45B




- **P45B V2 – Production cell made in alt. plant with standard can**
  - 33.3% unacceptable failures, 28.3% spin groove ruptures total
    - Bottom Ruptures: 15.0% (9)
  - Significant difference in cell robustness from the Taiwan production cell (33.3% vs. 13.3%), results are similar to 2023 production cell




- **P45B V3 – Production cell made in alt. plant with standard can and tooling change**
  - 35.0% unacceptable failures, all had a spin groove rupture
    - Bottom Ruptures: 10.0% (6)
  - Tooling change did not improve the robustness of the cell based on test data

# CONCLUSIONS

# CONCLUSIONS / OBSERVATIONS

- The P45B V1 cell is more robust to SWR/SGR than V2 made in alt. plant
  - Difference in production plant, equipment, processes, etc. affect cell safety robustness

- Most failures happen at the spin groove and crimp. Sidewall ruptures on the can wall are rare and usually are observed in conjunction with a spin groove rupture

- Comparing exclusively all cells made in the alt. plant, the thicker spin groove does improve the robustness to SWR/SGR by ~7-8%

- Based on the data, there was no improvement in robustness with the tooling change, on the contrary, it made it slightly less robust ~2-3%

# PROPOSED FUTURE WORK

- Do cross section of the 5 cell designs to measure spin groove thickness in house and verify values provided by manufacturer
- Test P45B with thicker spin groove made in original plant to compare with alt. plant
- Test P50B with production can to compare robustness compared to P45B
- Test P50B with thicker spin groove to compare to production can

[1] For 18650 sidewall rupture test results, reference 2022 NASA Aerospace Battery Workshop presentation named: Lithium-Ion Sidewall Rupture Characterization with 3 Battery Designs

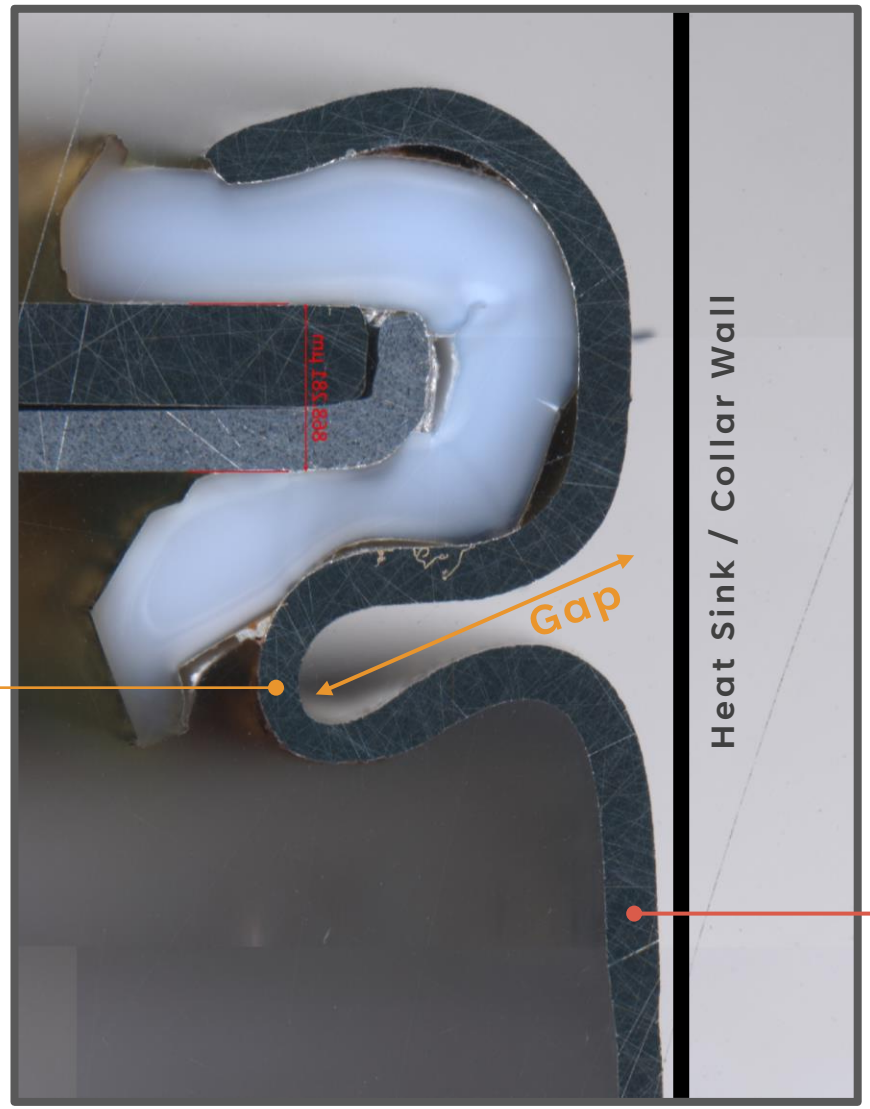
2 For 21700 sidewall rupture test results, reference 2023 NASA Aerospace Battery Workshop presentation named: Lithium-Ion Sidewall Rupture Characterization- 21700 Cell Format

# BACKUP SLIDES

# SGR VS SWR SEVERITY

**Spin Groove Rupture:**

**The gap between the spin groove and the heat sink/collar wall allows for the abrasive ejecta torch to develop, increasing the risk of further damage.**




**Sidewall Rupture:**

**Ejecta plugs the rupture against the heat sink/collar wall, therefore preventing ejecta torch from developing reducing the risk of further damage.**

# CONCLUSIONS (CONT.)

- 21700 cells are more propense to bottom ruptures than 18650 cells[1]
  - Reinforcing the cell bottom can help reduce bottom ruptures, but data suggest there are other factors that affect bottom rupture propensity.

- Other features that might affect propensity to SGR/SWR:
  - Cell constraints and support on battery pack
  - Cell design: vent pressure, crimp/header release, vent holes size, etc.
  - Other cell features such as bottom vents

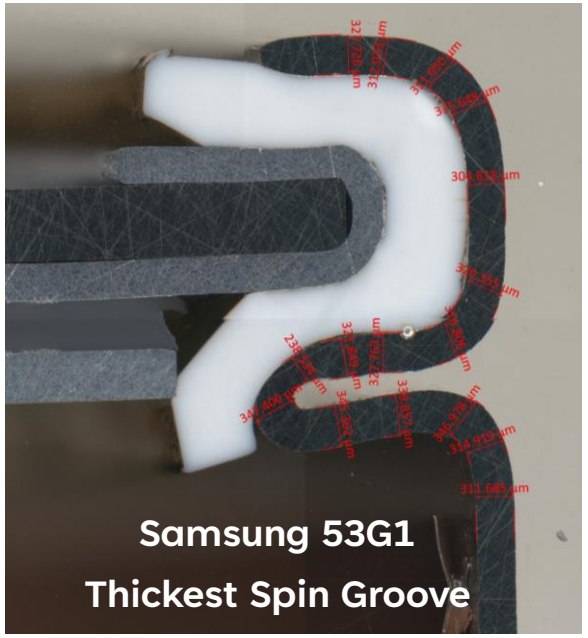
- Future work: Test Molicel P45B and P50B cells with reinforced spin groove and crimp.

[1] For 18650 sidewall rupture test results, reference 2022 NASA Aerospace Battery Workshop presentation named: Lithium-Ion Sidewall Rupture Characterization with 3 Battery Designs

2 For 18650 sidewall rupture test results, reference 2022 NASA Aerospace Battery Workshop presentation named: Lithium-Ion Sidewall Rupture Characterization with 3 Battery Designs

# SPIN GROOVE MEASUREMENTS

| | Samsung 53G | LG M52V | Samsung 50S | Molicel P45B |
|---|---|---|---|---|
| **Avg. Can Wall Thickness** | 237 µm | 213 µm | 200 µm | 225 µm |
| **Avg. Spin Groove Thickness** | 324 µm | 321 µm | 271 µm | 269 µm |
| **Min. Spin Groove Measurement** | 239 µm | 279 µm | 203 µm | 202 µm |



Samsung 53G1
Thickest Spin Groove



Molicel P45B
Thinnest Spin Groove

# COLLAR BREACH WITH NO SWR/SGR

- Some cells shifted down inside the collar causing collar breaches without SGR/SWR.
  - Majority observed with header releases (indication of high kinetic TR event)
  - Recommendations: tighter process control when preparing cells, tighter collars for specific cell design, battery design feature to prevent cells from sliding out.



Example of how cell slipped inside collar during TR - Picture taken pre-cell extraction

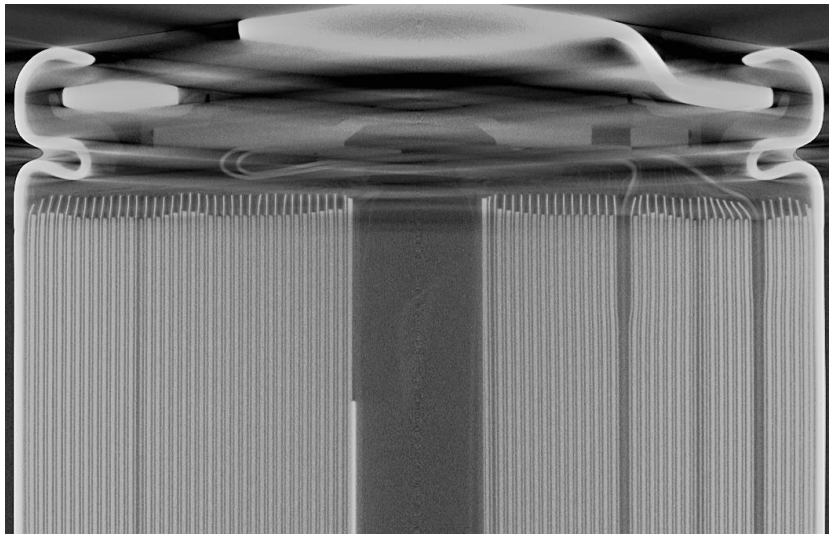
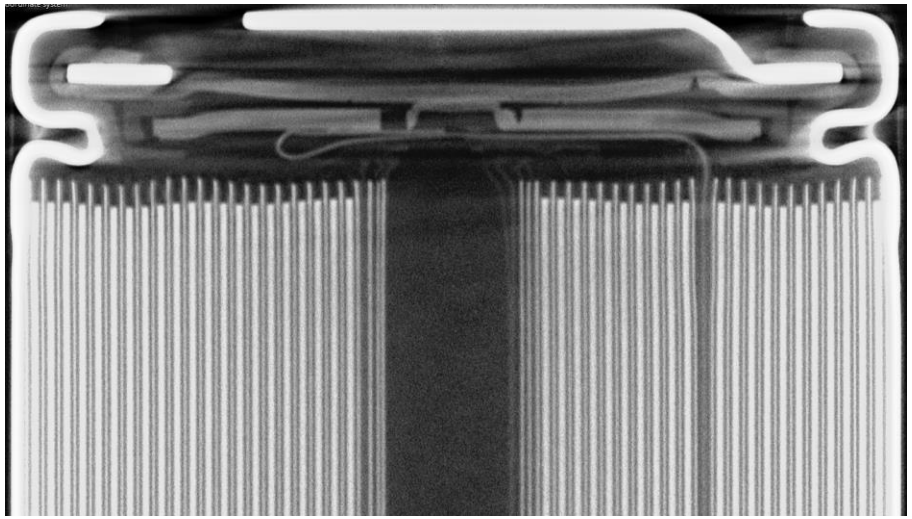




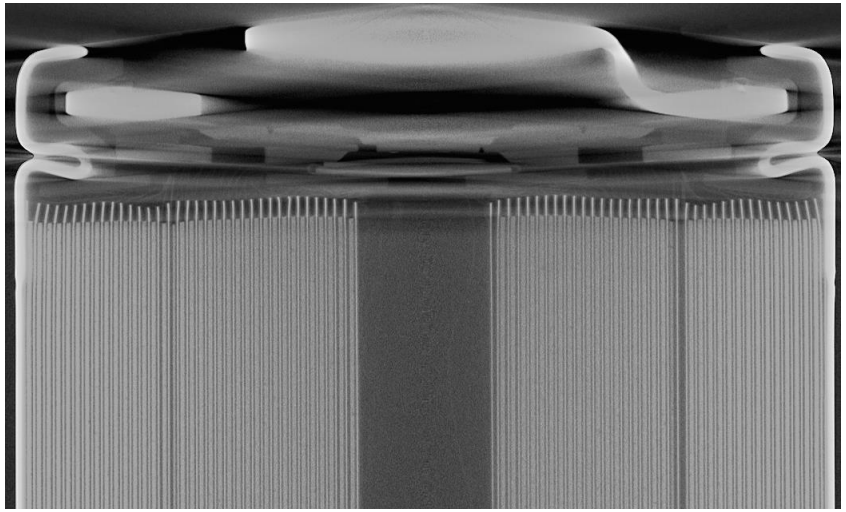
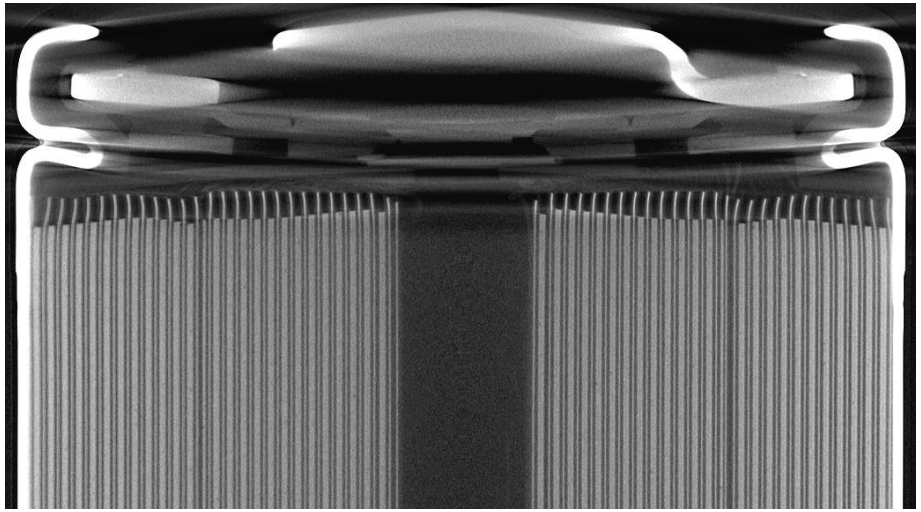


Examples post-cell extraction/inspection. Note: different cells from picture to the left.

# TEST MATRIX

| | Molicel INR21700 P45B | LG INR21700 M52V |
|---|---|---|
| **Nominal Energy** | 4500 mAh | 5096 mAh |
| **Diameter / Height** | 21.55 mm (Max) / 70.15 mm (Max) | 21.27 mm (Max) / 70.60 mm (Max) |
| **Can Wall Thickness** | 225 ± 10 microns | 213 ± 10 microns |
| **Qty. tested @ SoC** | 270 @ 100% (4.2V) | 270 @ 100% (4.2V) |
| **Cell CT Image** |  |  |

# TEST MATRIX (CONT.)

| | Samsung INR21700 50S | Samsung INR21700 53G |
|---|---|---|
| **Nominal Energy** | 5000 mAh | 5300 mAh |
| **Diameter / Height** | 21.25 mm (Max) / 70.62 mm (Max) | 21.35 mm (Max) / 70.15 mm (Max) |
| **Can Wall Thickness** | 200 ± 10 microns | 237 ± 10 microns |
| **Qty. tested @ SoC** | 180 @ 100% (4.2V) | 90 @ 100% (4.2V) |
| **Cell CT Image** |  |  |

# SWR CHARACTERIZATION WITH **UNSUPPORTED** CELLS

## CELL LEVEL TESTING

Cells triggered into TR in unsupported configuration looked promising in terms of SWR rates:

- Panasonic NCR A&B = 10% SWR
- Samsung 30Q = 7% SWR

## BATTERY TESTING

When PPR tested in their battery configuration, both cells were found to experience much higher SWR rates.





# CAN WALL THICKNESS DETERMINATION

- Cell cans extracted during normal cell Destructive Physical Analysis (DPA), without the header nor bottom.
- Average can wall thickness taken using an optical microscope with ± 10 µm accuracy.
  - ➢ Note: Can thickness increase at spin groove and bottom not included in this average.

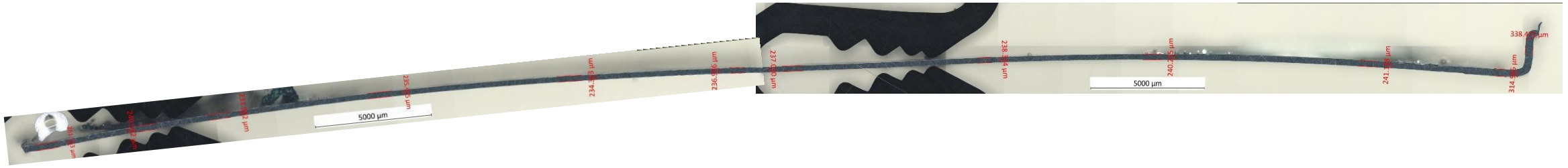


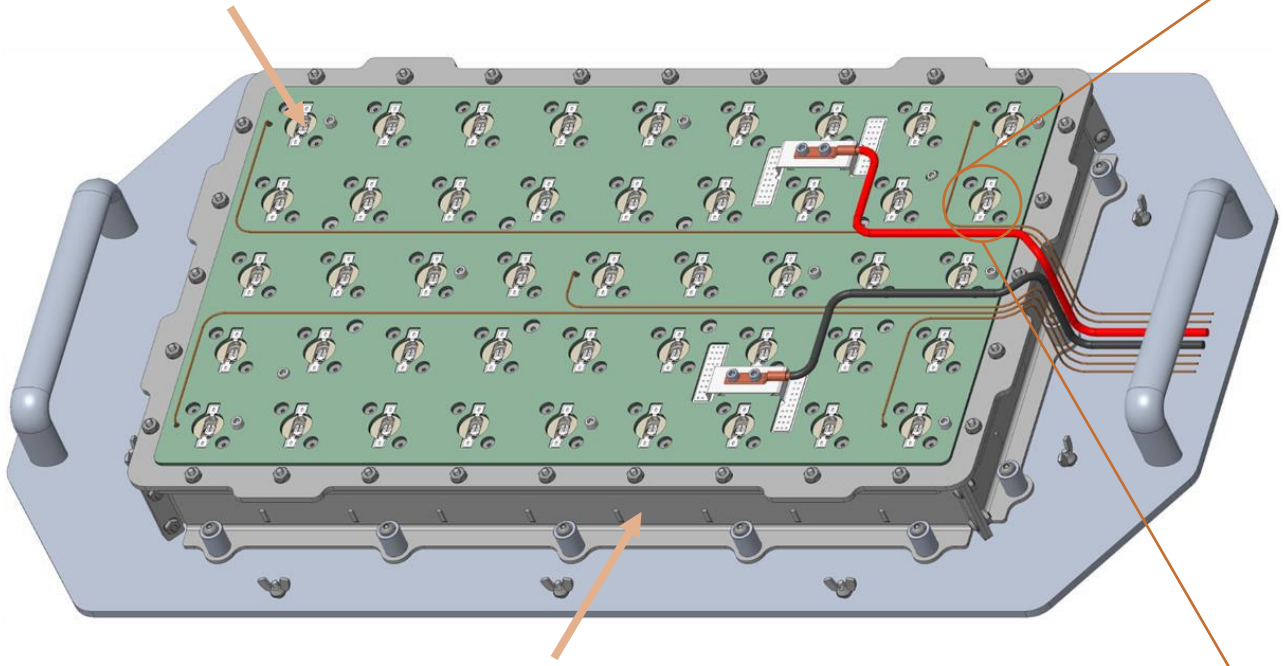

**Figure:** Cross section of Samsung 53G1 cell used to determine can wall thickness. Same technique used for the other cells.

# THERMAL RUNAWAY (TR) SWR VIDEO

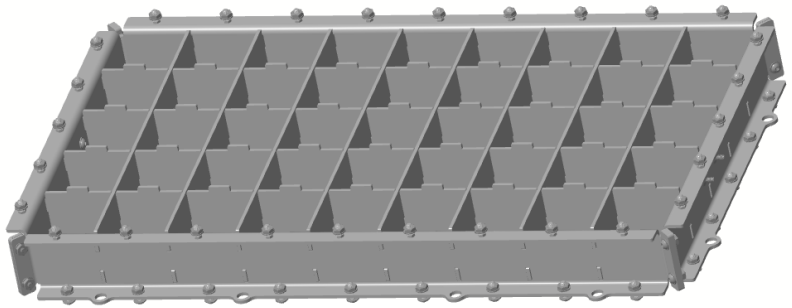


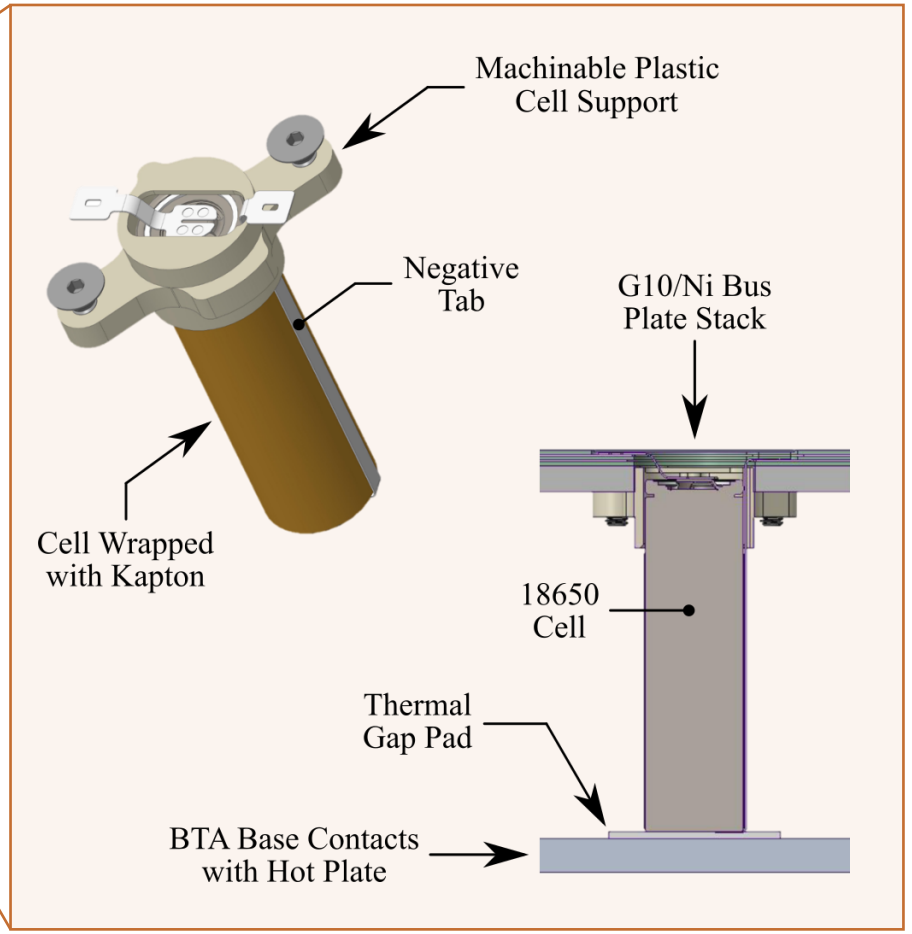
# DESIGN A- 18650 TEST CAMPAIGN IN 2022

Mica covers (not shown) to protect adjacent cells from ejecta



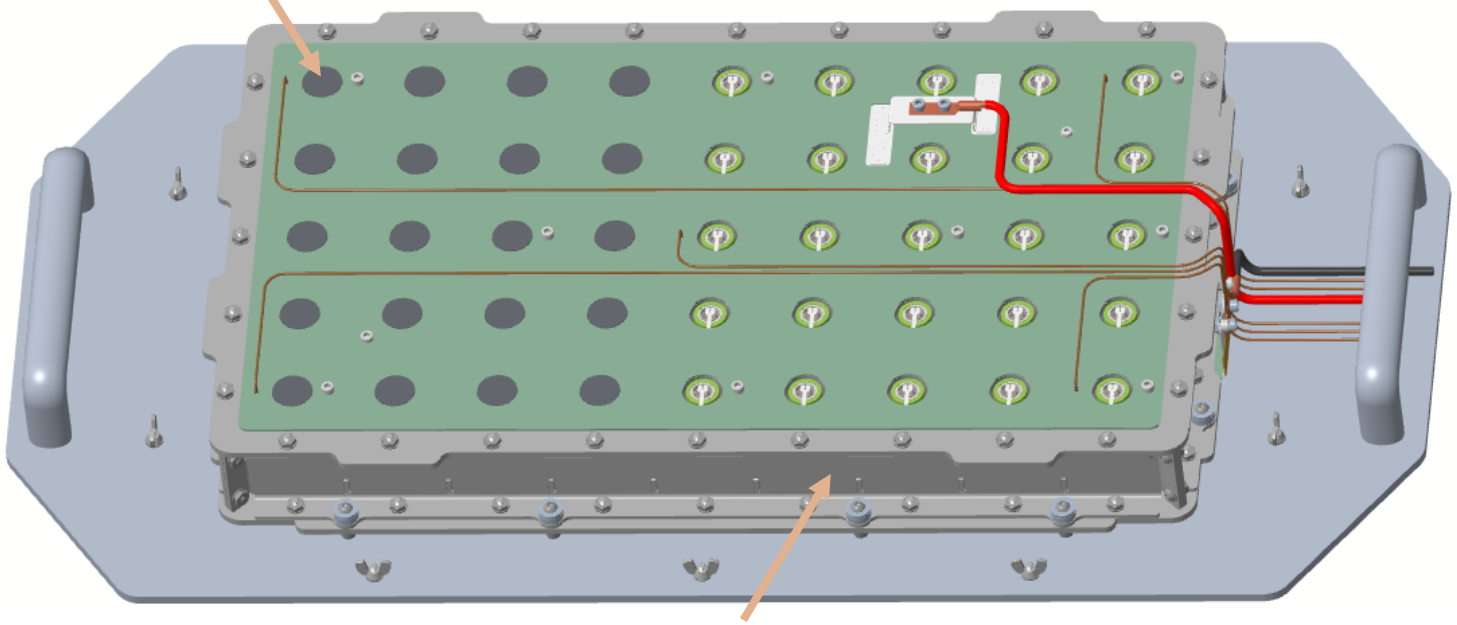
Cell Partition



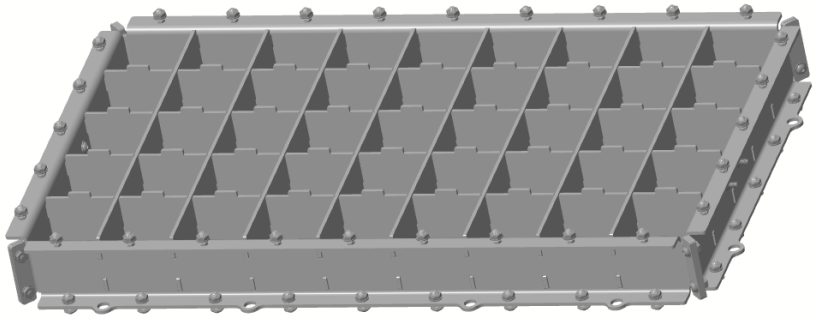


# DESIGN B- 18650 CAMPAIGN IN 2022

Mica covers to protect adjacent cells from ejecta



Cell Partition



Salient features: Length and header constraint

