Thermal Runaway Single Cell Material Testing and Puncture Location Investigation

Space Power Workshop 2025

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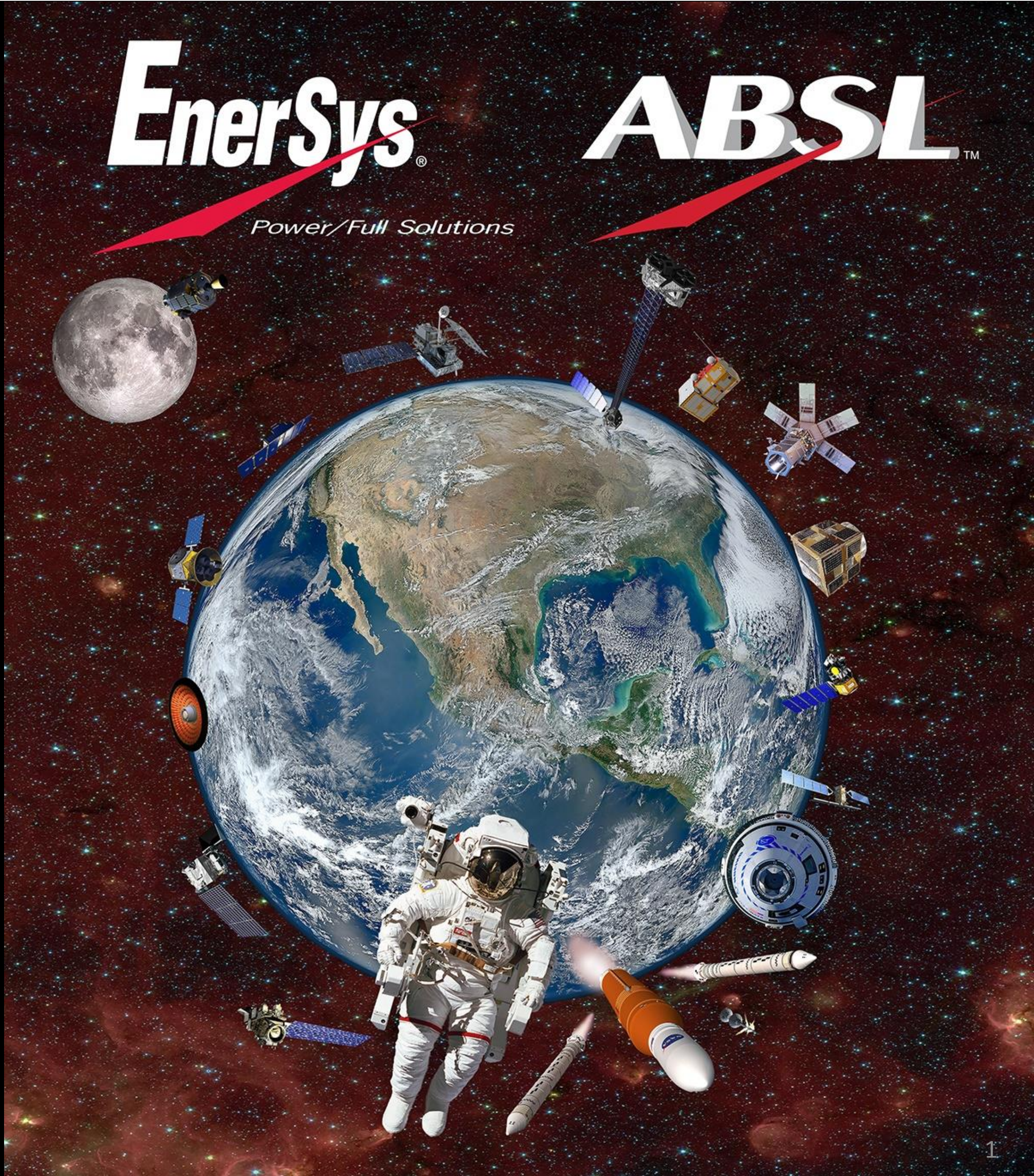
Approved for Public Release



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The Power of EnerSys

EnerSys® Power/Full Solutions ABSL

- World's Largest Industrial Battery Company ~ $4.0 B annual sales
- Leading brands in wide range of end-user markets
- US-owned / Publicly Traded
- Global – Over 10,000 employees with over 30 locations in 18 countries
- Recent acquisition of Bren-Tronics

ABSL
Longmont, CO

- Motive Power
  - Forklifts
- Energy Systems
  - Telecom
  - UPS/Utility/ESS
- Specialty
  - Transportation
  - Aerospace & Defense

Bren-Tronics® an EnerSys company · HAWKER · CYCLON · QUALLION · ABSL · ARMASAFE plus

ABSL Facilities Overview

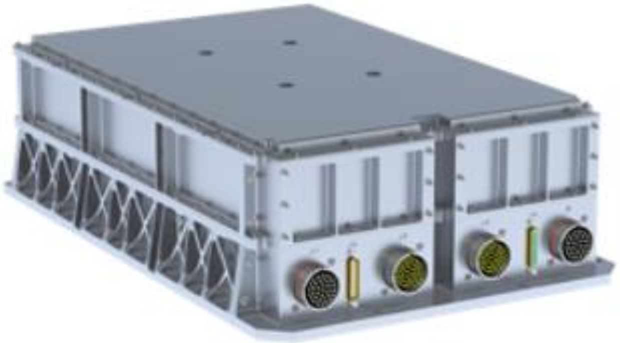
Longmont, CO

- ABSL opened its original US facility in 2008
- ABSL joined the EnerSys family in 2011
- ABSL expanded and moved into its current US facility in 2013
- The facility expanded into its neighboring space in 2019
- The current facility has 41,000 sqft of assembly, test, inspection, office, and meeting space
- 100+ passionate staff members

- Wide range of engineering capabilities
- ABSL cell screening & processing
- Contamination-controlled manufacturing rooms
- Destructive and environmental test laboratories
- Dedicated product development space
- Secured inventory stores
- In house CT Scanner
- 3rd party Vibration Lab across the street

Space Batteries - Standard Designs

- Sizes: 8s3p – 8s84p
- Capacities: 8.4Ah – 252Ah
- Cont. Current: 14 A – 290 A
- Custom Battery option


8s80p E35


8s72p E35


8s3p I28

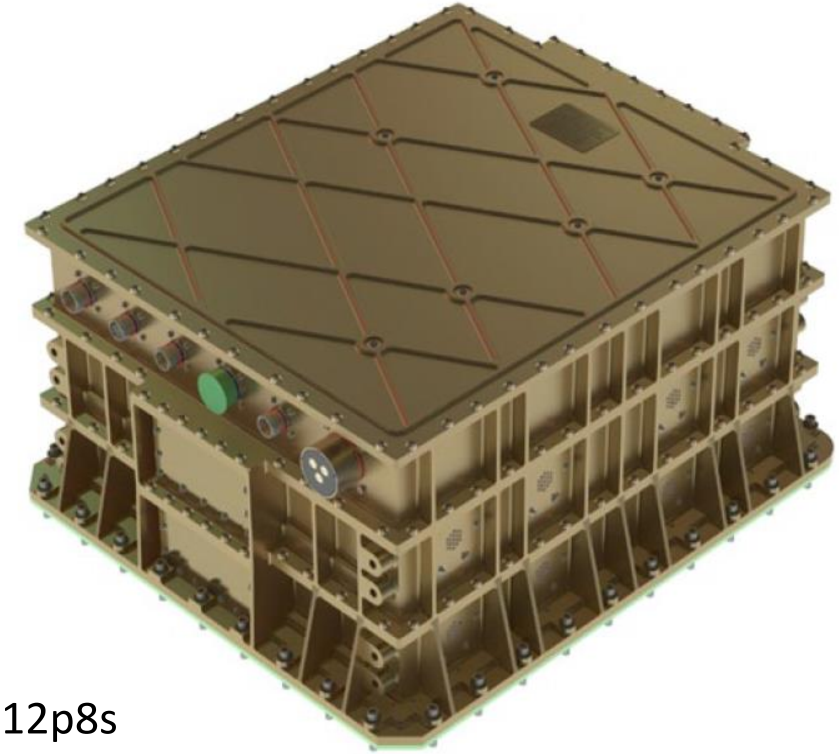

8s44p I28


8s10p E35

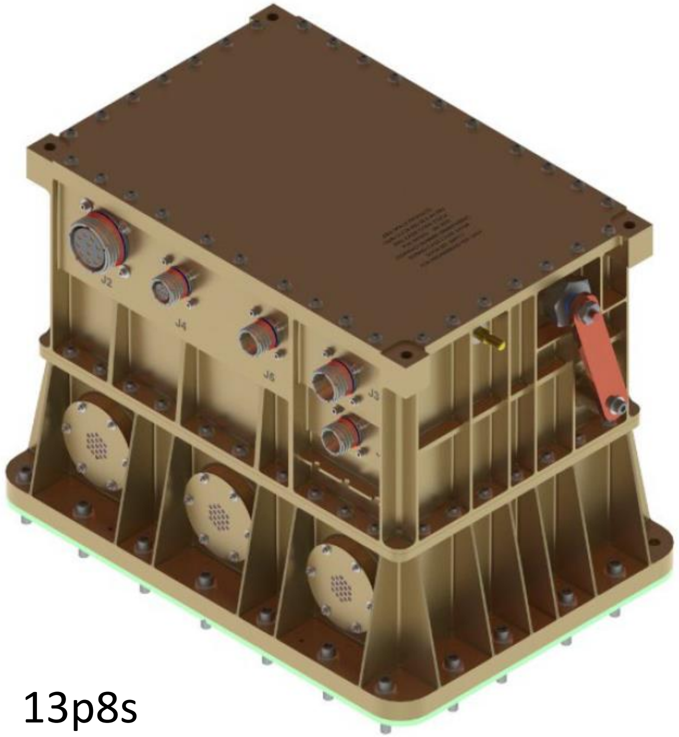

8s16p E35

Custom Designs for Crewed Space Flight

Configuration		Capacity
Battery	Cell	(Ah)
112p8s	ABSL E35	392
13p8s	ABSL E35	45



112p8s



13p8s

Motivation – Crewed Space Flight

Battery Thermal Runaway (TR) Propagation Requirements in JSC 20793 Rev D and the EP-19 Interpretation Memo – Crewed Space Vehicle Battery Safety Requirements

The battery is fully successful and passed propagation testing if the following conditions are achieved (3 test requirement):

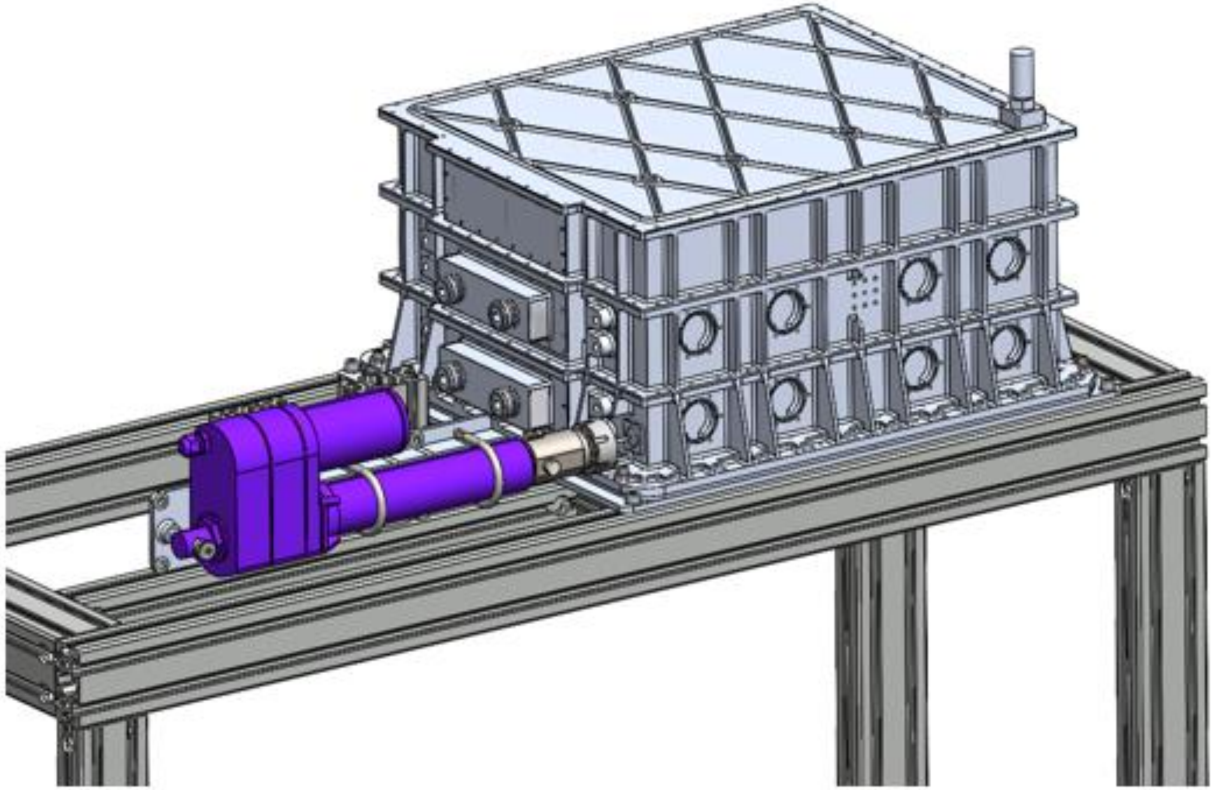
1. Only the trigger cell(s) achieves TR
2. Other cells in the battery are not damaged, vented, ignited, leaking electrolyte, the CIDs, PTCs, and/or fuses have not triggered
3. Neighboring cells or cell banks can be cycled within ±5% of pre-test capacity
4. No flames exit the battery enclosure

OR

1. No flames, sparks, gases, or fluids shall exit the containment vessel
2. Exterior temperatures of the containment vessel shall not exceed 60°C

Motivation – Battery Level

During Test 1 of 3 for the TR Safety Requirement testing for our 112p8s Battery, a containment breach was discovered in our Anodized Aluminum bottom cover



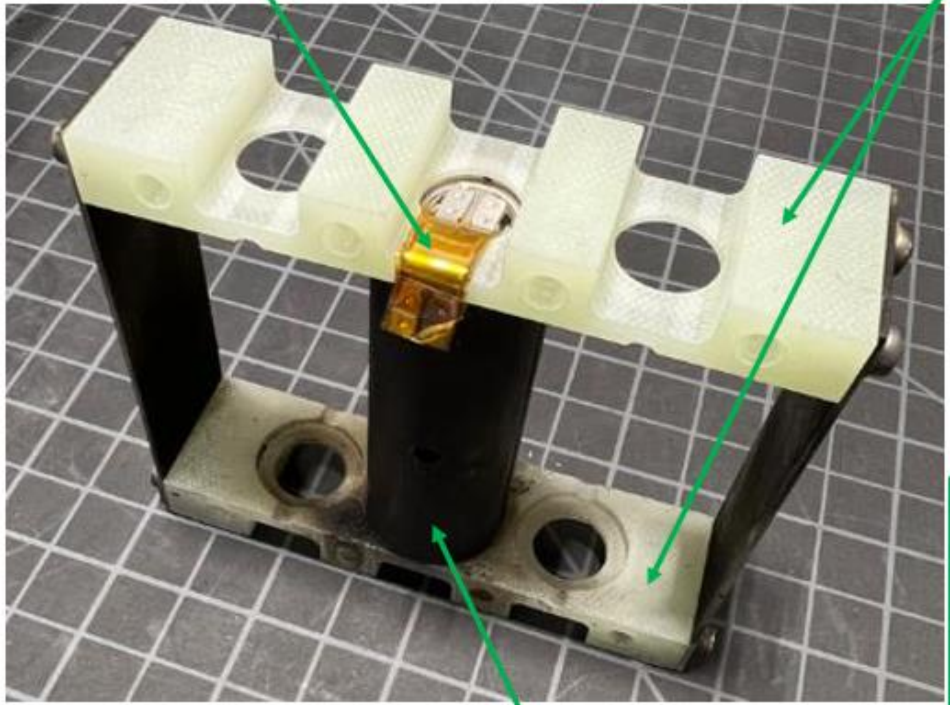
Test Objective

- **<u>Goal:</u>** Qualify materials that can withstand the energy release during a worst-case scenario thermal runaway event produced by the ABSL E35 cell to be used in battery level implementation
  - Test set up to mimic original failure mode
  - Recreate the failure a statistically relevant number of times
  - Prove out possible replacement materials

Test Design – Failure Recreation

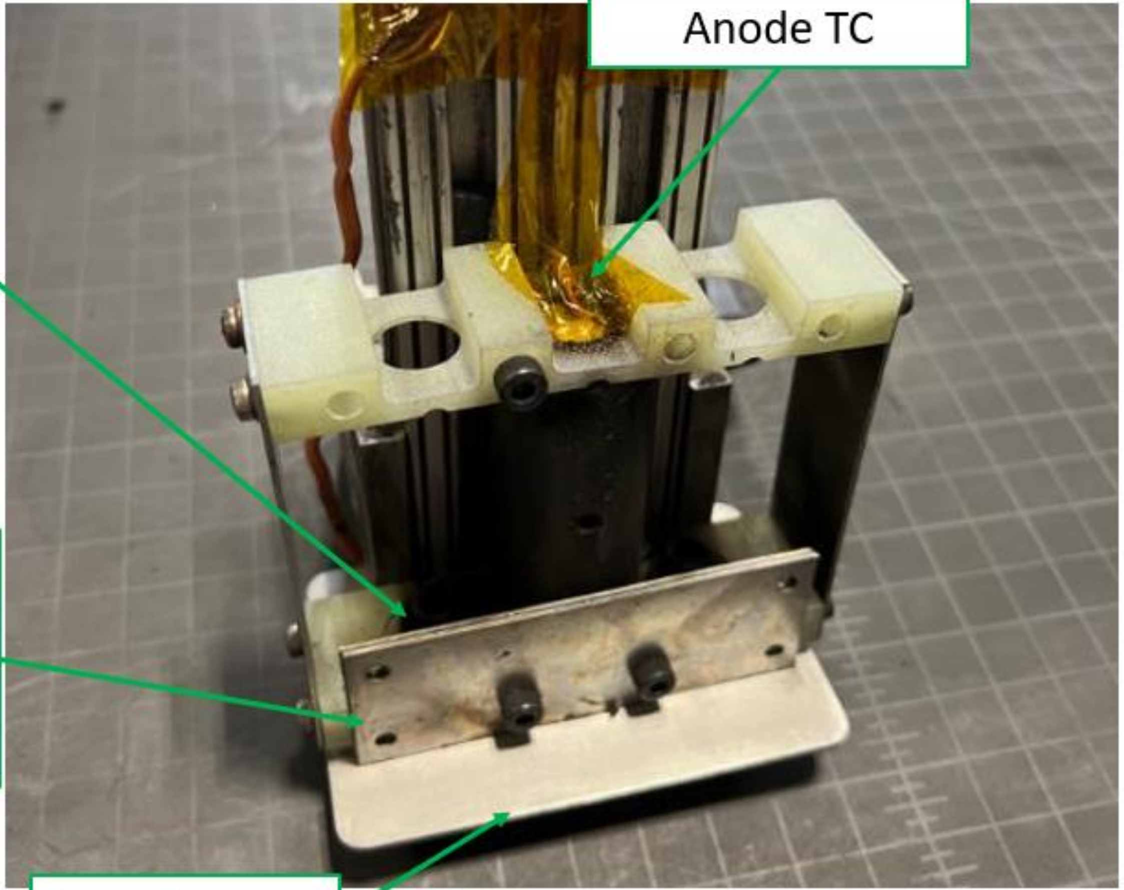
- Through many iterations and trials, the following were determined to be controls used for failure recreation:
  - All cells used from same lot
  - All cells pre-charged to 100% SoC (4.2V)
  - Cells held in Al interstitial mockup
  - Cells soak at 60°C for a minimum of 1 hour
  - Cell orientation – cathode facing downward towards test material
  - Same Anodized Aluminum and thickness as the bottom cover (thickness X)
  - Spacing from cell cathode to the test coupon
  - Each cell had a nickel tag welded onto the cathode
  - Tungsten Electrode Nails (3.18mm diameter)
  - Nail penetration depth ~ 75% through the cell
    - Center Radial Puncture

Test Design

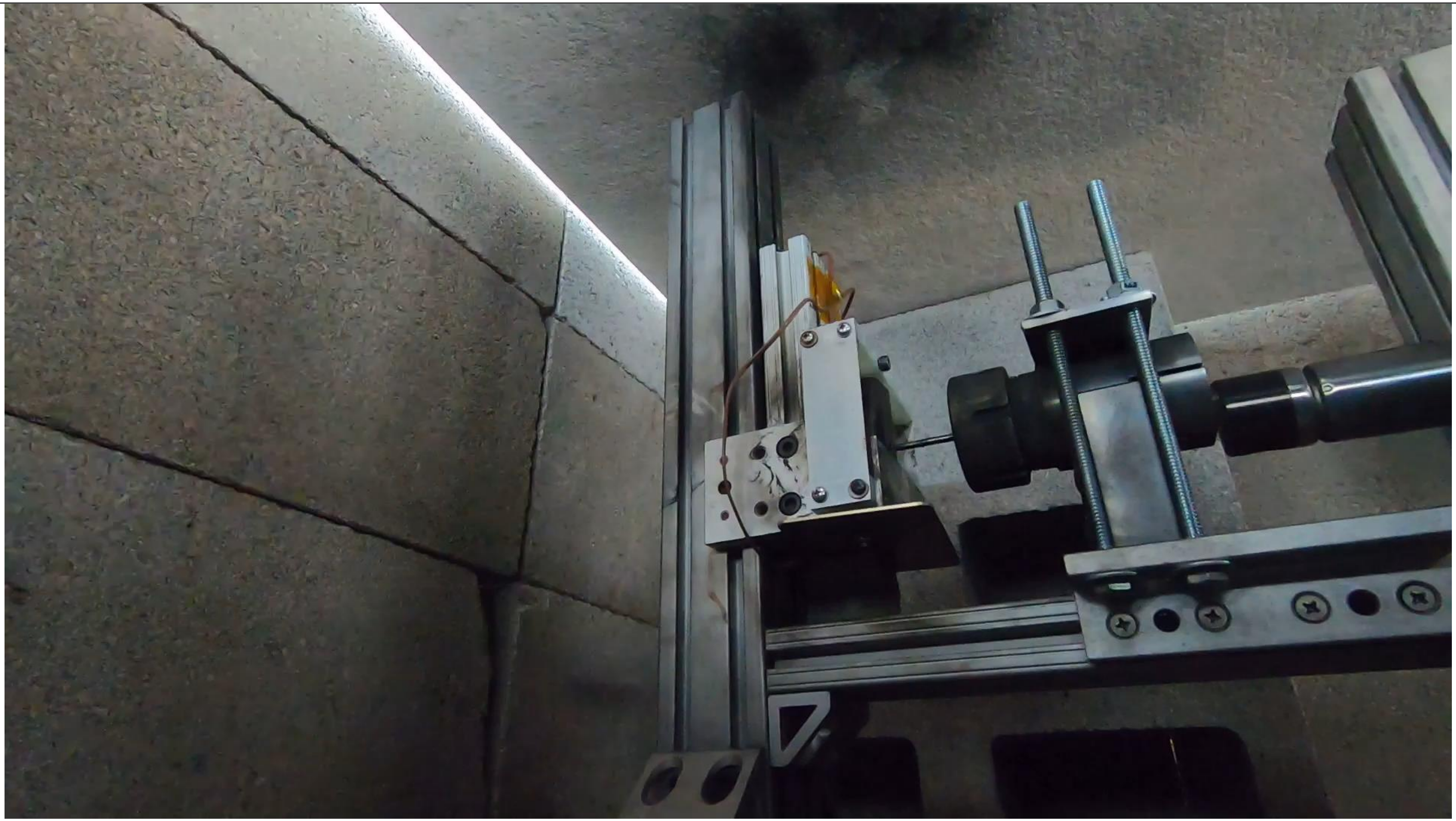


Spacers to control distance between cathode and coupon

Extra shims to enclose cathode and to replicate venting restrictions



TR Control Test



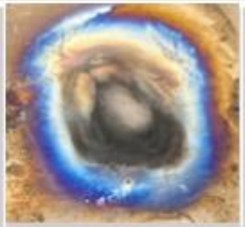
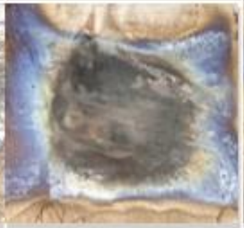
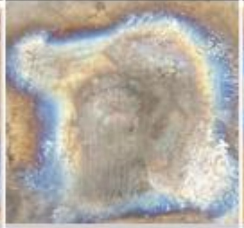
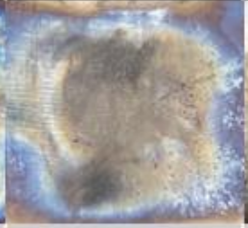
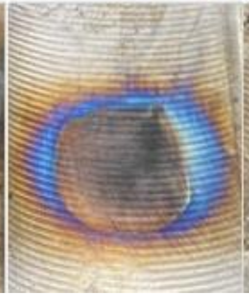
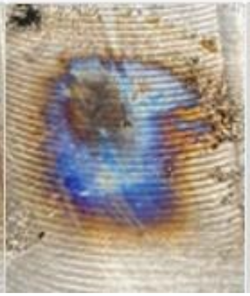
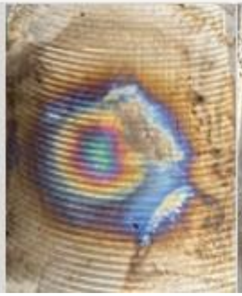
TR Control Test

Control Group – Anodized Aluminum (Thickness X)

- 4 of 10 with significant damage, close to burn through
- 6 of 10 with full burn through

Metals Tested

- All materials were to be tested 10 times unless a burn thru occurred, then testing for that material was suspended

Material	1	2	3	4	5	6	7	8	9	10
Titanium Thickness A								Test Suspended		
Titanium Thickness B										

Other Materials Tested

- All materials were to be tested 10 times unless a burn thru occurred, then testing for that material was suspended
- Images are of the Al coupon protected by shielding material - all commercially available flame blocking materials

Material	1	2	3	4	5	6	7	8	9	10
A			Test suspended							
B			Test Suspended							
C										

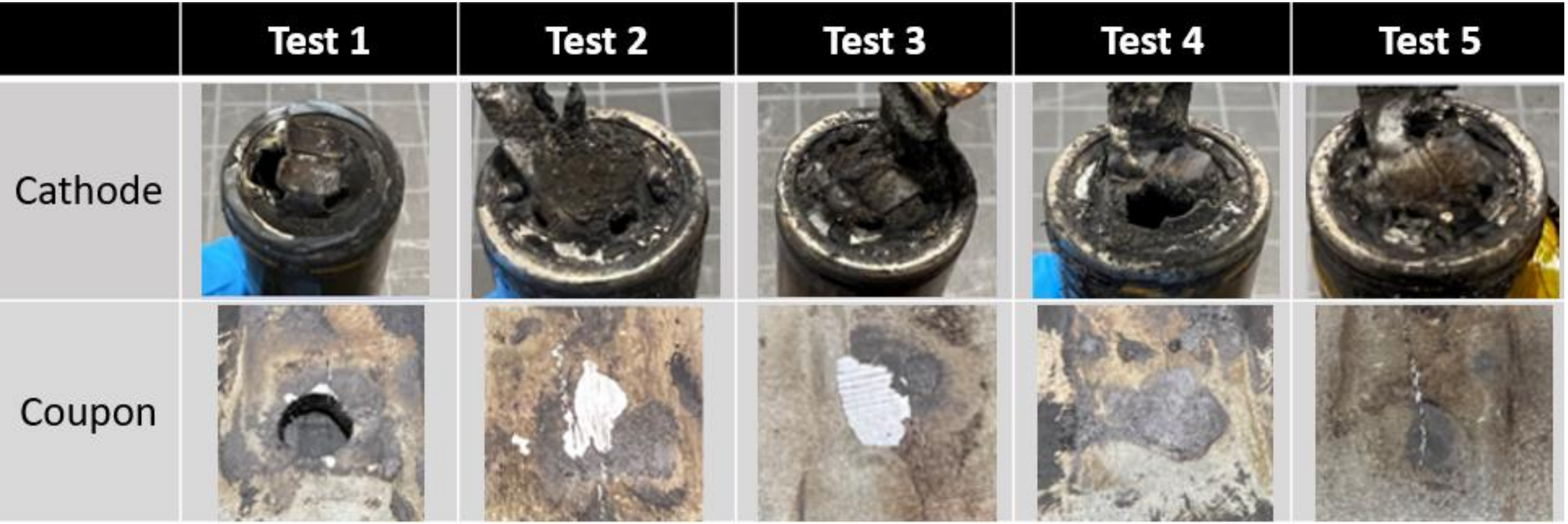
Material Selection

- Once materials were narrowed down and proven to withstand a TR event, other tradeoffs to take into consideration were:
  - Mass
  - Cost
  - Lead times
  - Machinability and implementation
  - Other (Outgassing, dissimilar metals, etc.)
- After the chosen material was implemented at the battery level, both batteries restarted their Thermal Runaway Test Campaigns per JSC20793 Rev D and experienced no further containment breaches

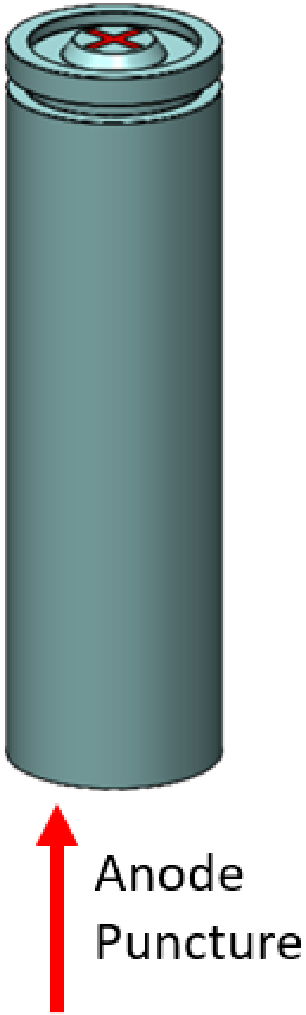
Puncture Location Investigation

- After our material testing, we also explored if the location of the nail puncture played a factor into what kind of thermal runaway event we could expect
- Question to answer: Which puncture location is better for testing a battery pack?
  - Test - Puncture the cells in 3 different locations and compare the following:
    - Cathodes
    - Coupon Damage
    - Cell Mass pre and post test
    - Pressure

Comparison – Anode



Avg Mass Delta: 29.735g



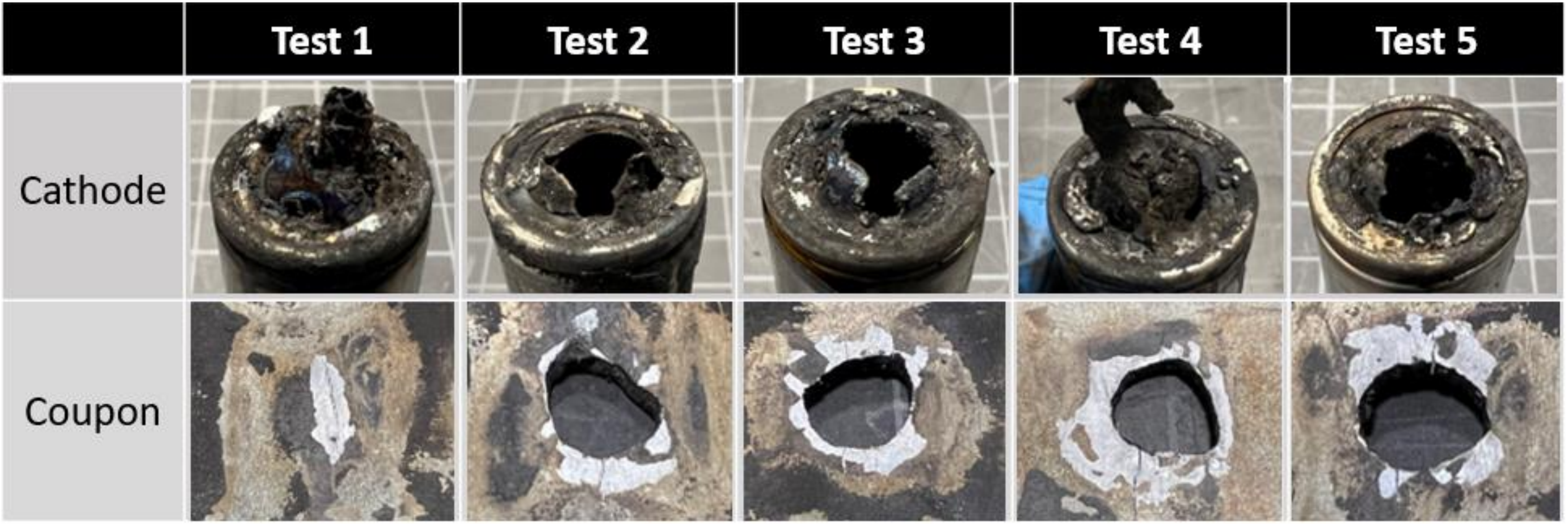
Comparison – Radial Anode

	Test 1	Test 2	Test 3	Test 4	Test 5
Cathode					
Coupon					

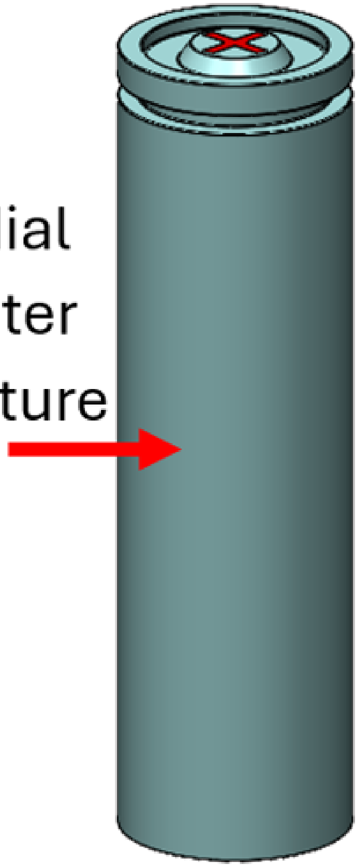
Radial Anode Puncture

Avg Mass Delta: 32.556g

Comparison – Radial Centered



Radial Center Puncture



Avg Mass Delta: 29.393g

Comparison - Pressure

- Pressure can be compared from battery level and virtual cell level tests
  - Virtual Cell – test article with same cell layout, but less free air volume and only one full string is populated with cells
- Radial puncture seen producing much higher-pressure spikes during TR event

Test	Puncture Location	Pressure (psi)
13p1s – Virtual Cell	Anode	16.38
13p8s – Battery Level	Anode	11.07
13p8s – Battery Level	Center Radial	34.86
13p8s – Battery Level	Center Radial	30.49

Summary of Findings

Puncture Location	Burn Thrus on Anodized Al	Avg. Mass Loss (g)	Battery/Virtual Cell Testing?	Average Pressure (psi)
Anode	1/10	29.735	Yes	13.73
Radial – Anode Biased	0/5	32.556	No	N/A
Radial - Centered	6/10	29.393	Yes	32.68

- Radial Puncture vs Anode puncture yields wildly different thermal runaway events
  - Radial puncture: more “violent” short events
    - Cathode cap is mostly/entirely blown off from event
  - Anode puncture: longer duration but less forceful
    - Cathode cap is still mostly intact after TR event

Conclusion

Different puncture locations are better for testing different aspects of a battery pack

- Radial nail puncture thermal runaway better tests battery containment, material durability, pressure build up
  - High pressure release, most likely chance for containment breach
- Anode nail puncture thermal runaway better tests ejecta mitigation to surrounding cells during virtual cell/ battery level tests
  - Lower pressure release limits the distribution of ejecta, localizing it around the trigger cell

Acknowledgments

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  - Heath Schoonover
  - Matt Trias
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  - Wes Hoffert
  - Josh Fedders