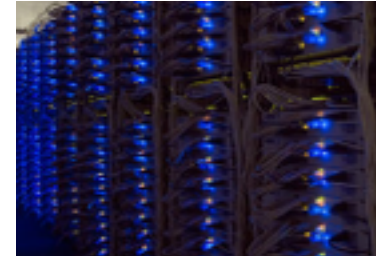
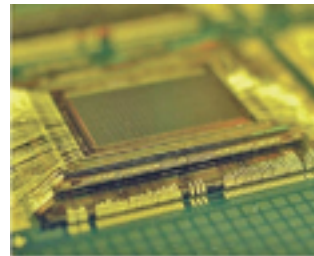




**Carbon Fiber Cooling™**



# **LiB Thermal Runaway Shield**

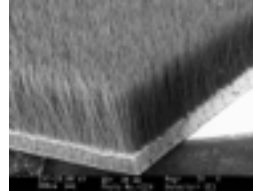
**Michael Mo, Co-Founder and CEO**

**KULR Technology**

**Battery Power 2017, Dallas**

# KULR Carbon Fiber Cooling Solutions

Thermal Interface Material  
(FTI)

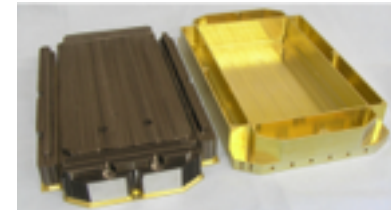


Lithium-Ion Battery  
Protection  
(LiB-TRS)

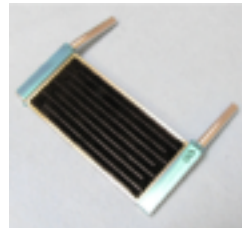


Proprietary  
Carbon Fiber  
Architecture

PCM Heat Sink

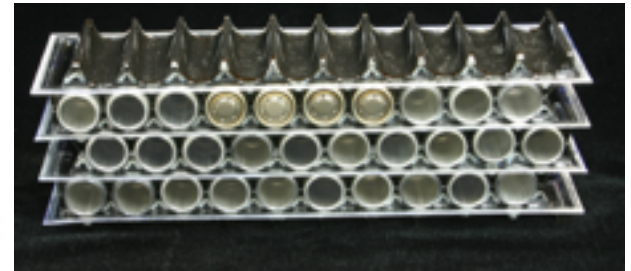


Fiber Heat Exchanger  
(FHX)



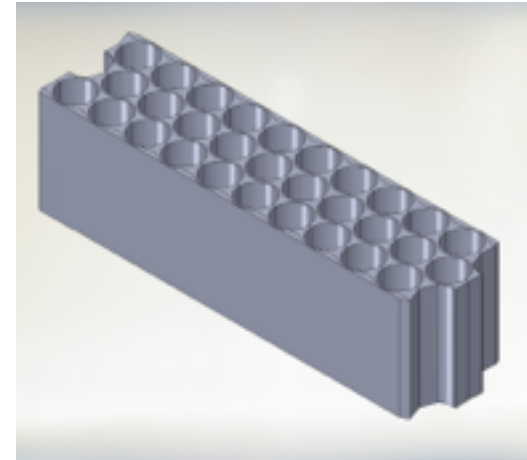
# Lithium-Ion Battery Thermal Runaway Shield (TRS)

- KULR presents a vaporizing heat sink for passive prevention of thermal runaway propagation (TRP) in Li-ion batteries
- Development with NASA JSC since 2015
- A polymer shell containing water and carbon fiber wicks between rows of cylindrical Li-ion cells
- When a cell is triggered into thermal runaway, the adjacent shell surface melts and water begins to vaporize and dissipate heat in the process
- Carbon fiber wicks remain wet to protect neighboring cells from overheating
- Less than 20g of water suffices to block an 18650 cell TRP



# Space Application Considerations: Weight, Vacuum, Gravity

- Hexagonal arrays with pitch 19-22mm are preferred for compactness and fluid flow
- Longer TRS favors lower pitch
- TRS is vacuum compatible
- Completely passive solution
- Operating temperature is between 0C° to 60C°
- Achieves 220 Wh/kg with LG M36 Cells



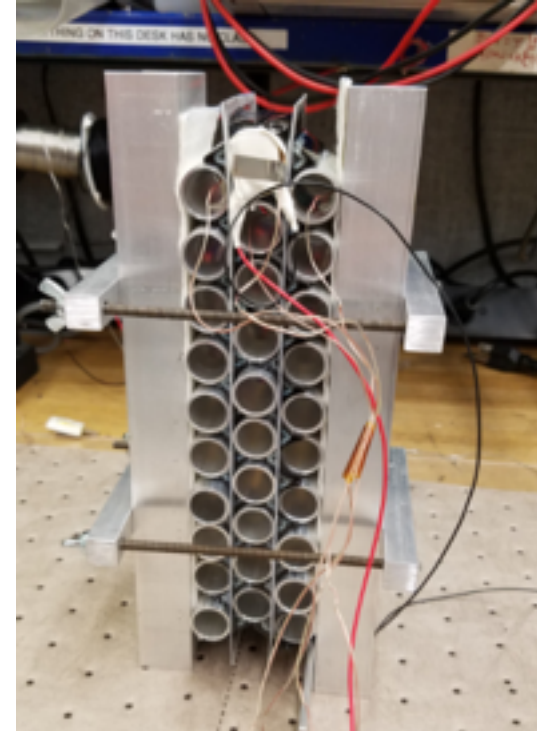
# TRS Weight Overhead and Sensible Heat Capacity

Pitch (mm)	Unit Cell Water (g)	Water mass (g) for given number of cells										
		3	4	5	6	7	8	9	10	11	12	13
19	2.00	5.99	7.99	9.98	11.98	13.98	15.98	17.97	19.97	21.97	23.96	25.96
20	3.86	11.58	15.44	19.30	23.16	27.02	30.88	34.74	38.60	42.46	46.32	50.18
21	5.79	17.38	23.17	28.97	34.76	40.55	46.35	52.14	57.93	63.73	69.52	75.31

Pitch (mm)	TRS Increases Sensible Heat Capacity		
	18650 Cell Capacity J/K	TRS J/K	Increase
19	37.8	8.27	22%
20	37.8	15.98	42%
21	37.8	23.98	63%

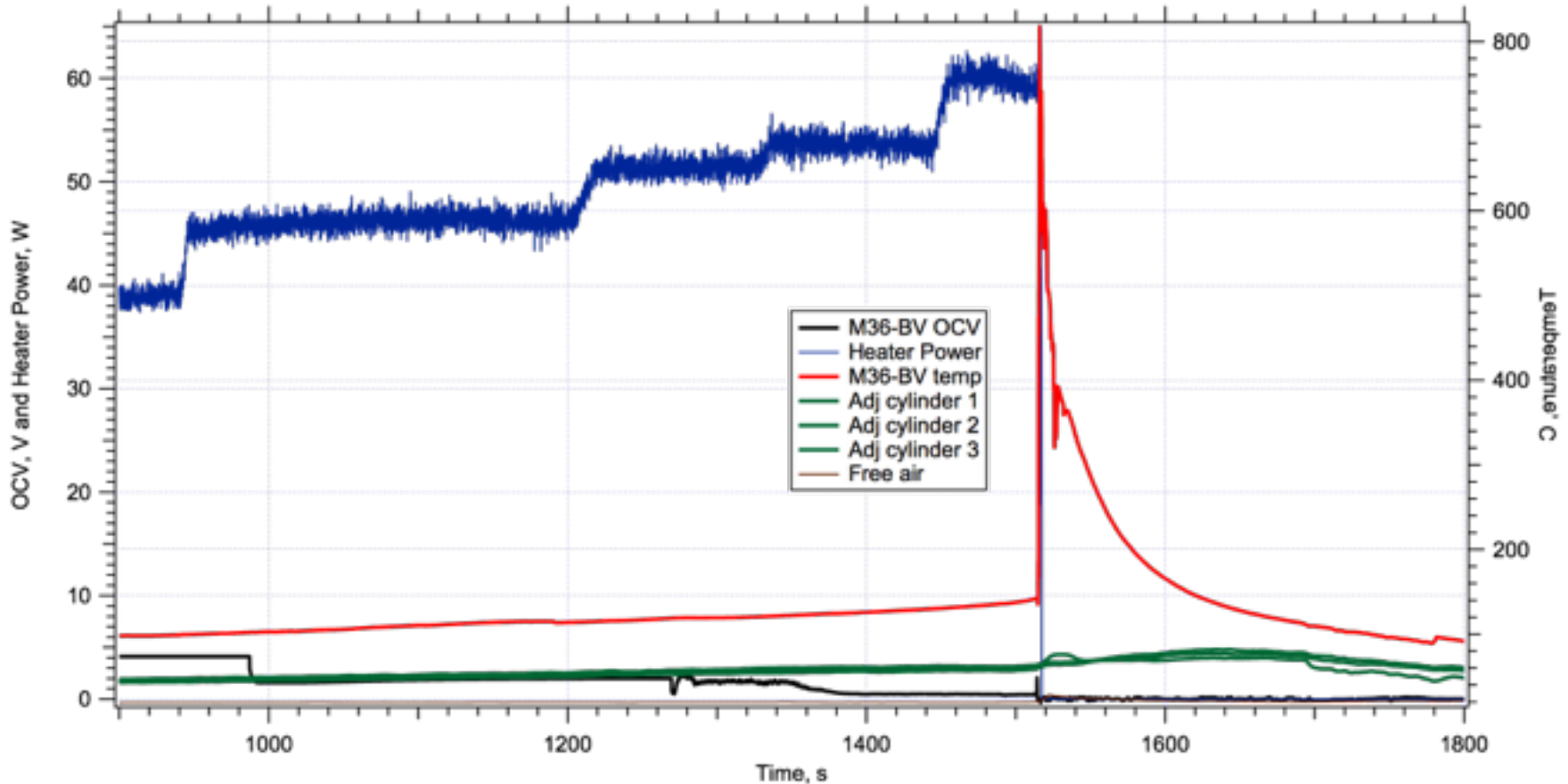
# NASA TRS Single Cell Test

- LG M36 BV Cell
- One TC on trigger cell in 12'oclock position
- One TC on each of the 3 adjacent tubes
- Bottom heater
- Trigger cell at top position



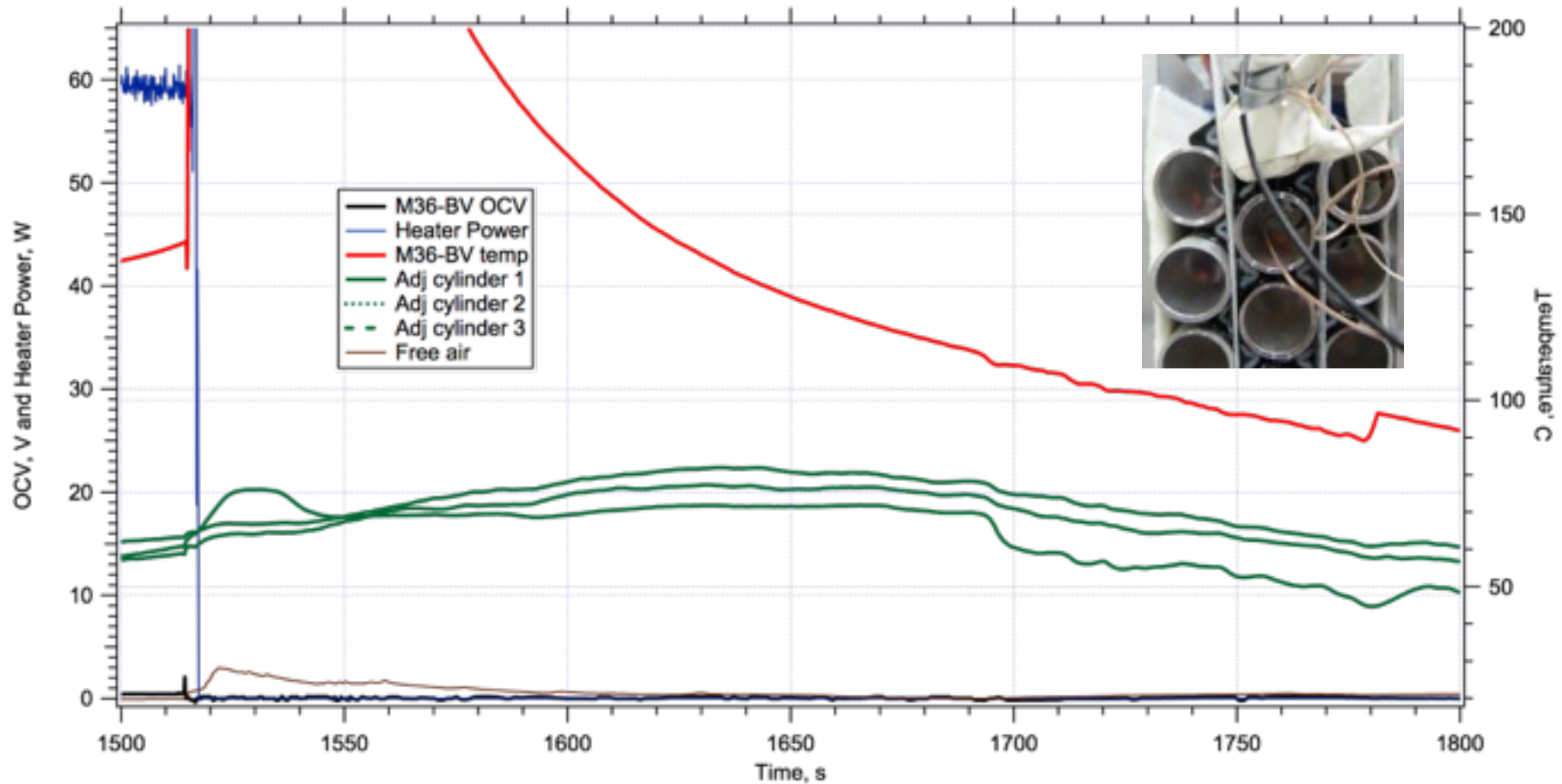
# NASA TRS Single Cell Test

Trigger cell was at 102C when OCV dipped to 2.9V, then 124 when dipped to 0.5V. It was 143C at OTR and reached a max of 818C



# Test Result Close Up View

Max temperature rise on the adjacent cylinders was 18.5C, 10.9C, and 18.7C



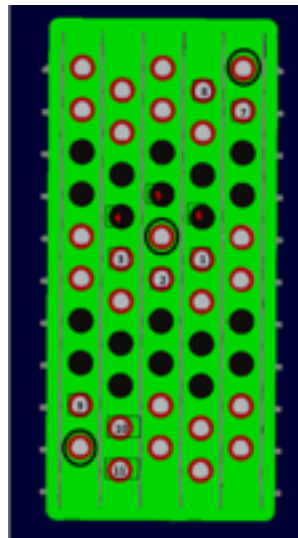
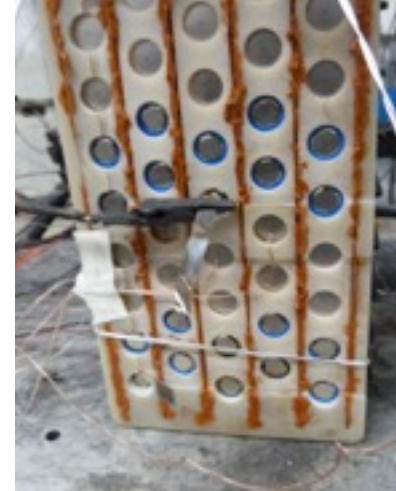


# Post Test Photo

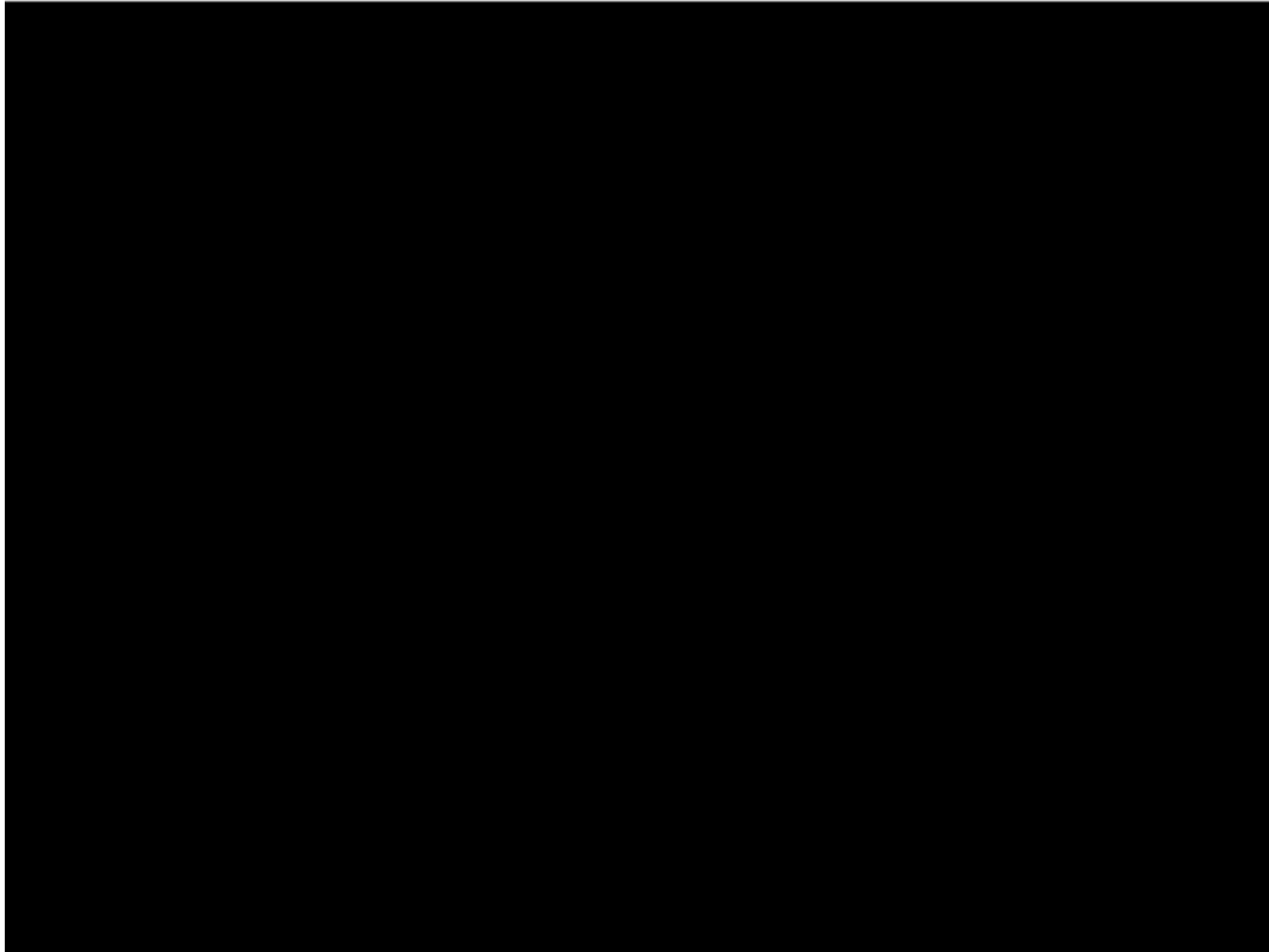


# NASA TRS 50-Cell Block Test Set-Up

- Three trigger cell locations
- 10-Cell 21mm Pitch Configuration
- LG M36 3.3Ah 18650 cells
- Thicker can wall (250  $\mu\text{m}$ )
- ISC device in bottom of JR
- TC welded to bottom of adjacent cells.

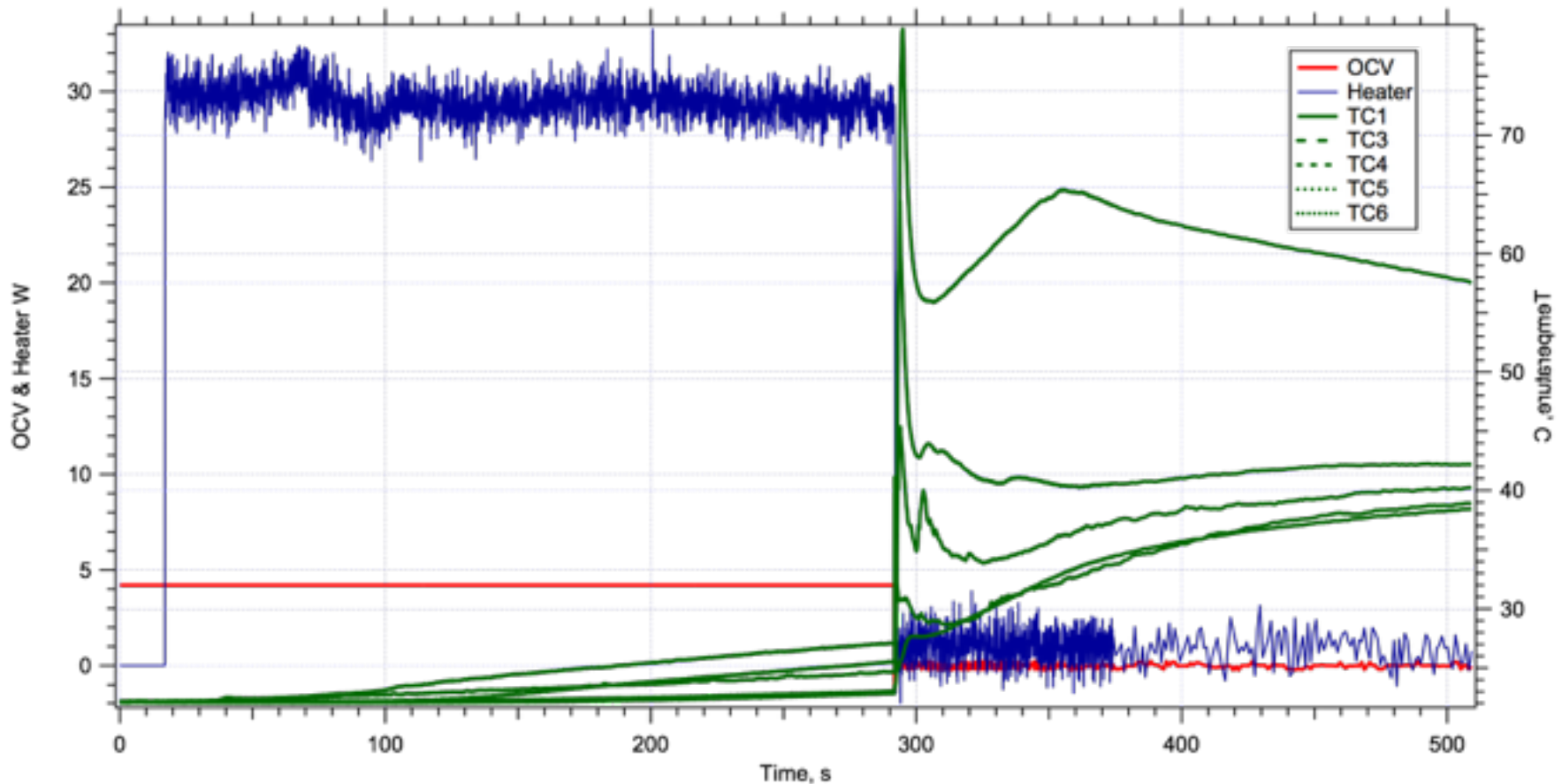


# TRS Interior Trigger Cell Test Video

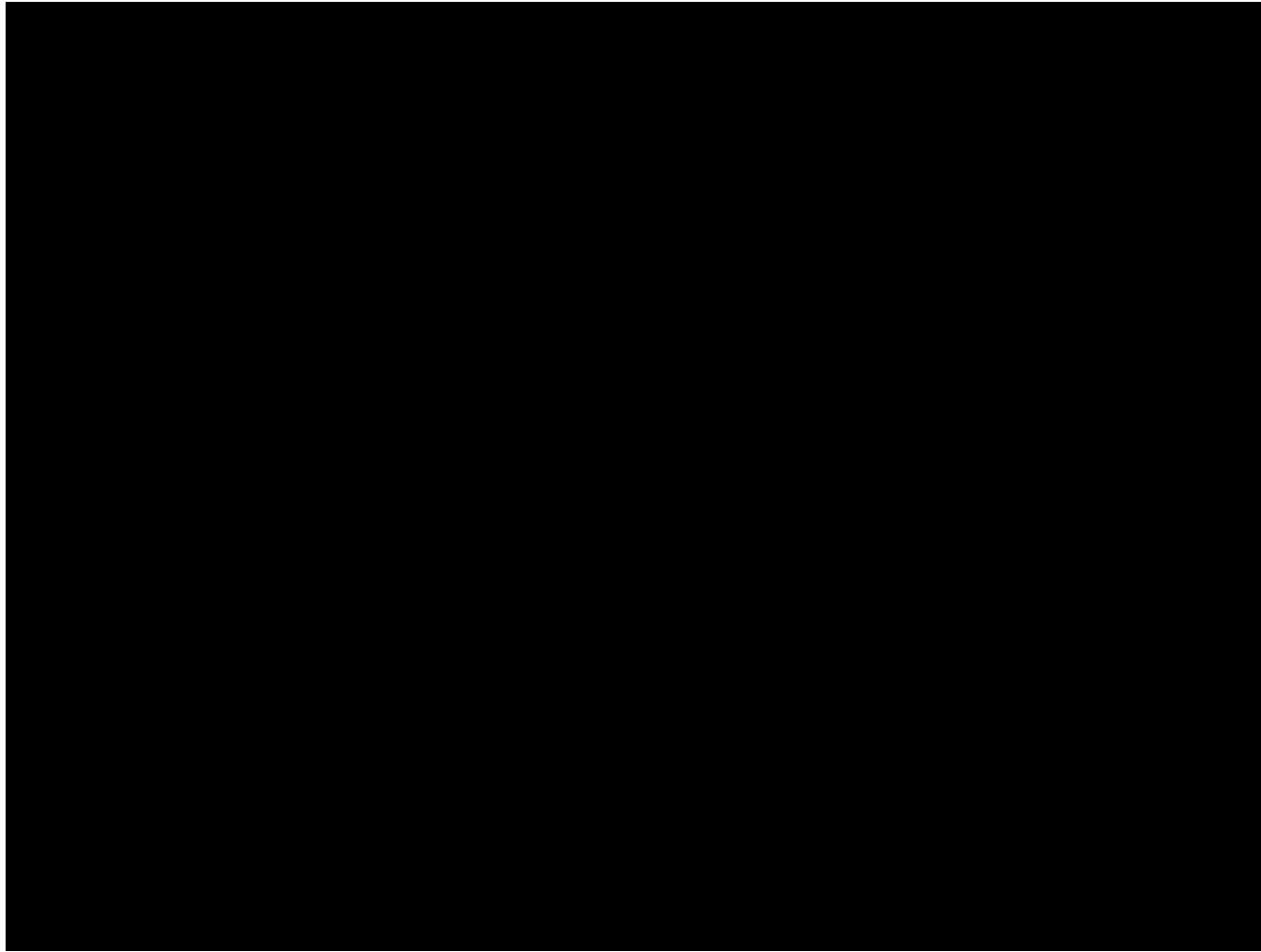


# TRS Interior Trigger Cell Test Result

Heater power at 30W for 275s. Onset of TR in 275s. Maximum sustained adjacent cell  $\Delta T = 40^{\circ}\text{C}$   
All six adjacent cells showed no electrical performance degradation in post test discharge

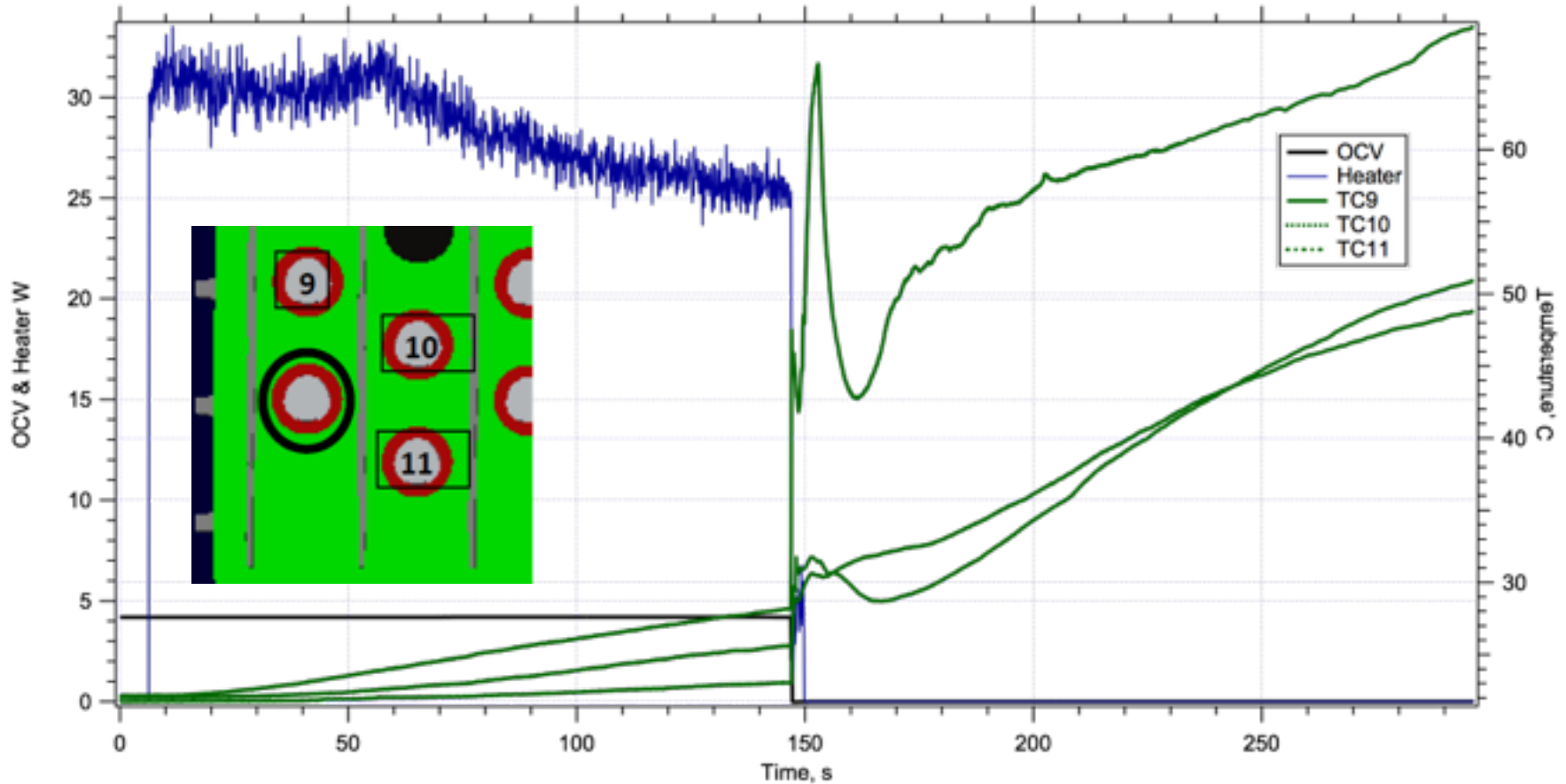


# TRS Upper Corner Cell Test Video

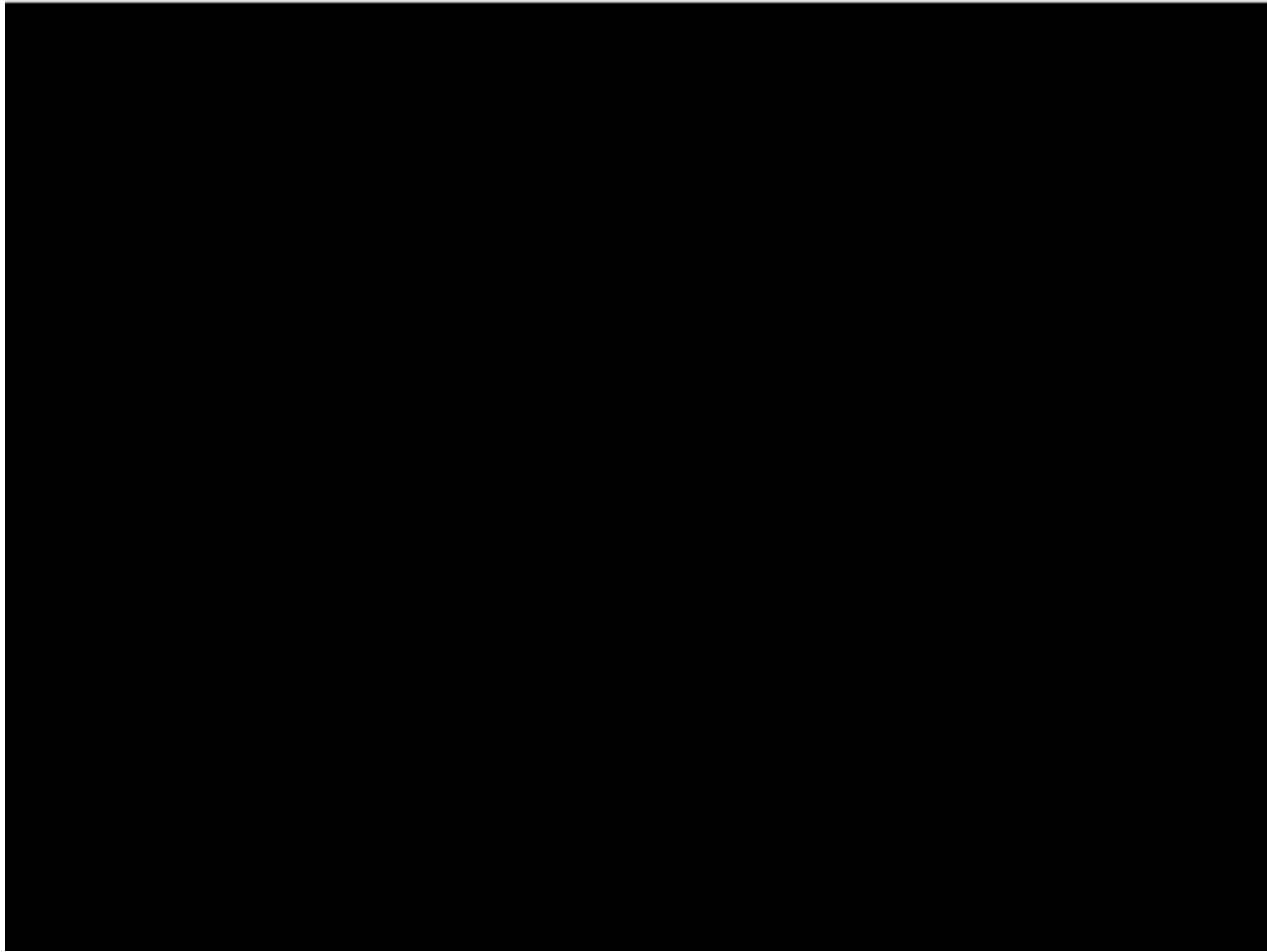


# TRS Upper Corner Trigger Cell Test Results

Heater power at 27W for 141s. Onset of TR in 140s. Maximum sustained adjacent cell  $\Delta T > 40^{\circ}\text{C}$   
All 3 adjacent cells showed no electrical performance degradation in post test discharge

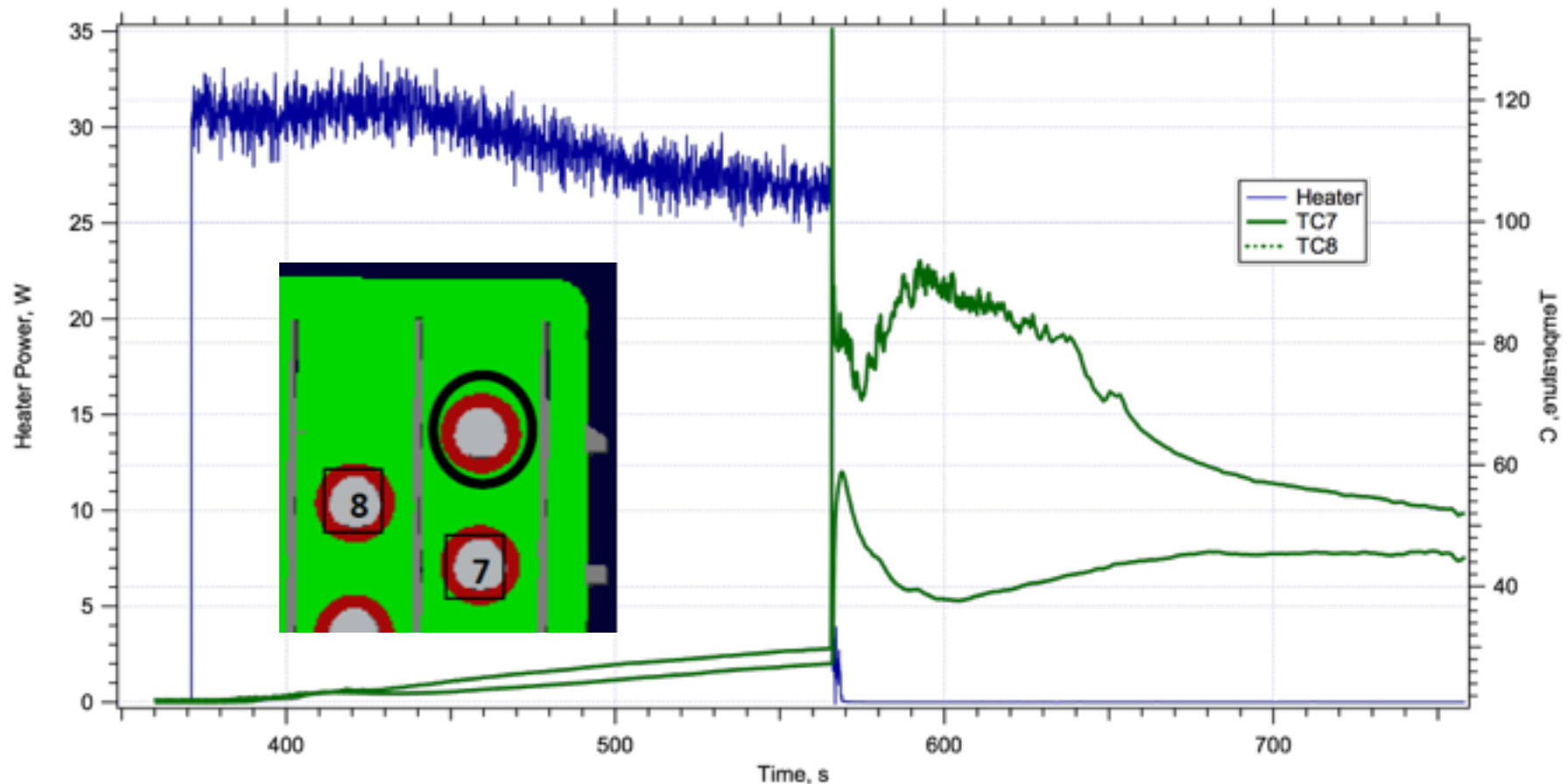


# TRS Bottom Trigger Cell Test Video



# NASA TRS Bottom Corner Trigger Cell Test Results

Heater power at 29W for 195s. Onset of TR in 194s. Maximum sustained adjacent cell  $\Delta T = 63.2^\circ\text{C}$   
All 2 adjacent cells showed no electrical performance degradation in post test discharge





# Post Test Examination

All three trigger cells had embedded internal short circuit (ISC) device in bottom of JR and experienced bottom rupture.



# Interior Trigger Cell Examination



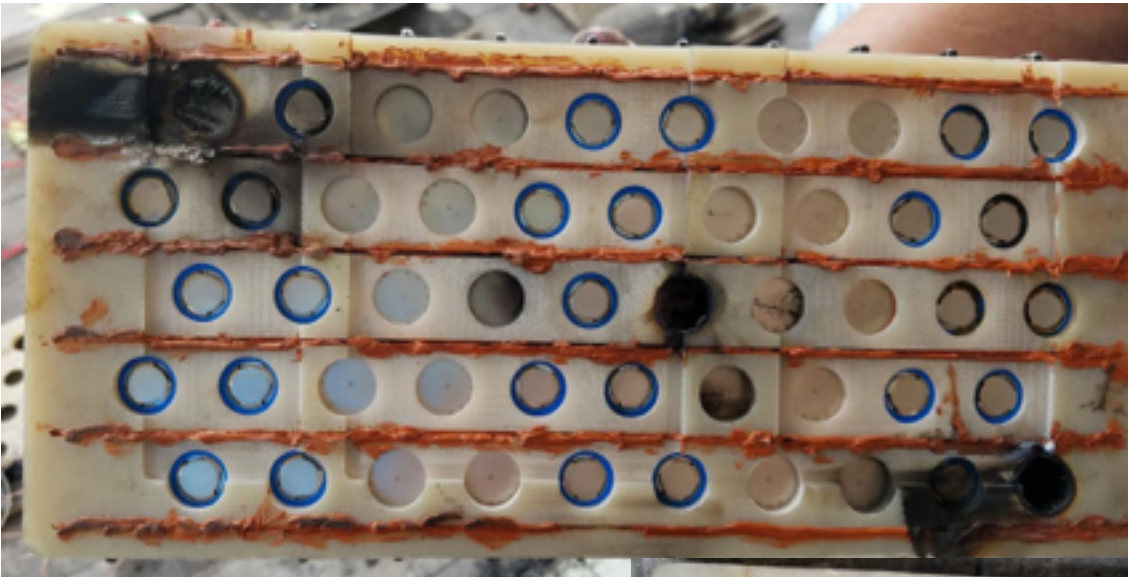
# Upper Corner Trigger Cell Examination



# Bottom Corner Trigger Cell Examination



# Post Test – 50 Cell Brick Enclosure Sides



# Post Test Adjacent Cell Good OCV Retention

- TC1 =4.14 V
- TC2 =4.14 V
- TC3 =4.15 V
- TC4 =4.15 V
- TC5 =4.14 V
- TC6 =4.15 V
- TC7 =4.15 V
- TC8 =4.10 V
- TC9 =4.15 V
- TC10 =4.15 V
- TC11 =4.15 V

# Preliminary Conclusions

- All 3 trigger cells activated into TR with minimal biasing of adjacent cells
- Adjacent cell max  $\Delta T$  was 63.2°C, which is comparable to Al interstitial heat sink performance, but for much less mass
- All adjacent cells were not damaged with good OCV retention
- Next suite of tests will be with 0.040" Ni bus plates to verify cell temperature gradients during 3C discharge
- Next suite of tests on 20mm pitch TRS

# NASA TRS Applications

## NASA's Future Applications

- **Robonaut 2**
  - To enhance and reduce frequency of manned spacewalks
  - High energy density and high specific energy battery needed
  - 90V, 4 kWh, 7 hour mission
- **Mars Rover Vehicle**
  - Terrestrial demonstration vehicle needing high voltage, power battery
  - 400V, 4 kWh, 1 hour mission
- **Valkyrie, RoboSimian**
  - Terrestrial dangerous operations robot
  - 90V, 2kWh, 1 hour mission
- **X-57 Electric Plane**
  - All electric aircraft for flight training
  - 400V, 50 kWh, 1 hour mission







**THANK YOU**

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