SIDEWALL RUPTURE CHARACTERIZATION

21700 Cell Format

Jesus E. Trillo [1], David Petrushenko [1], Zoran Bilc [2], Eric Darcy [1]

[1] NASA Johnson Space Center
[2] S&K Engineering and Research

GUIDELINES FOR PASSIVE PROPAGATION RESISTANT (PPR) BATTERIES

1. **Reduce the risk of cell can sidewall breaches (Sidewall Rupture)**
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

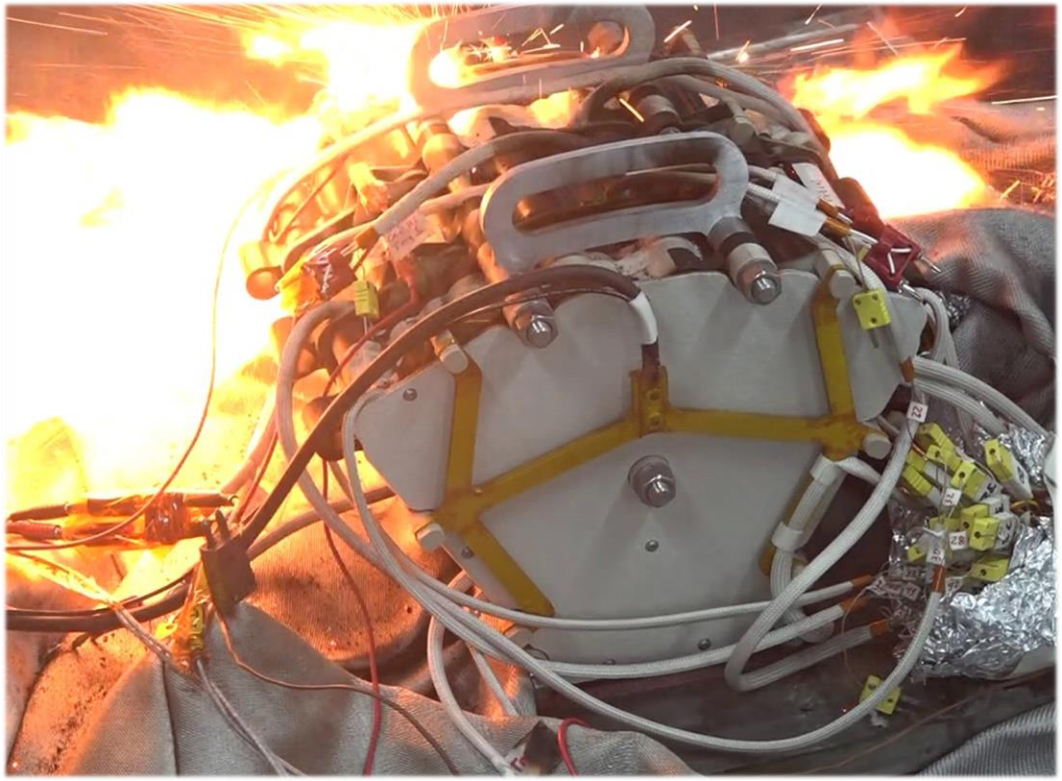


Figure: 134P-3S PPR battery pack developed by NASA successfully sustained 12 single trigger events without propagating thermal runaway

THERMAL RUNAWAY (TR) SWR VIDEO

SWR CHARACTERIZATION WITH **UNSUPPORTED** CELLS

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.

SWR CHARACTERIZATION WITH **UNSUPPORTED** CELLS

PROBLEM

False sense of low risk of SWR by unsupported cell-level characterization tests has led to costly PPR test failures.

SOLUTION

1. Include battery specific cell constraints and features
2. Test enough cells to provide a statistically defendable result.

   [1]From a lot of 60,000 cells, 270 cells must be tested to achieve 90% confidence

   *Only 1 failure allowed to reach 1x5 risk level, or 3 if testing >500 cells
3. Test different cells to compare performance.

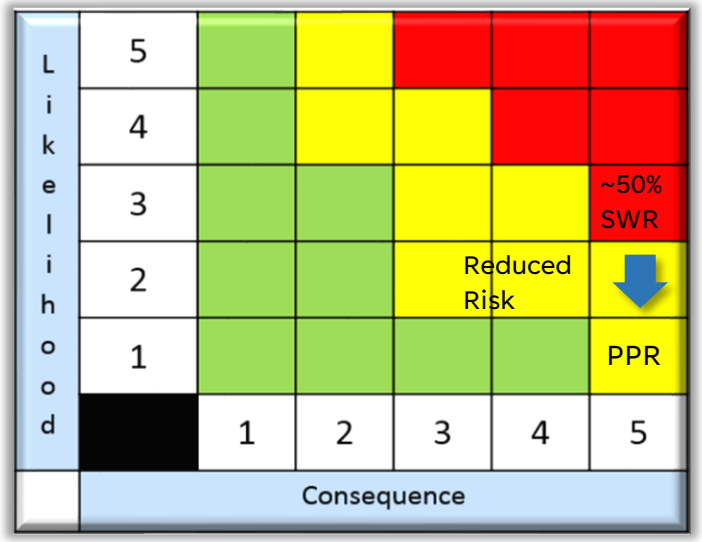


Figure: likelihood versus consequence matrix

[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 commercial 21700 cylindrical cells to sidewall 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

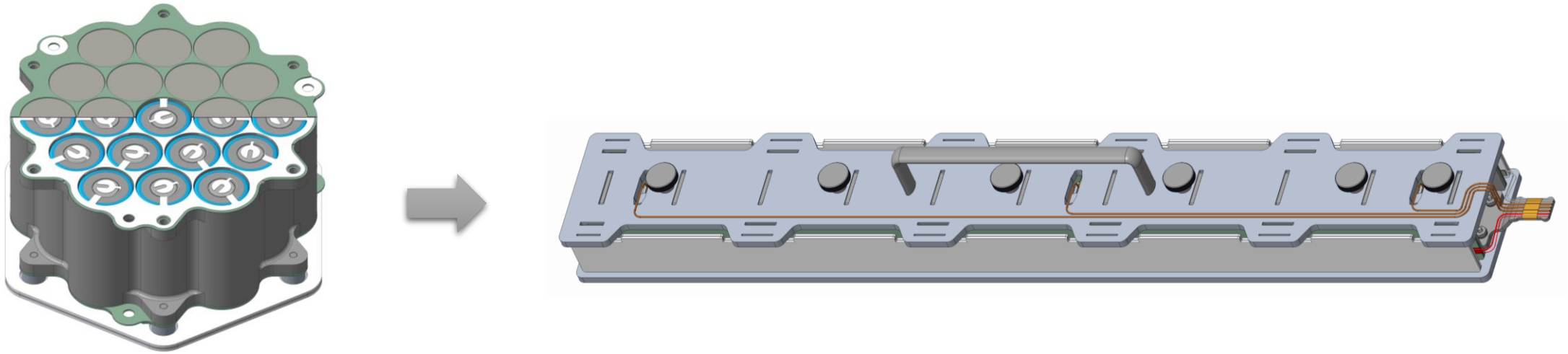
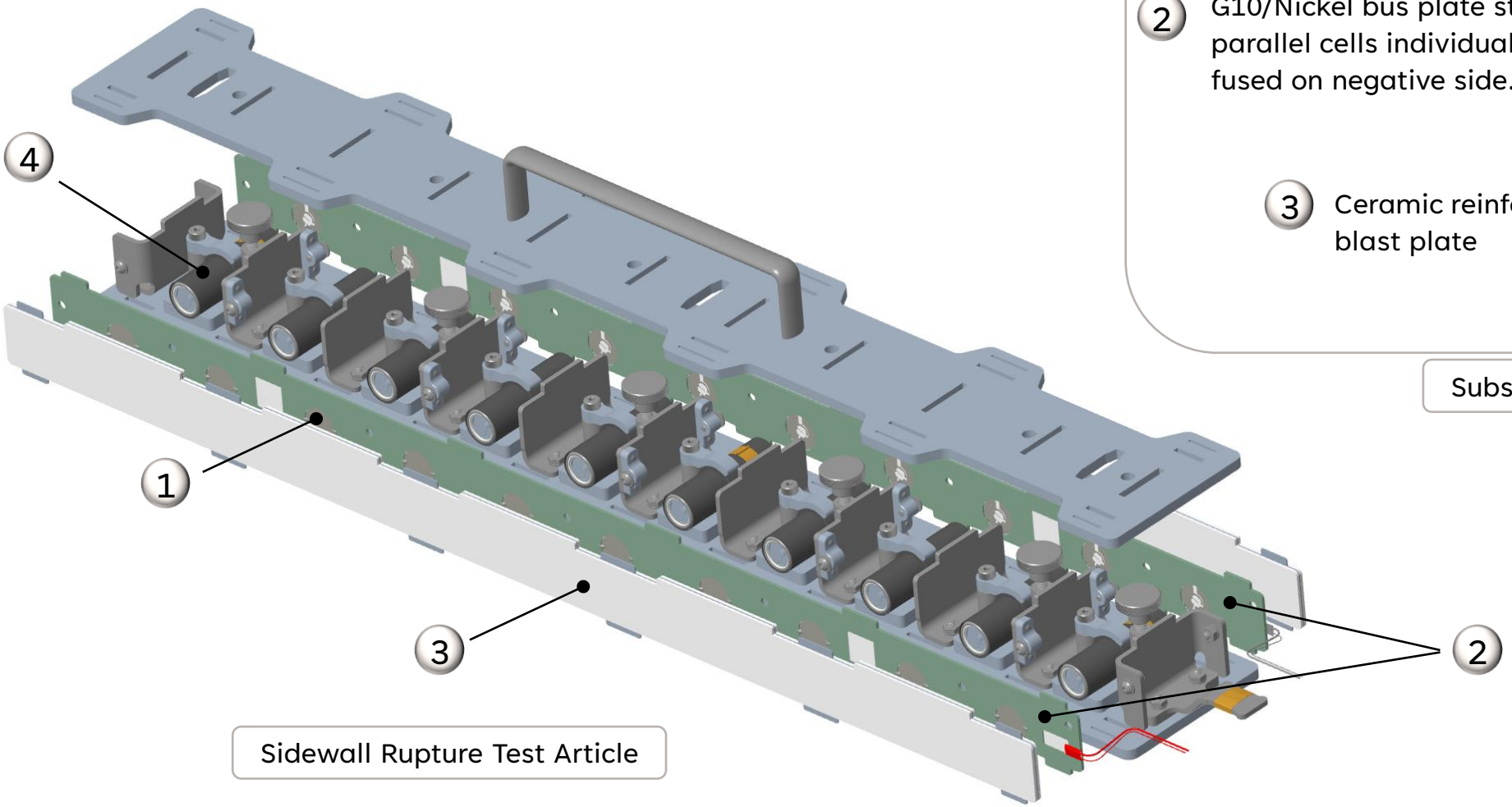


Figure: 21700 Sidewall rupture test article (right) designed to capture pertinent features of 21700 battery pack (left – subscale pack shown)

TEST ARTICLE DESCRIPTION



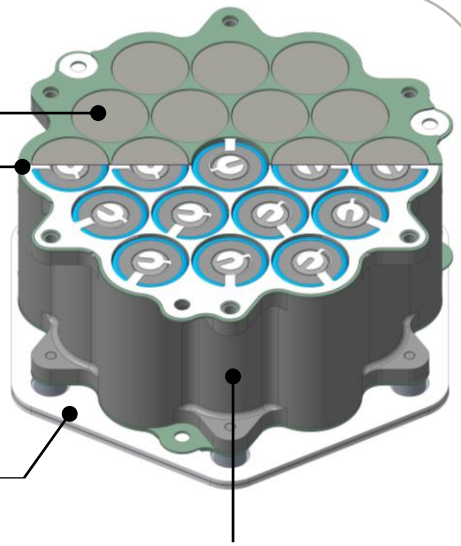
Sidewall Rupture Test Article

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.



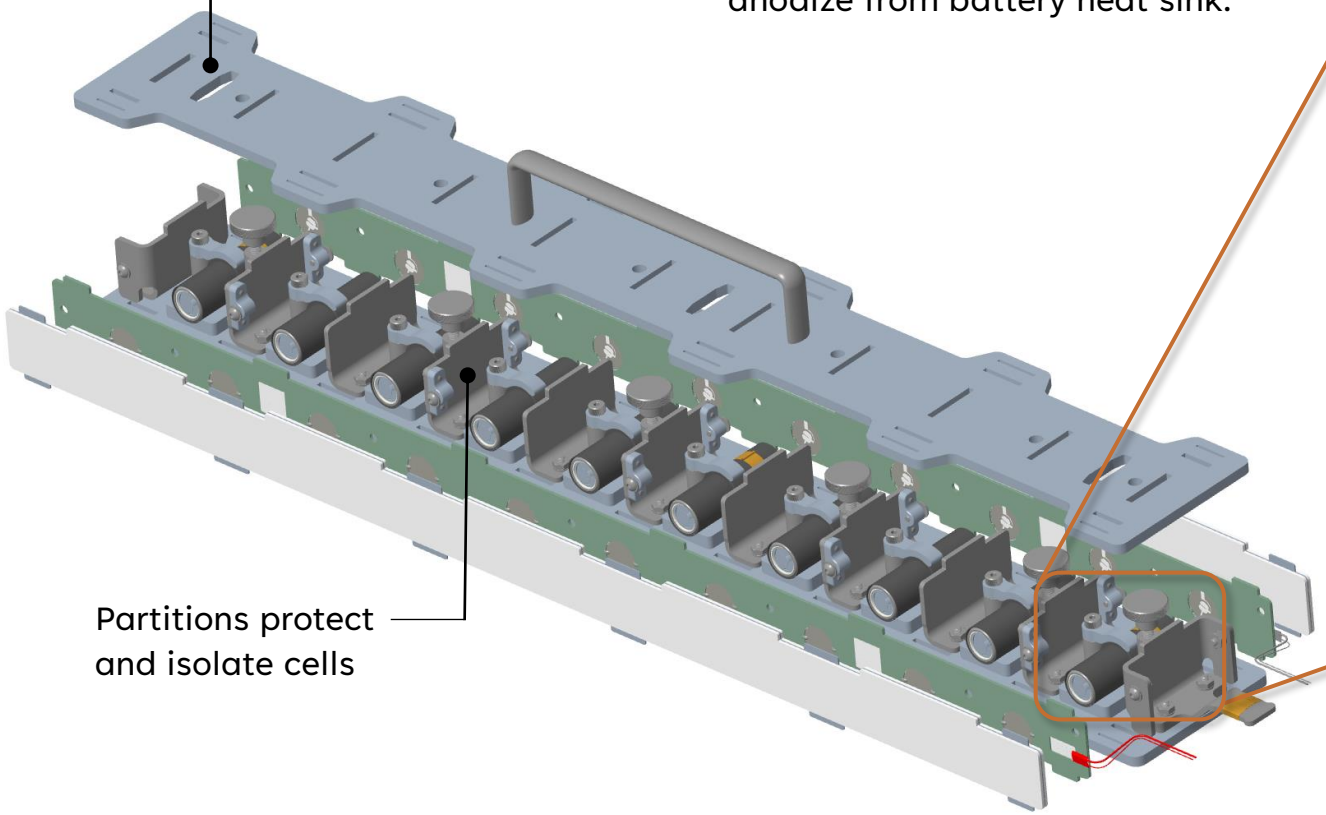
Subscale Battery Pack

TEST ARTICLE DESCRIPTION (CONT.)

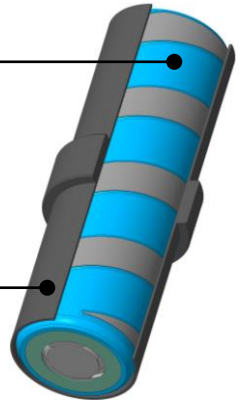
Cells are prepared the same as battery pack.

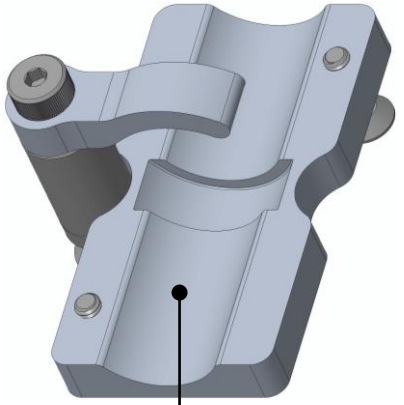
Aluminum cell tube replicates wall thickness (0.020”) and anodize from battery heat sink.

Protective cover.



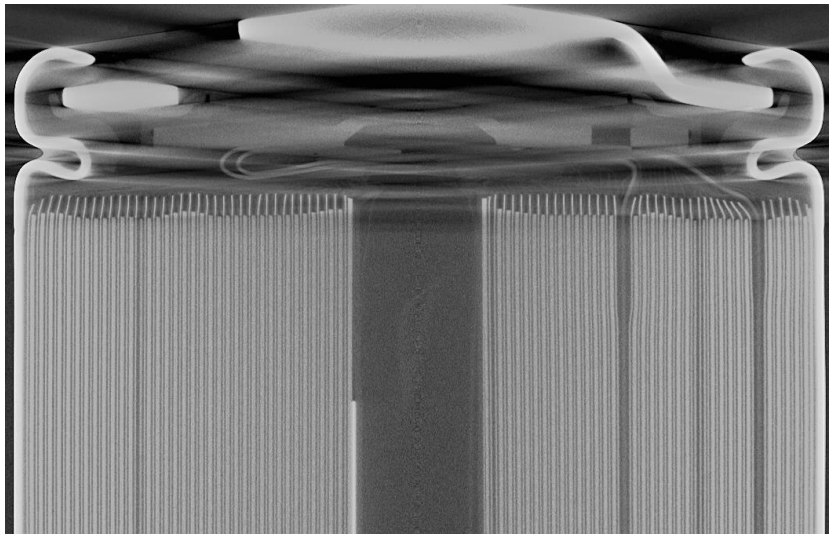
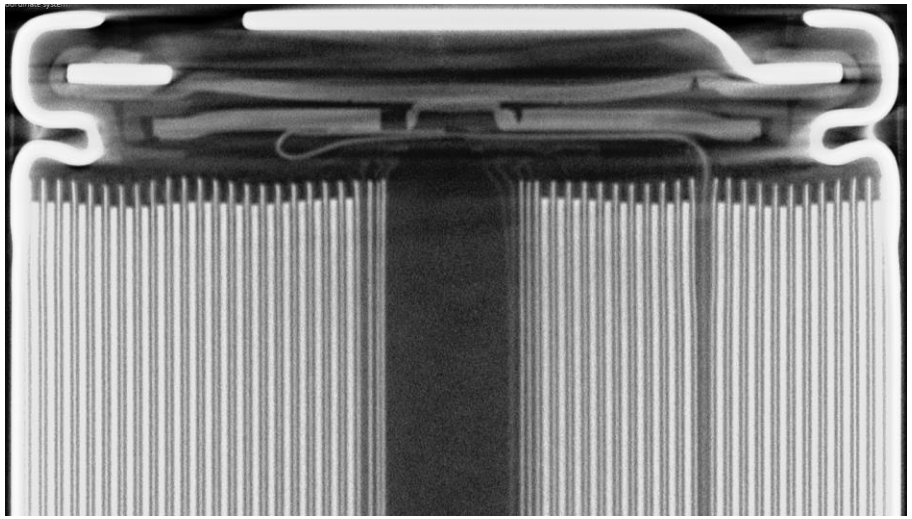
Partitions protect and isolate cells



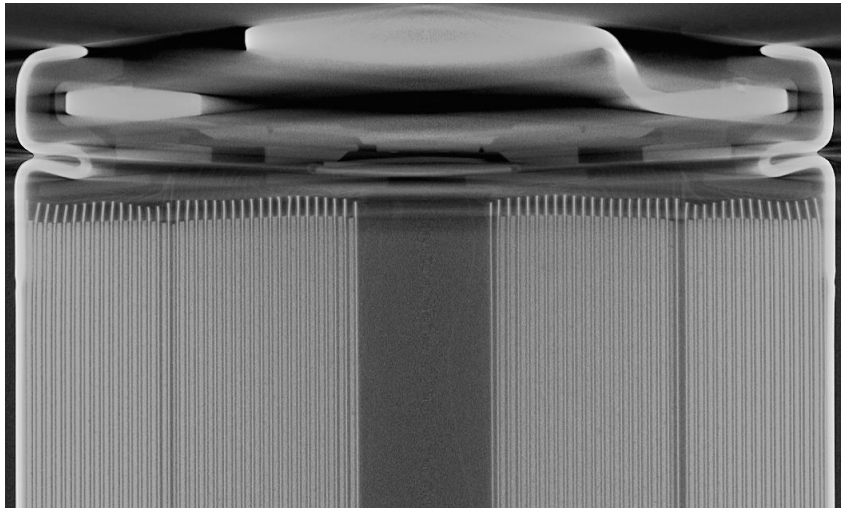
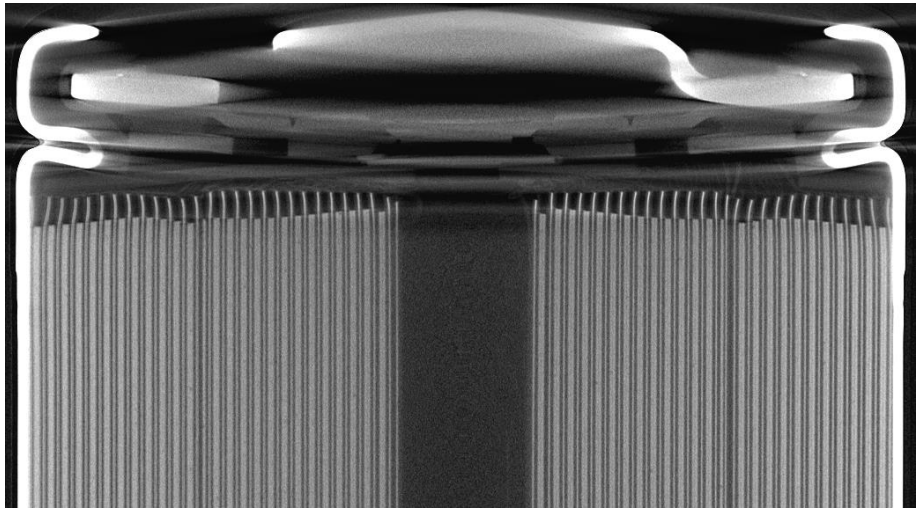


Cradle secures cell in place.

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		

TEST SETUP

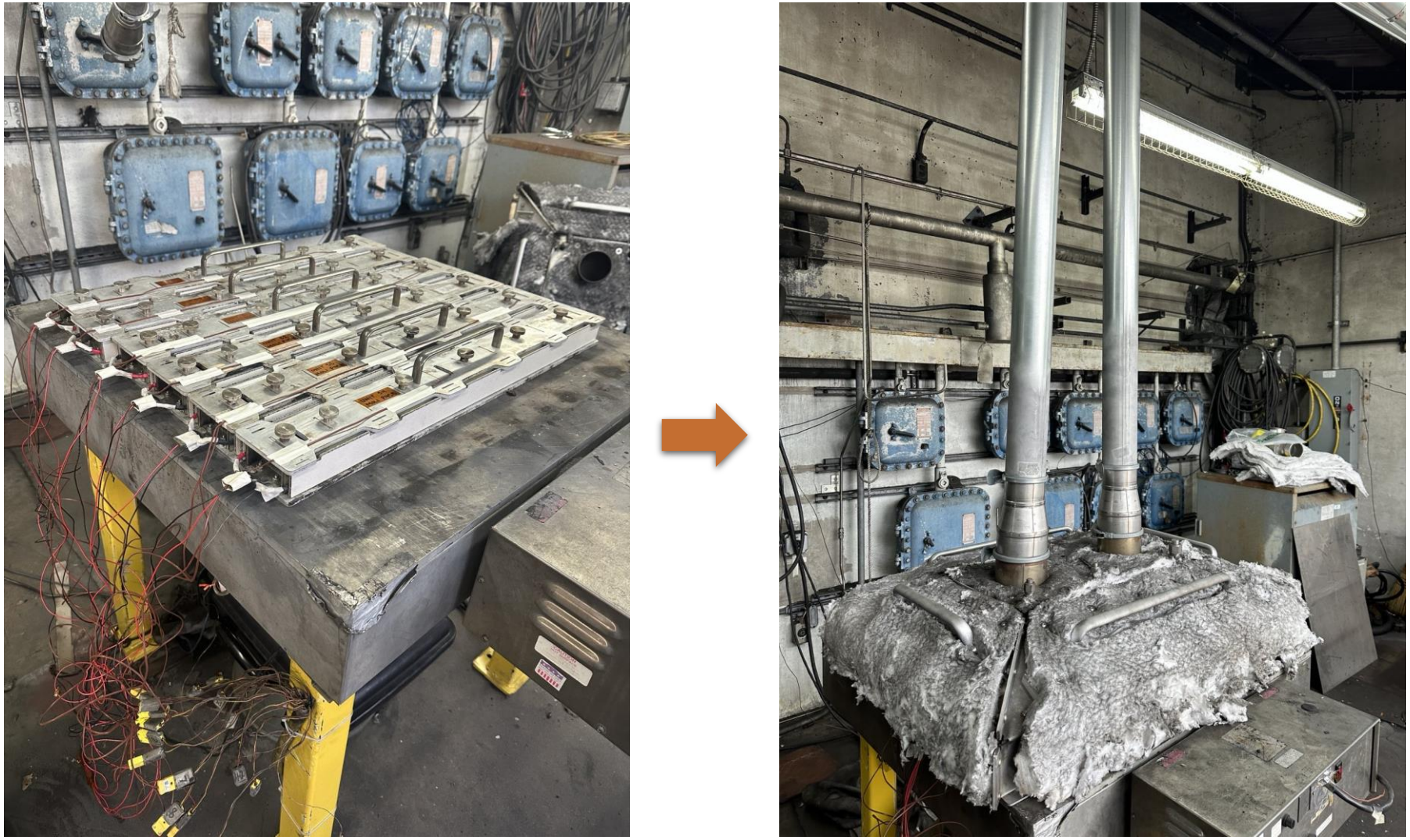
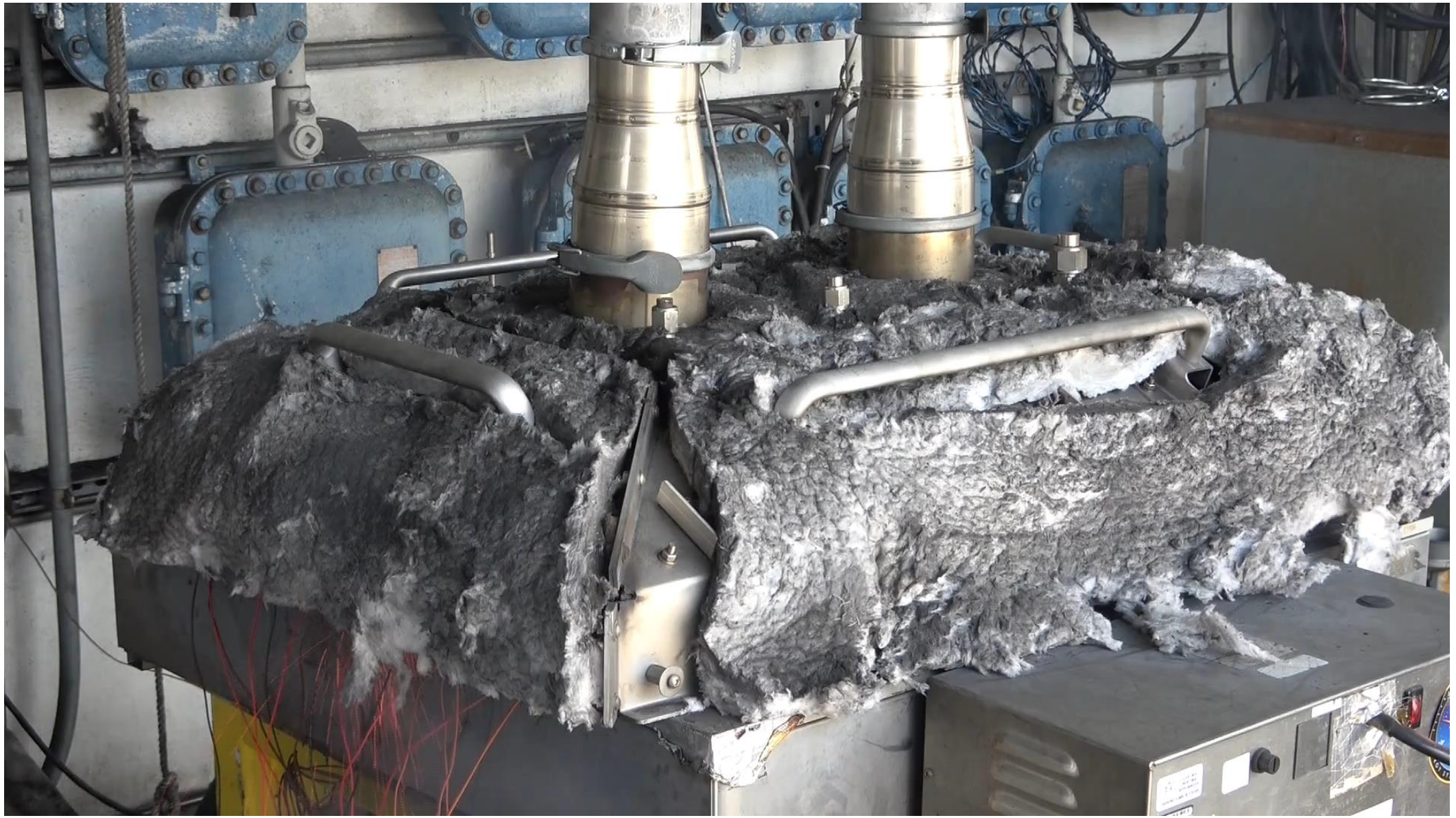


Figure: A 36” X 36” hot plate is used to heat 6 test articles at a time to trigger 60 cells into thermal runaway.

TEST SAMPLE VIDEO



POST TEST SEQUENCE

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

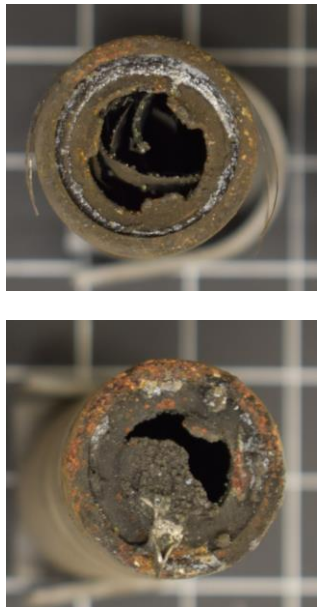
DEFINITION CRITERIA

ACCEPTABLE FAILURES

Nominal Top Vent

(NTV)

Cell vented only, no breach through the header.



Top Rupture

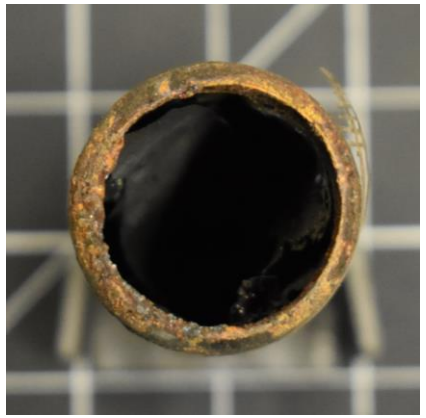
(TR)

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.

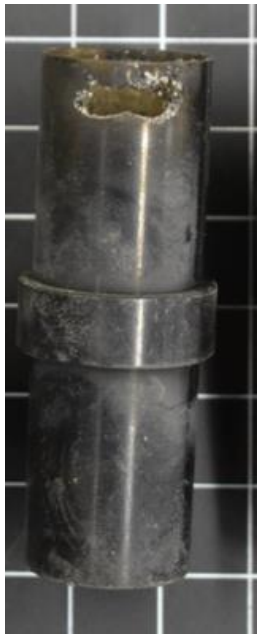
Bottom Rupture

(BR)

Breach through the bottom of the cell.

DEFINITION CRITERIA

UNACCEPTABLE FAILURES



Collar Breach (CB)

Breach of the aluminum cell tube.

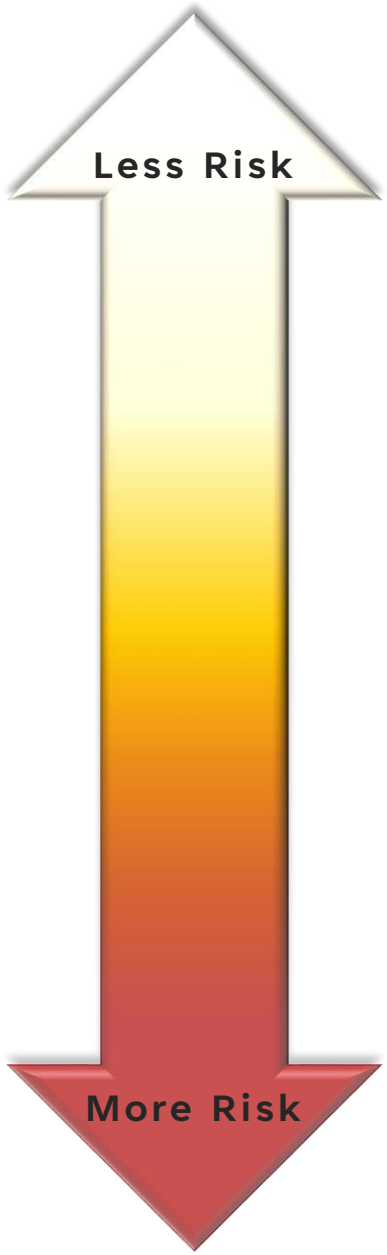
Spin Groove Rupture (SGR)

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

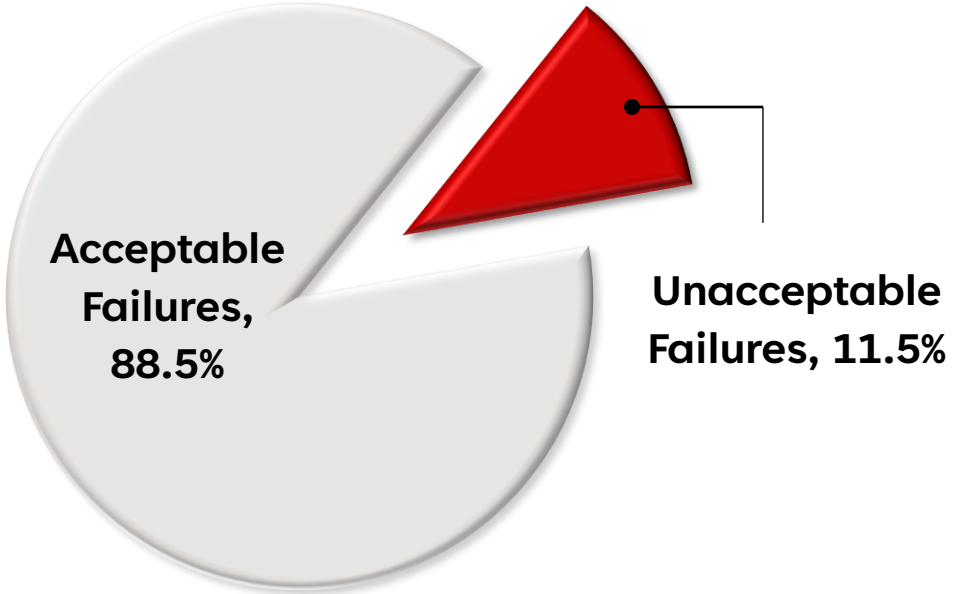
Sidewall Rupture

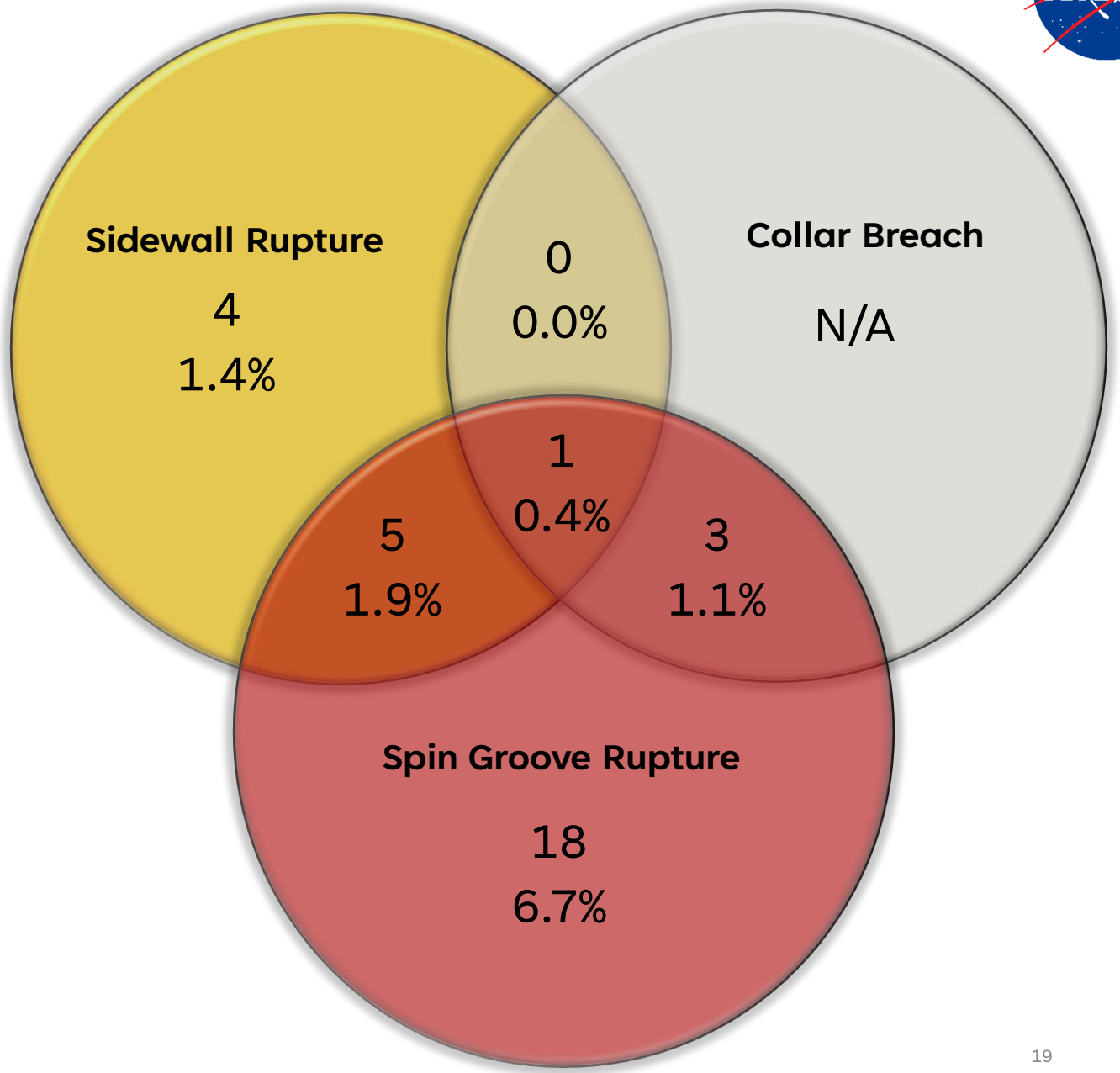
Spin Groove Rupture

Collar Breach

TEST RESULTS

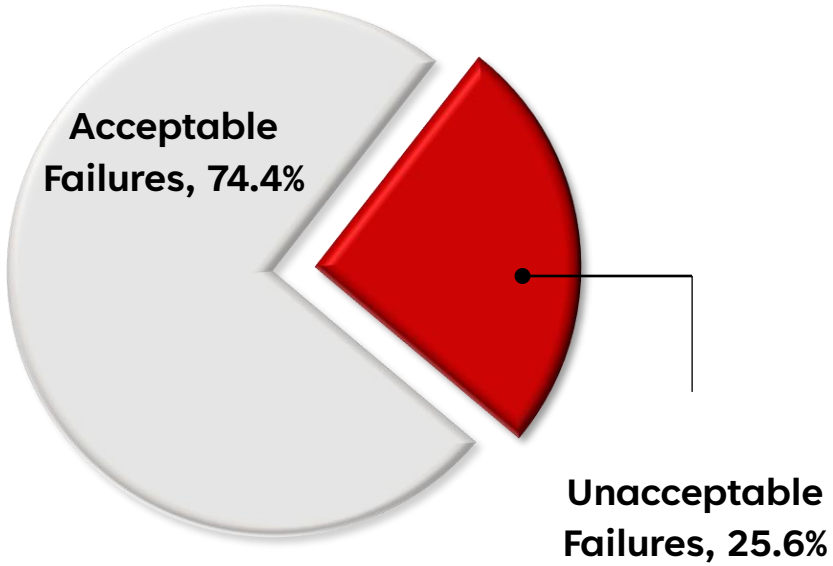
TEST RESULTS
LG M52V
270 CELLS, 100% SOC

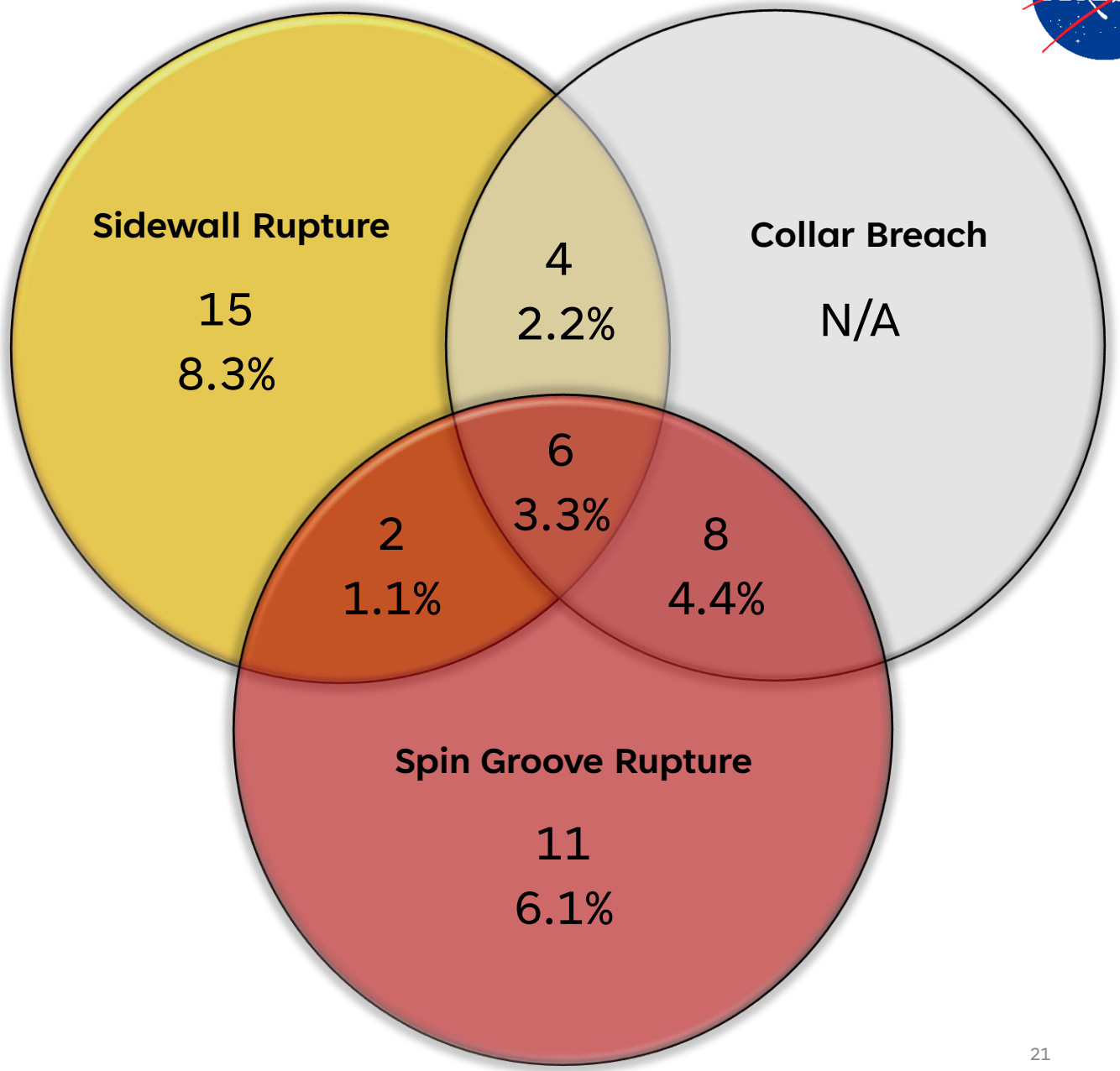




PHOTOGRAPHIC EVIDENCE – LG M52V

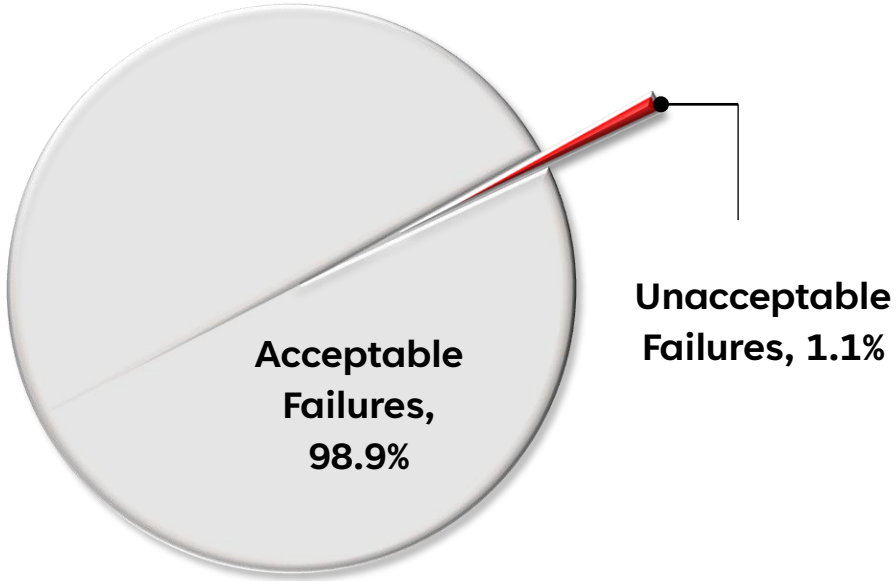
TEST RESULTS
SAMSUNG 50S
180 CELLS, 100% SOC

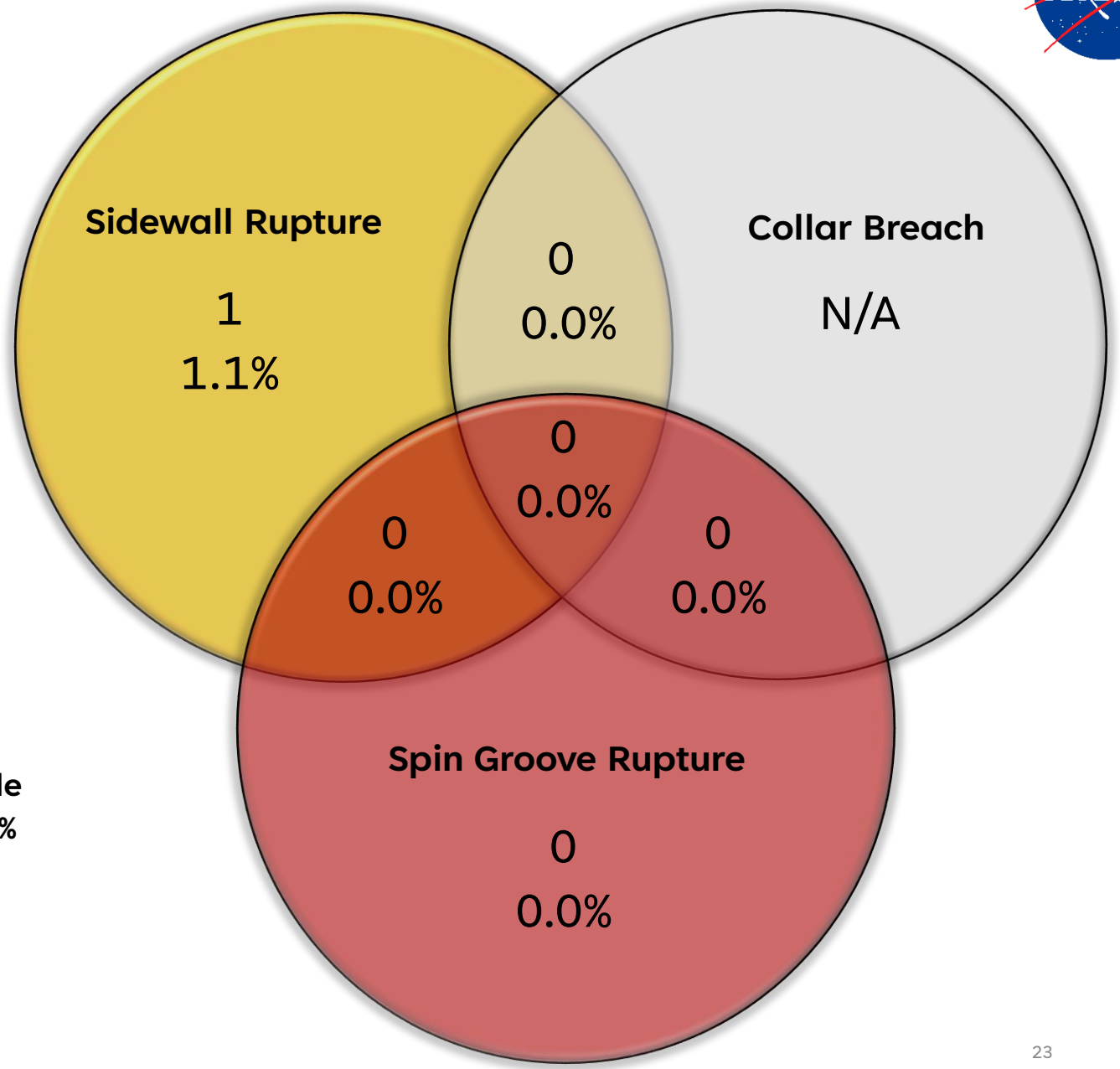




PHOTOGRAPHIC EVIDENCE – SAMSUNG 50S

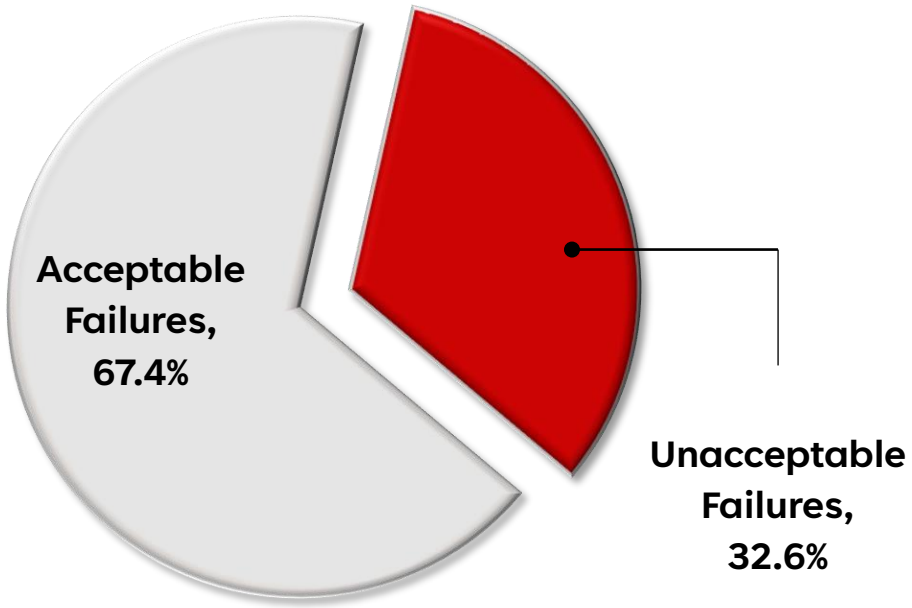
TEST RESULTS
SAMSUNG 53G
90 CELLS, 100% SOC

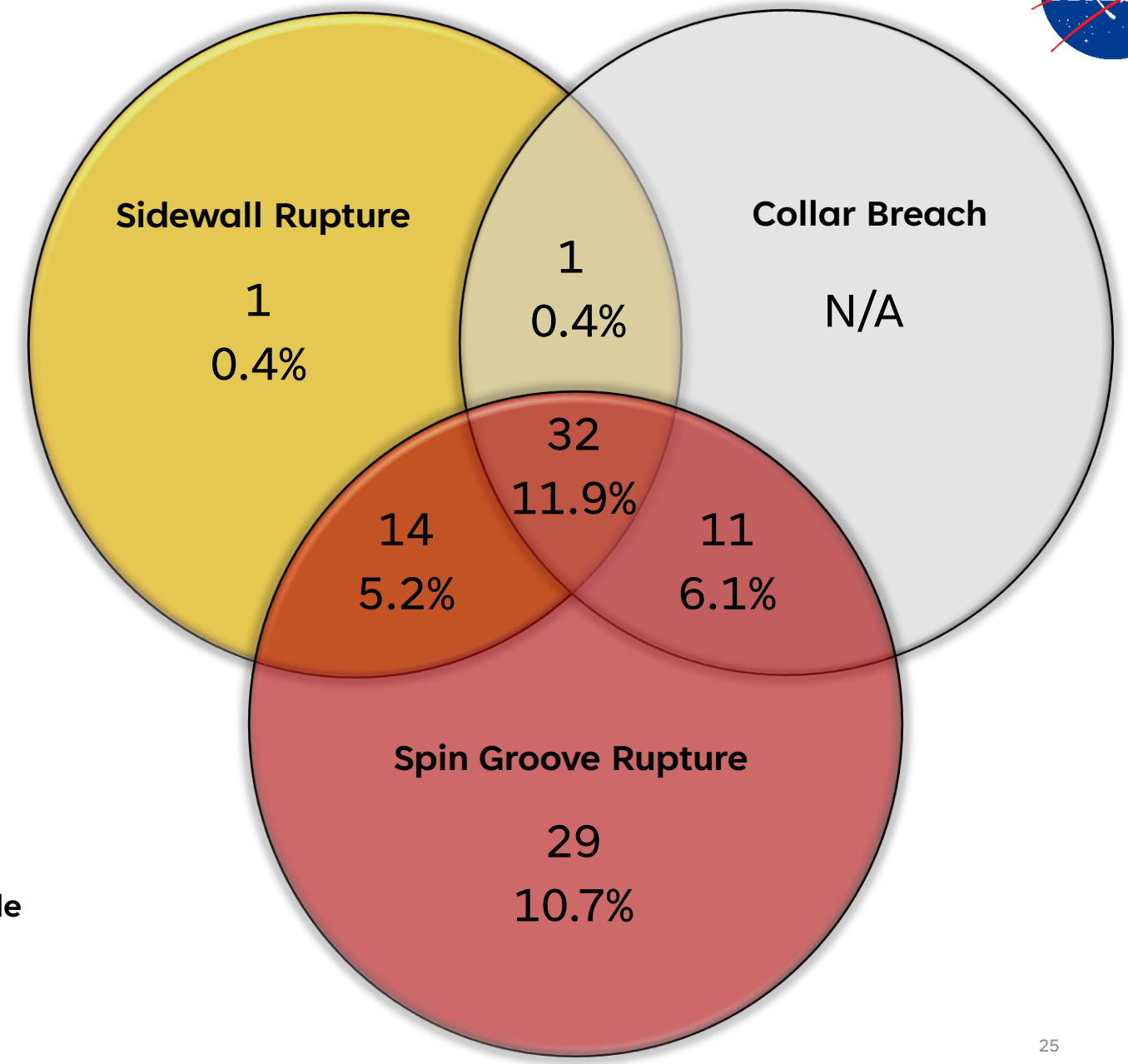




PHOTOGRAPHIC EVIDENCE – SAMSUNG 53G

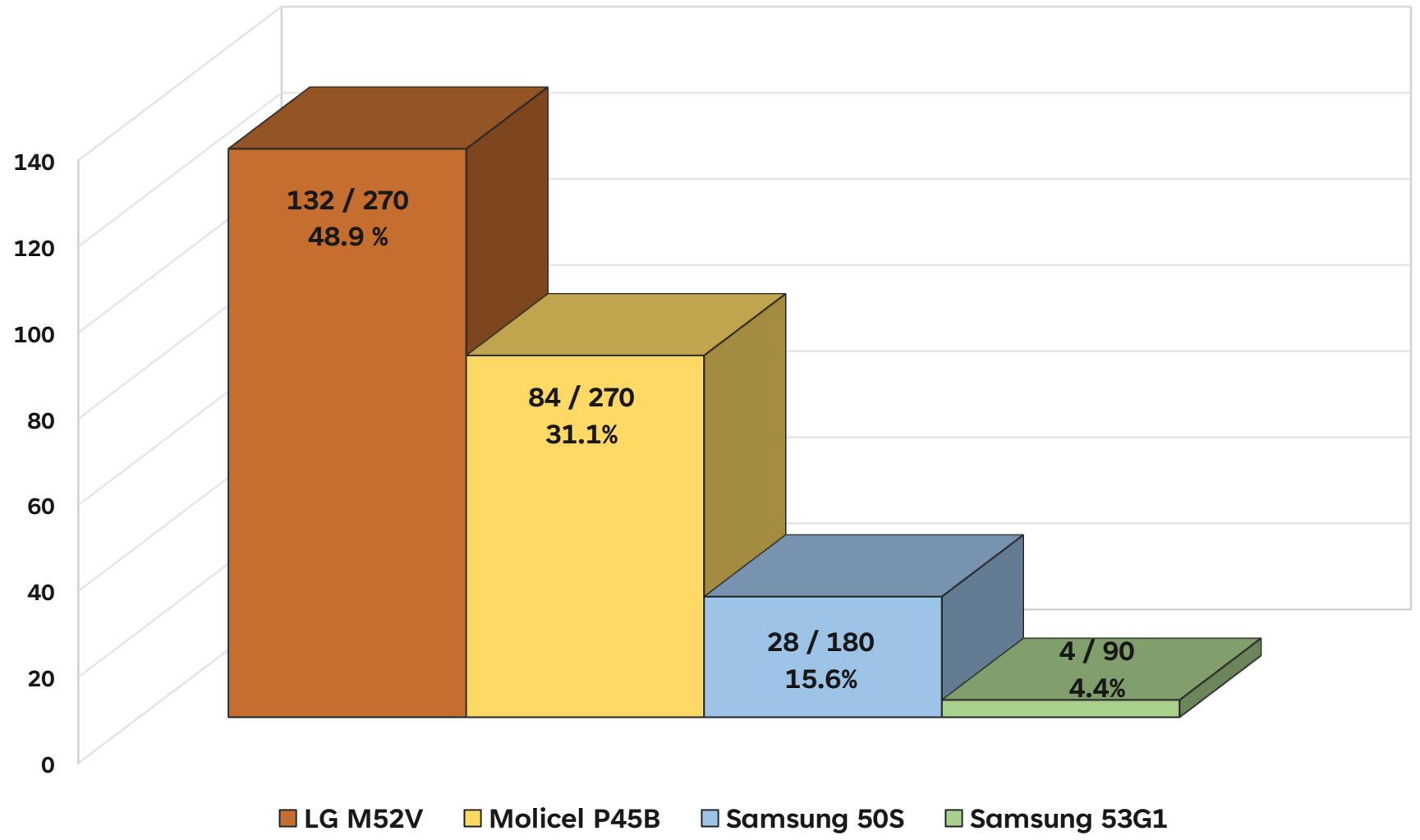
TEST RESULTS
MOLICEL P45B
270 CELLS, 100% SOC





PHOTOGRAPHIC EVIDENCE – MOLICEL P45B

BOTTOM RUPTURES



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.

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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.

CONCLUSIONS

SUMMARY OF RESULTS

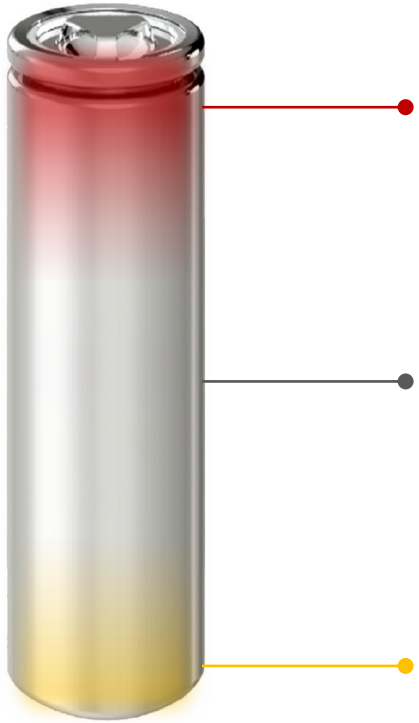
1. **Samsung 53G**: Best cell design in all aspects. Only one SWR out of 90 cells tested. Cell has the thickest can wall.

2. **LG M52V**: Second best cell in terms of SGR/SWR. Highest propensity to bottom rupture.

3. **Samsung 50S**: High propensity of SGR/SWR. Highest percentage of jelly roll ejections.

4. **Molicel P45B**: Highest propensity of SGR/SWR. Most observed at and above the spin groove area with a significant amount burning through the collar.

CELL CRITICAL FAILURE AREAS



Highest Risk: Majority of unacceptable failures happen at the spin groove (SGR) and just above and below the spin groove (SWR)

Lowest Risk: Very rare to see a sidewall rupture in the middle section of the cell body. Only one “split can” observed in this test series (most likely an outlier)

Moderate Risk: Some bottom ruptures happen close to the edge of the can and a few slightly breached through the sidewall. Some bottom collar breaches were observed

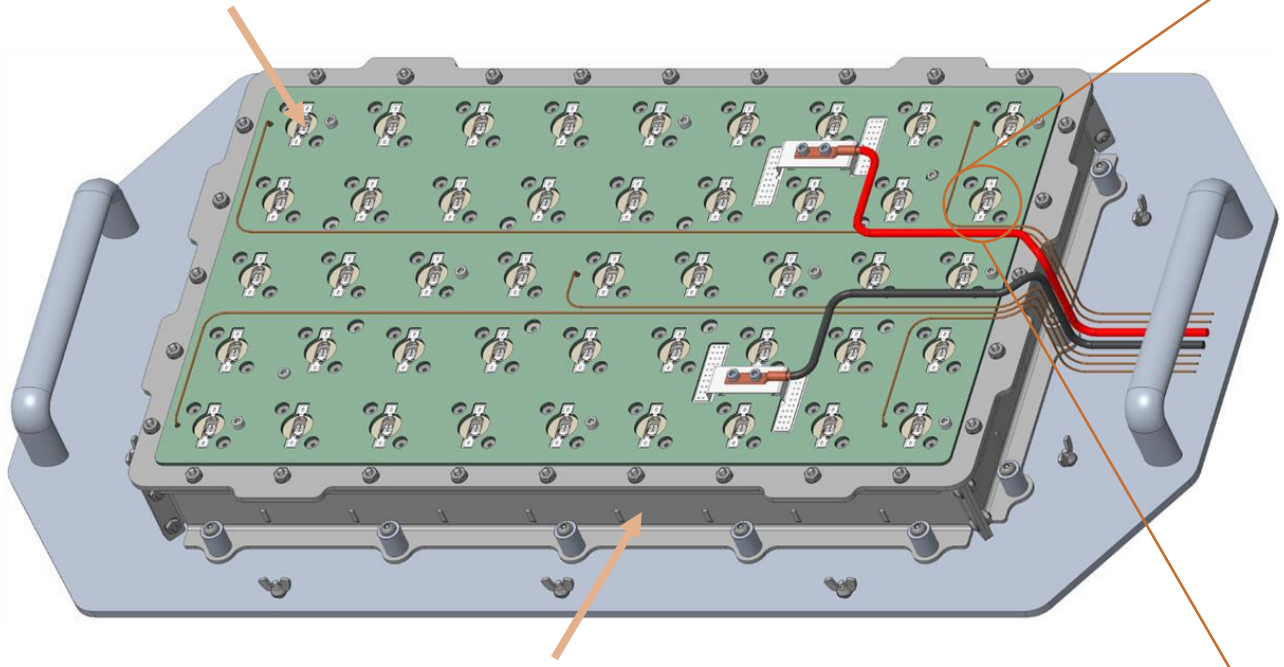
ADDITIONAL CONCLUSIONS

- 21700 cells are more propense to bottom ruptures than smaller format/lower capacity cells
  - If battery design tolerates bottom rupture, this should not be an issue.
- Thick can wall aids in preventing SGR/SWR – Samsung 53G
  - Also observed during 18650 SWR test campaign with the LG M36 cell.
- Other features that might affect propensity to SGR/SWR:
  - Cell constraints on battery pack
  - Cell header design: allowing for crimp to unfold and header to release, vent holes size, etc.
  - Other cell features such as bottom vents

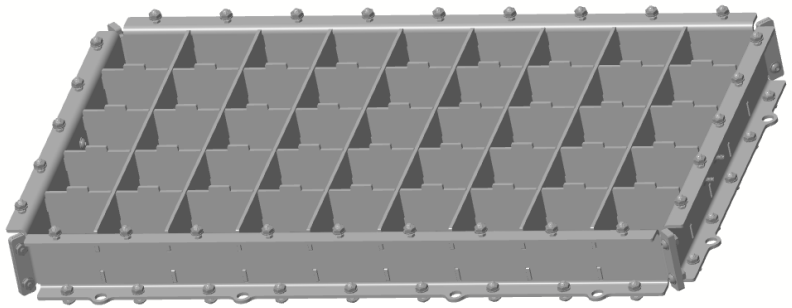
THANK YOU

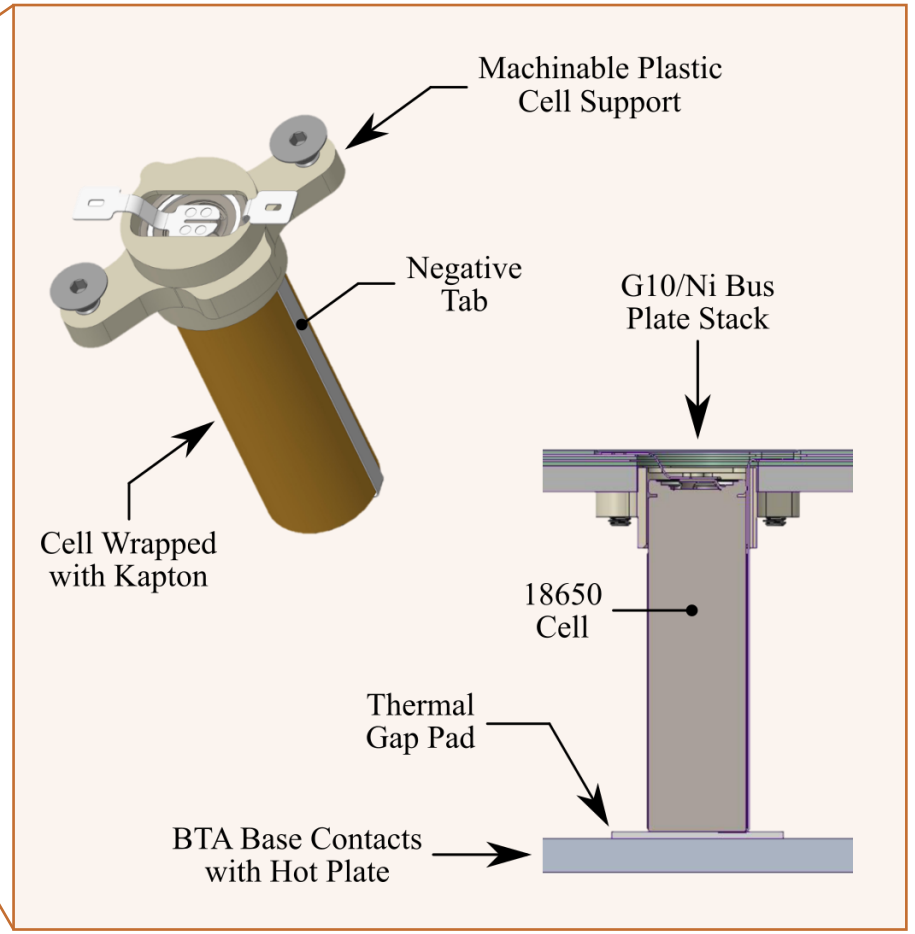
DESIGN A

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



Cell Partition

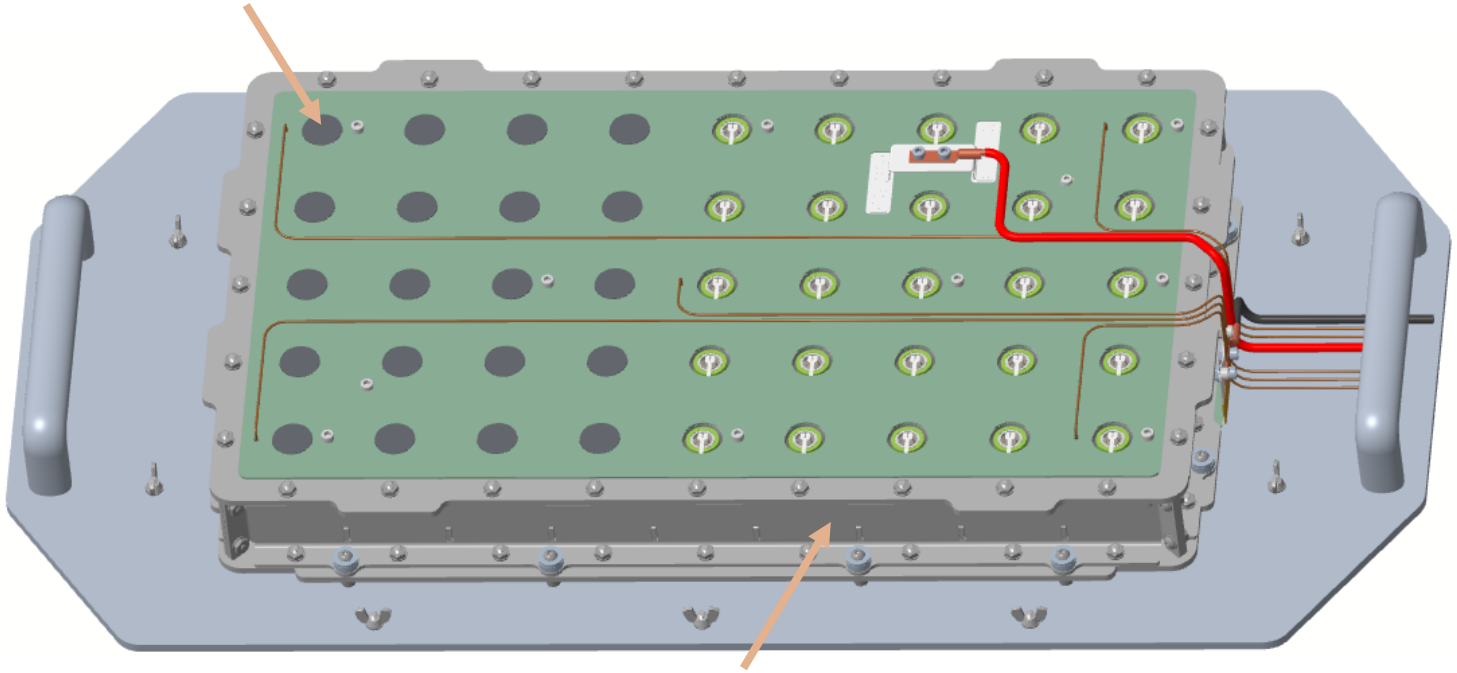




DESIGN B

Salient features: Length and header constraint

Mica covers to protect adjacent cells from ejecta



Cell Partition