ThermoArc – A Novel Thermal Runaway Trigger Method

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Thuong Dang Nguyen, Frank Davies, David Delafuente PhD.
Propulsion and Power Division (EP) / NASA Johnson Space Center

Intro / Overview

Battery safety is a critical to NASA’s mission particularly for human spaceflight

- A key safety requirement is preventing catastrophic propagating battery failures from a single cell thermal runaway (TR)
- Propagation testing is required to demonstrate the battery design is safe
- Propagation testing involves initiating thermal runaway in a single cell to assess the response of adjacent cells minimal external bias (thermally, electrically, or mechanically)

Methods of Triggering TR in Li-ion Cell

- Various approaches exist, each with unique strengths and weaknesses.
- Ideal methods replicate a single manufacturing defect leading to internal short

This presentation compares and introduces a novel method of triggering TR which

- Induces a localize internal short without can wall perforation
- Has the potential to be reliable, safe, and cost-effective

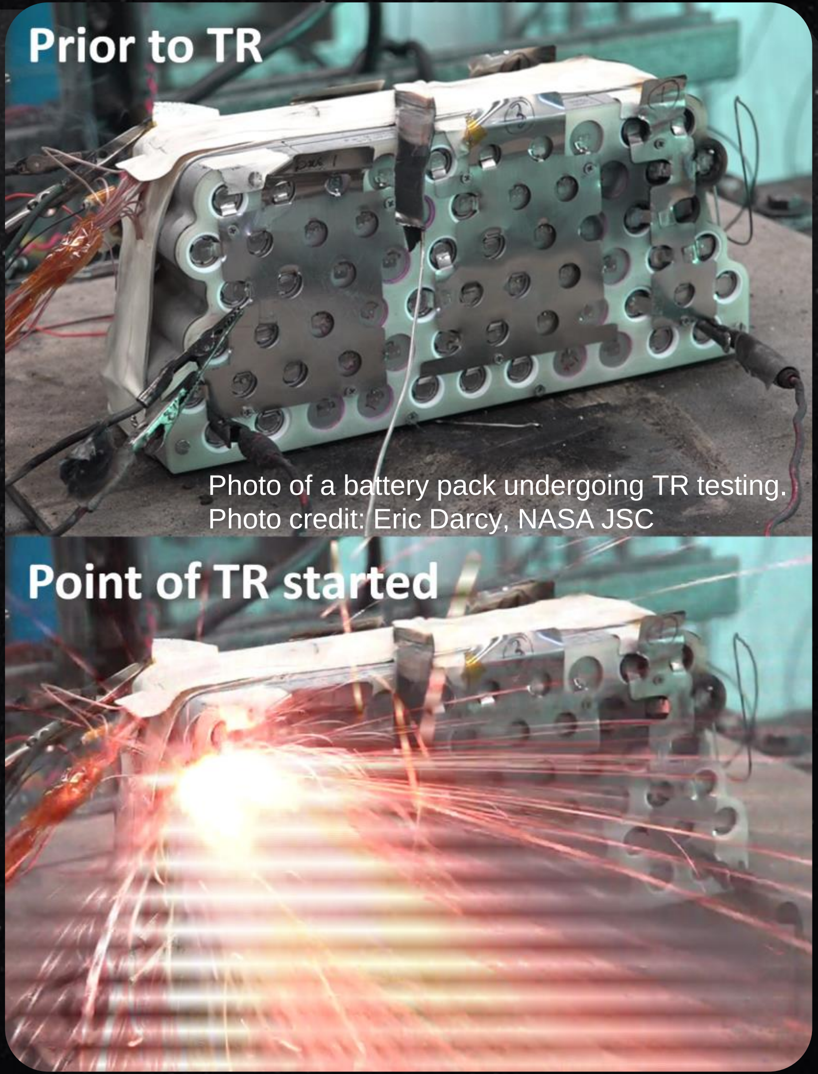
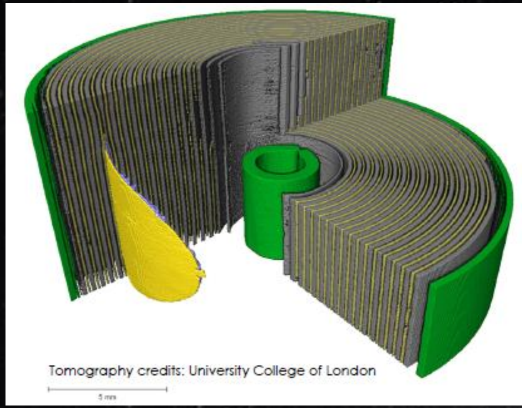
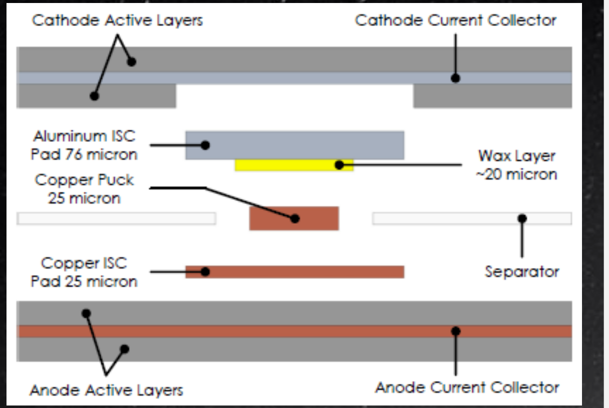


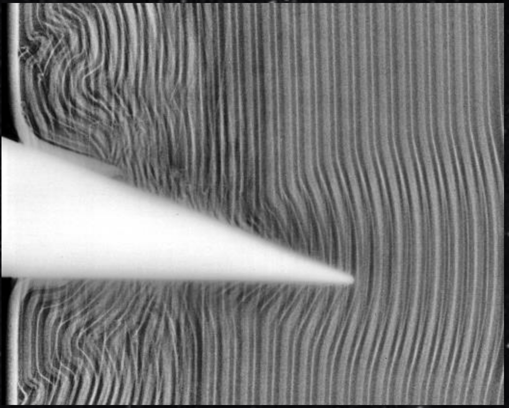
Photo of a battery pack undergoing TR testing.
Photo credit: Eric Darcy, NASA JSC

Existing and Mature TR Triggering Methods

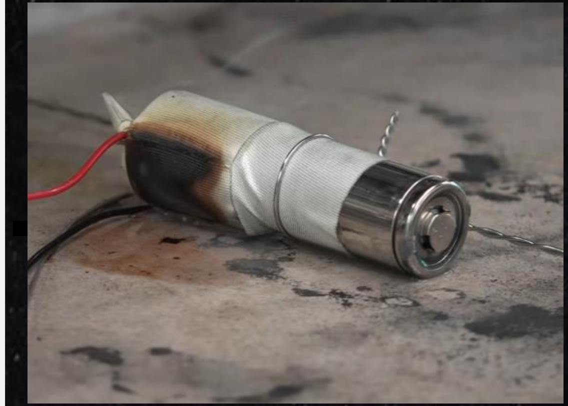




Internal Short Circuit Device
US Patent # 9,142,829 issued in 2015

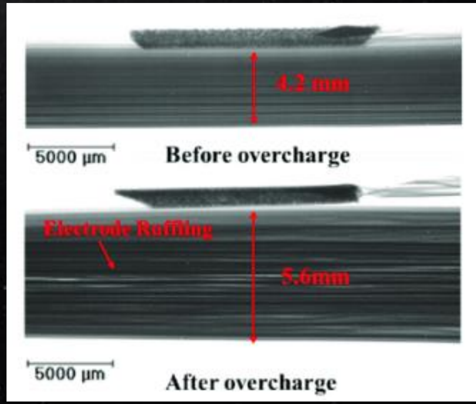


Nail Trigger Method



Heater Trigger Method

- Electrically isolate the trigger cell from the rest of the pack
- Overcharge the cell until it undergoes thermal runaway (TR)



Overcharge Method

Wu et al, **Electronics** 2019, 8, 751

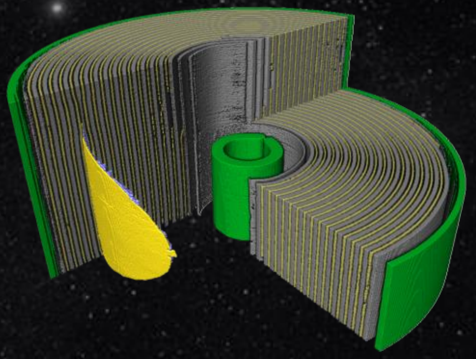
Existing and Mature TR Triggering Methods

TR Trigger Method	Heater	Nail	Overcharge	ISCD
No mechanical abuse	✓		✓	✓
No thermal abuse		✓		✓
Minimal energy input		✓		✓
Good signal-noise Ratio (FTRC)		✓		✓
Pack testing integration ease				✓
NASA's mission relevant (SoC)	✓	✓		✓
No cell modification from manufacturers	✓	✓	✓	
Cost effective	✓	✓	✓	

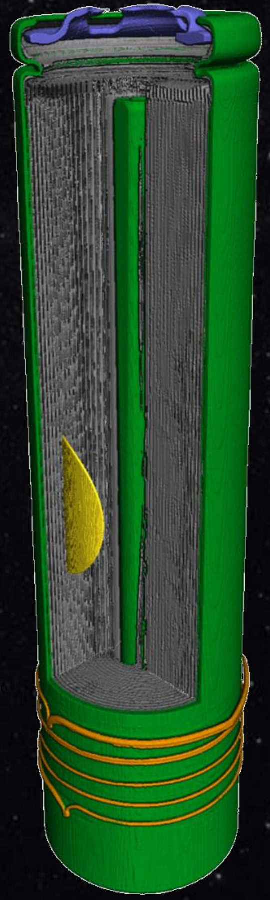
Rationale for ThermoArc Development

In an ideal world, all thermal runaway testing would use Internal Short Circuit Devices (ISCD), as they are considered the gold standard due to their ability to simulate internal shorts, mimicking real-world failures. However, ISCD has notable drawbacks, including high costs and the need for manufacturers to modify the cells.

To address these challenges, the ThermoArc method was developed to retain the advantages of ISCD while eliminating the need for manufacturer involvement and significantly reducing costs.



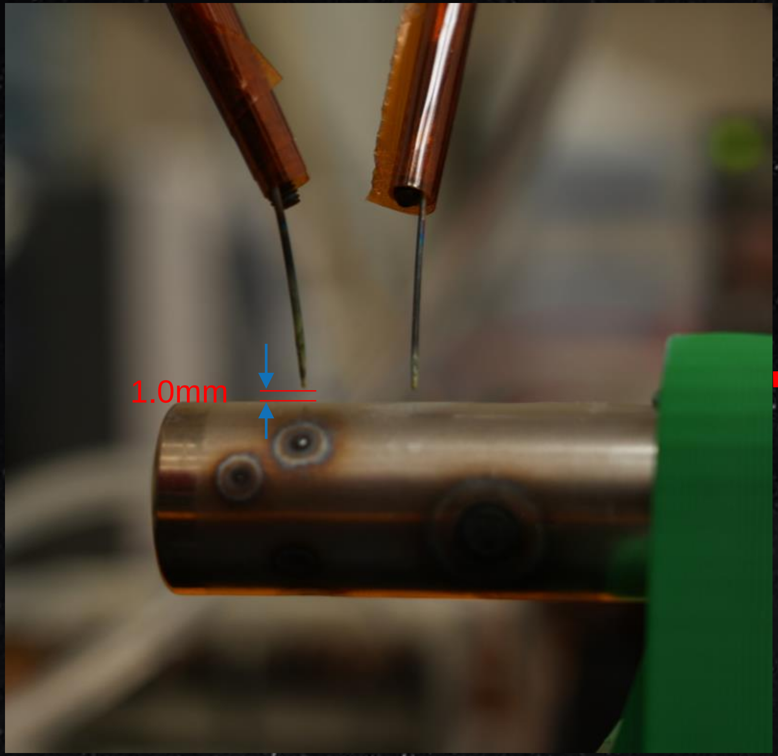
2016 Award Winner



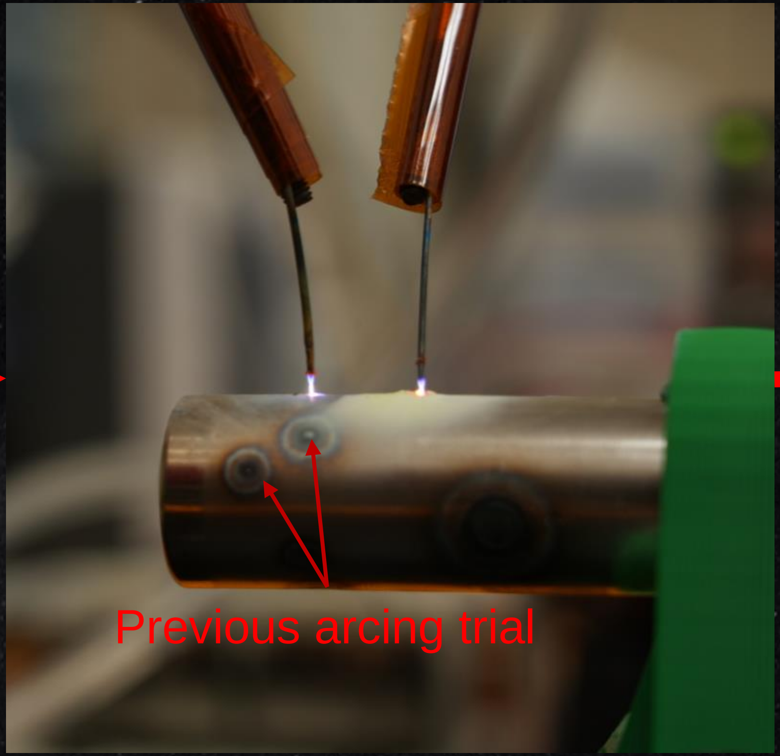
Finegan et al, ***Energy Environ. Sci.,*** 2017, 10, 1377

What is the ThermoArc Trigger Method?

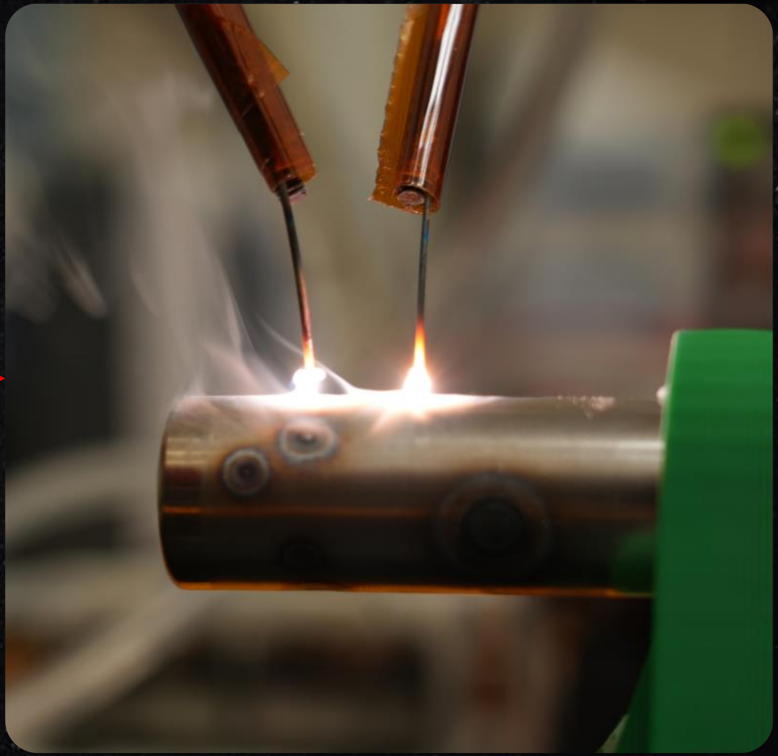
Patent Application Pending
NASA Case No. MSC-27597-1



An 18650 li-ion battery cell with two electrodes positioned against the battery cell's can wall, separated by an air gap of 1.0 mm

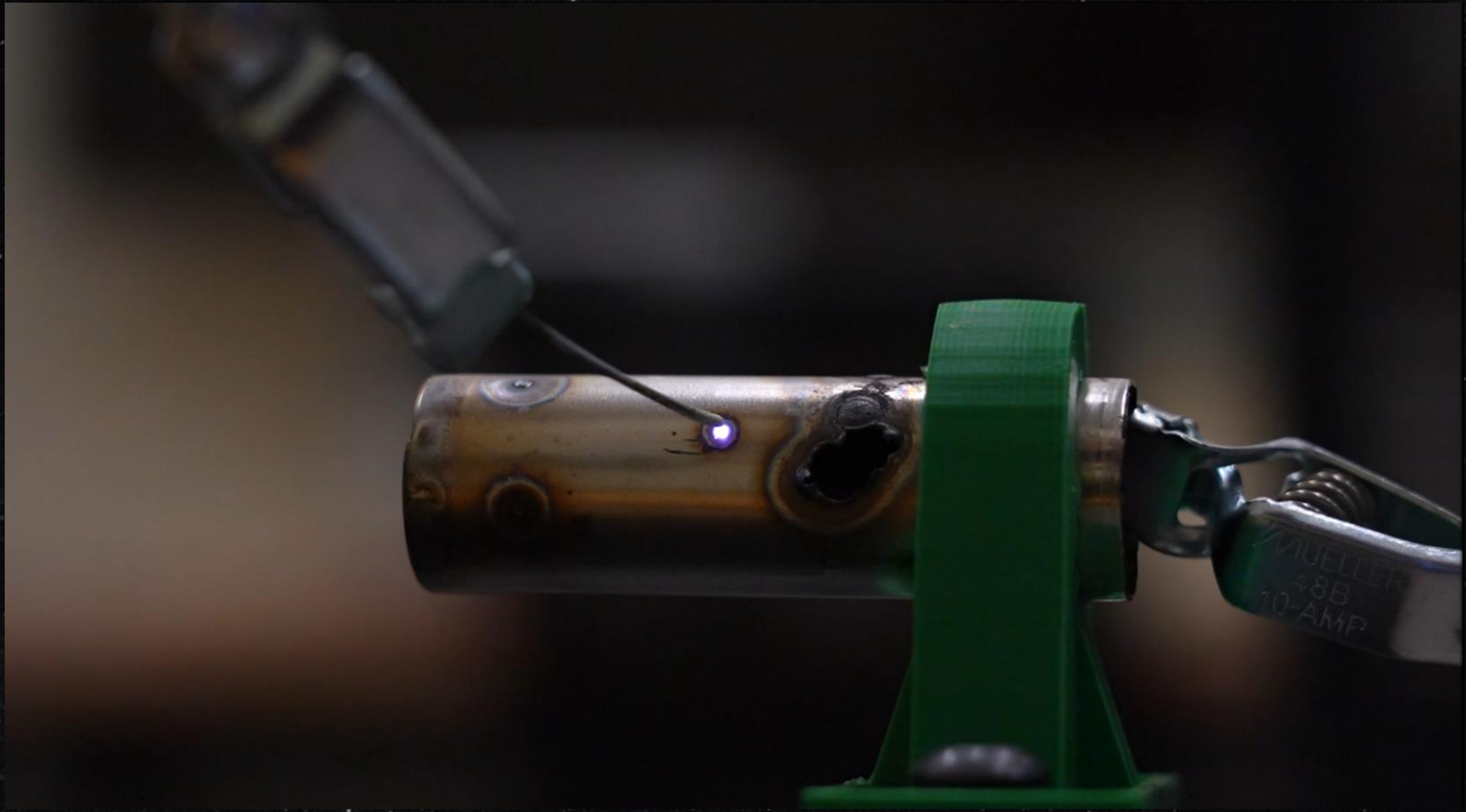


By applying a sufficiently high voltage to the electrodes, an electrical arc discharge will occur between the electrodes and the cell



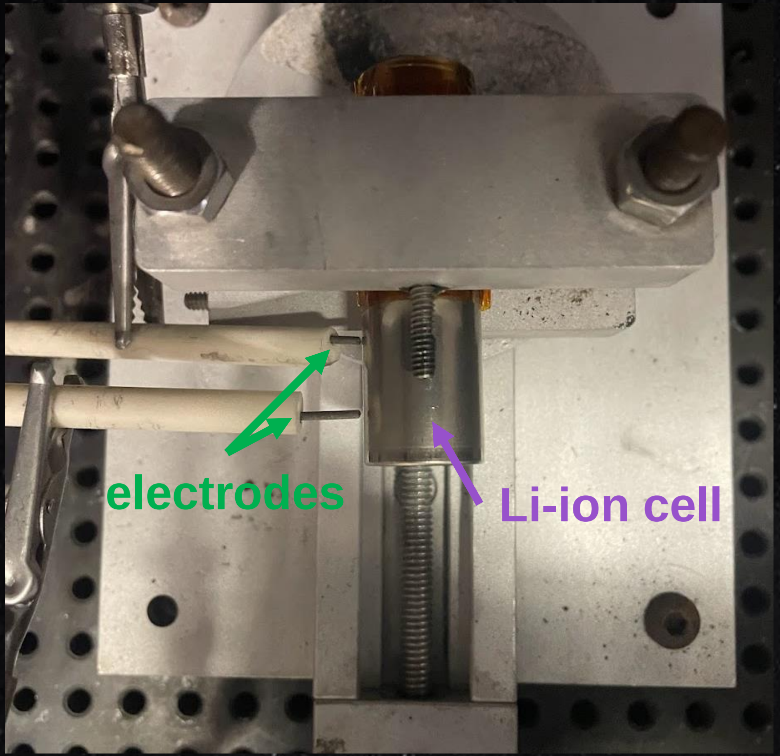
Once the electrical arc is established, the electrical power can be adjusted to control the amount of heat produced by the arc, adjusting the heat generated on the can wall

Video of ThermoArc Generates Heat on the Cell Can

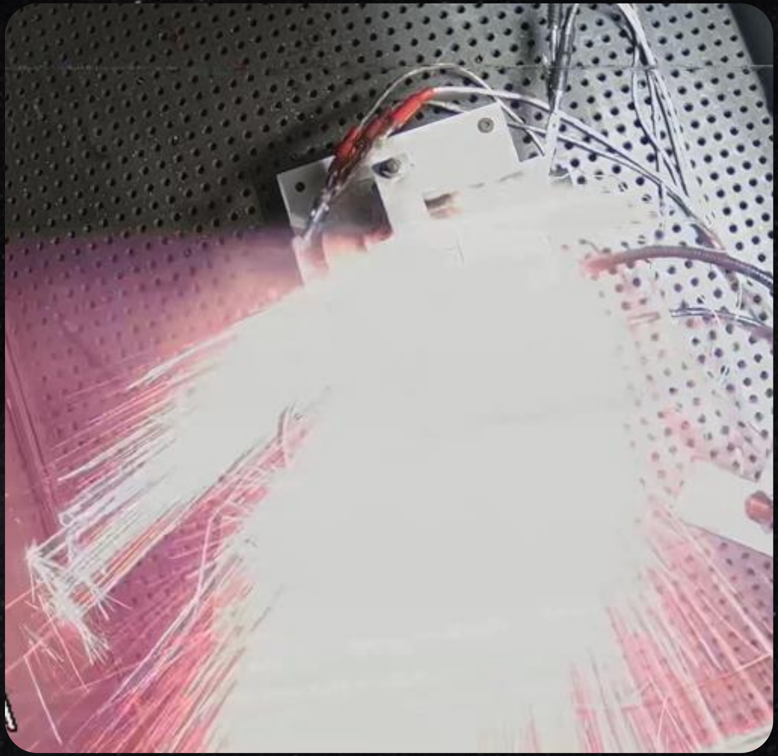


A single arc can be achieved by integrating the other electrode as part of the can wall, electrically.
The arc power in the video is set to low (20W), and the video is sped up by a factor of 32x

Single cell Li-ion TR Triggering Test (initial result)



A single-cell thermal runaway (TR) triggering testing setup. Two electrodes are positioned on the left side of the lithium-ion cell, which is securely strapped down by a fixture

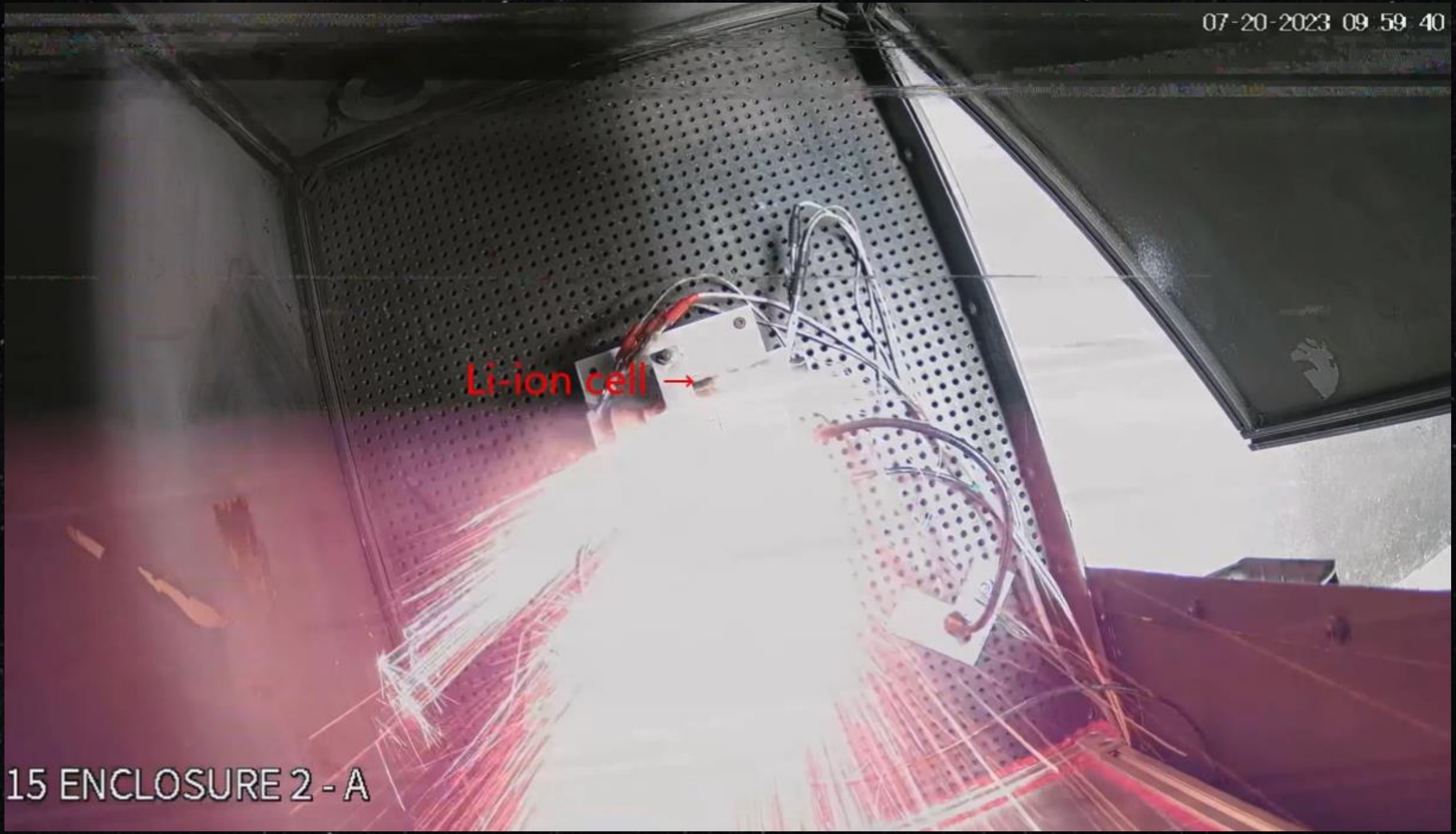


The Li-ion cell test subject is undergoing thermal runaway (TR) using the ThermoArc method

A Molicel M35A post thermal runaway using the ThermoArc method

Note: A tiny hole was formed in the can wall where the electrode was positioned, and this is due to excessive power of the arc

Video of the Li-ion Cell Undergo TR using ThermoArc



The first successful thermal runaway was achieved using the ThermoArc method. The operator did not turn off the arc as the thermal runaway occurred

Technical Specification of the ThermoArc

Input Electrical Power: 25W to 350W

Thermal energy conversion: 20%-25%

Heating zone: 0.5 mm diameter (estimate)

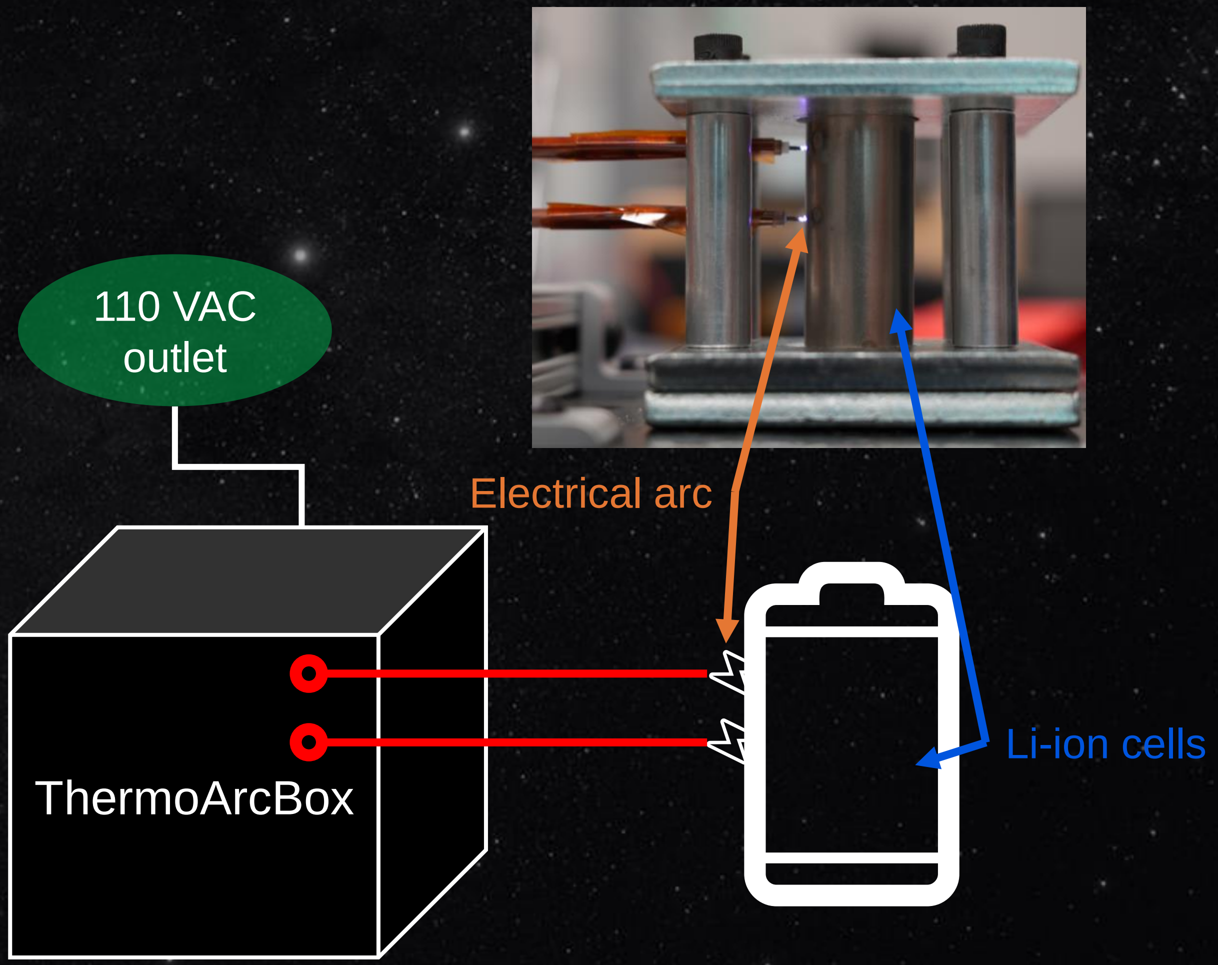
Timer to trigger: 15 seconds ↔ 3 minutes

Total heat input: 3kJ (estimate)

Voltage of striking the arc: ~3kV

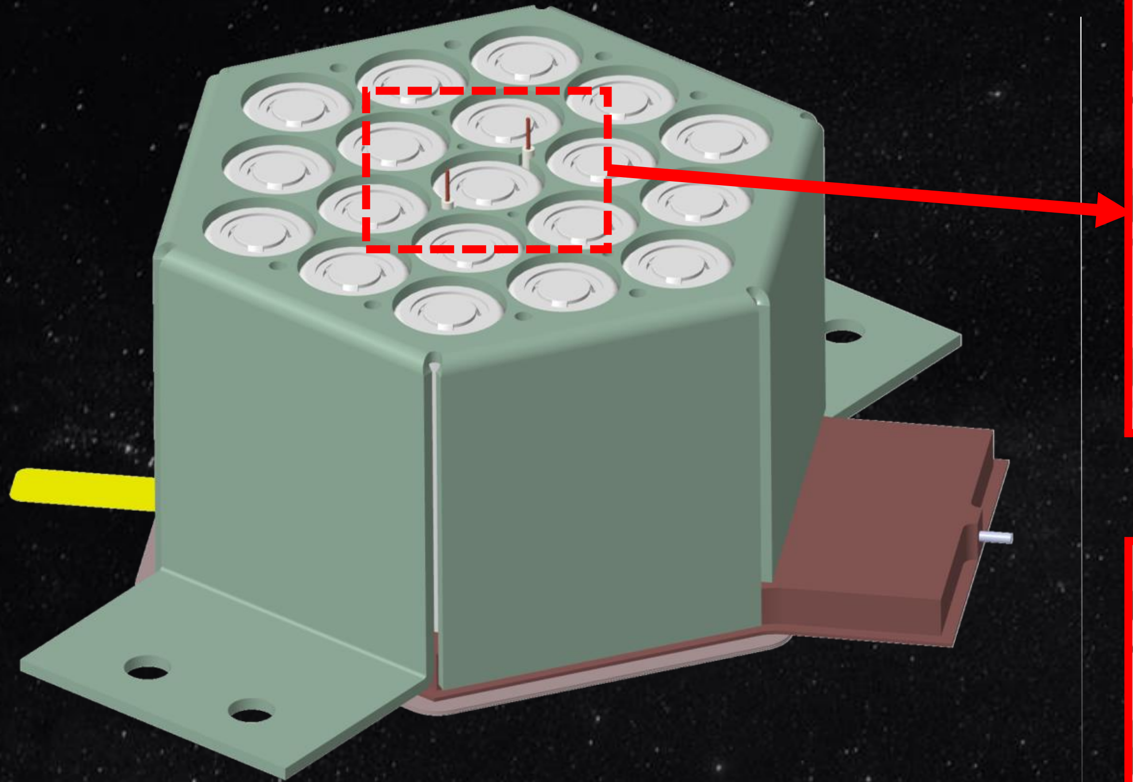
Voltage of sustaining the arc: ~100V

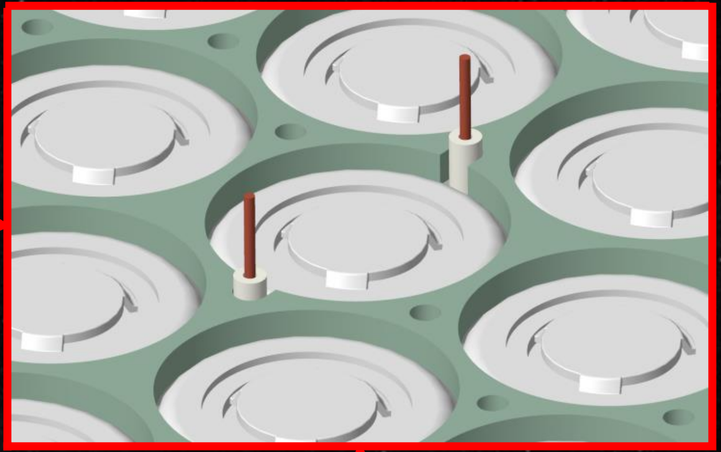
Distance of electrode tip to can wall: 0.69 mm



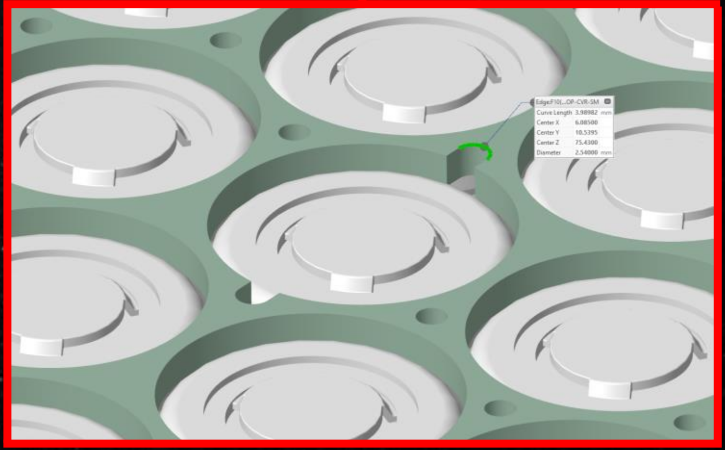
ThermoArc Setup

Proposed Pack Integration Testing





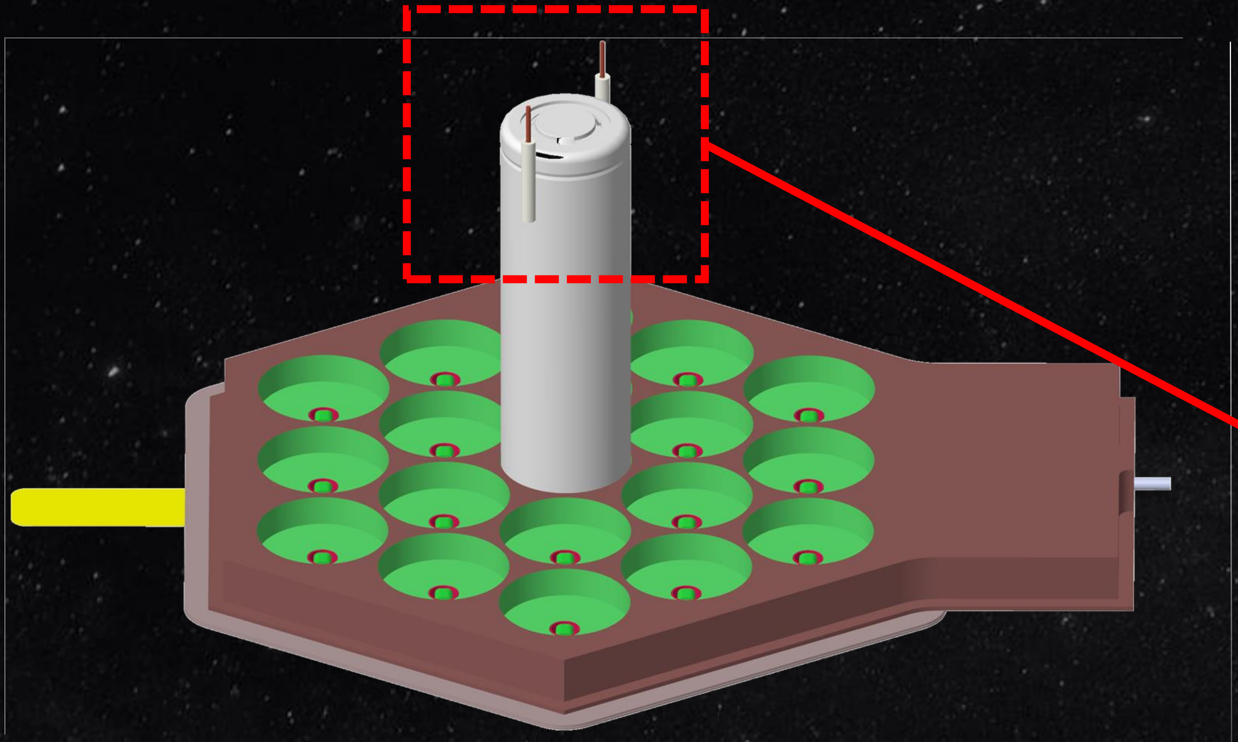
Two ThermoArc electrodes integrated into the center cell, preparing the pack for thermal runaway (TR) testing.



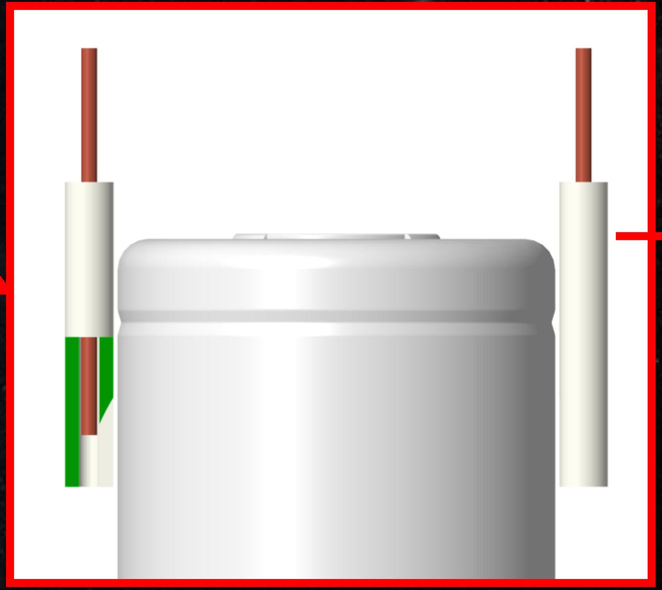
ThermoArc electrodes removed, revealing the empty cavities designed to accommodate the electrodes.

This is an example of integrating the ThermoArc into a battery pack. Two holes, each with a diameter of 2.5 mm, were carved between the cells to accommodate the ThermoArc electrodes, enabling the induction of thermal runaway (TR) in the center cell

Proposed Pack Integration Testing (cont.)



The ThermoArc electrodes are installed against the center cell, with the neighboring cells removed for clarity of illustration.



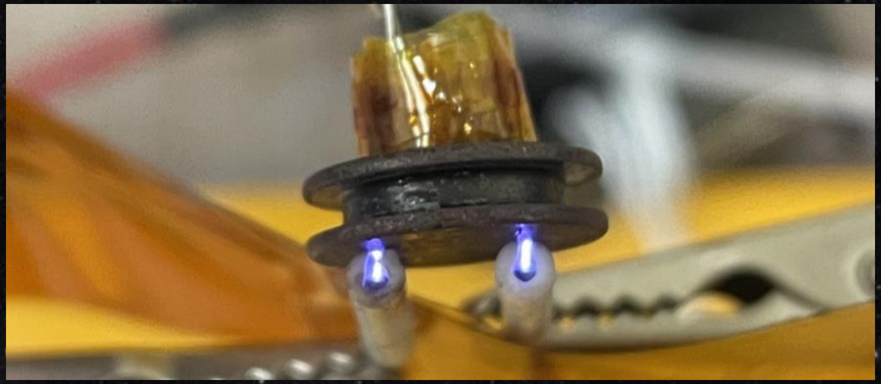
A zoomed-in view of the center cell, showing a cross-section of the ThermoArc electrodes and the ceramic insulator, highlighting the arc path.

ThermoArc vs Other TR Triggering Methods

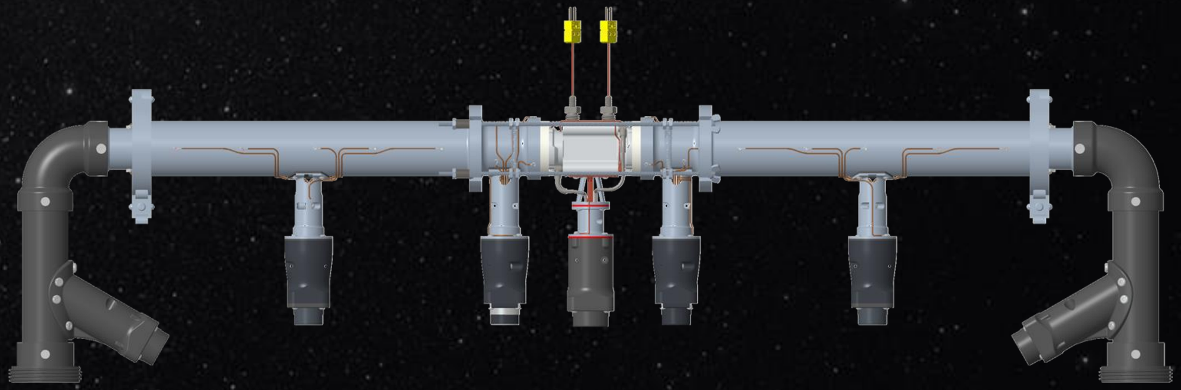
TR Trigger Method	Heater	Nail	OVC	ISCD	ThermoArc
No mechanical abuse	✓		✓	✓	✓
No thermal abuse		✓	✓	✓	✓
Minimal energy input		✓		✓	✓
Good signal-noise Ratio (FTRC)		✓	✓	✓	✓
Pack testing integration ease				✓	✓
NASA's mission relevant (SoC)	✓	✓		✓	✓
No cell modification from manufacturers	✓	✓	✓		✓
Cost effective	✓	✓	✓		✓

Future work

- Dial in the parameters that prevent perforation of cell can wall from the arc (with various cell designs at different can wall thickness)
- Quantify the thermal energy required by the ThermoArc method to induce thermal runaway (TR) in the Li-ion cell
- Integrate the ThermoArc method into the FTRC
- Evaluate the thermal energy released by the cell using FTRC
- Employing high-speed radiography to observe failure mechanism of Li-ion cells caused by localized heat generated from ThermoArc
- Perform integration testing on the battery pack to ensure proper integration with minimal bias to the battery pack



Test setup of the quantification of the ThermoArc heat generation



Fractional Thermal Runaway Calorimetry (FTRC) – Battery Failure Calorimetry
https://ntrs.nasa.gov/citations/20205010312

National Aeronautics and Space Administration

Thank you

Authors: Thuong Dang Nguyen, Frank Davies, David Delafuente PhD.
Propulsion and Power Division (EP) / NASA Johnson Space Center
Contact: thuong.d.nguyen@nasa.gov