


Johnson Space Center Engineering Directorate

L-8: Safe Li-Ion Batteries

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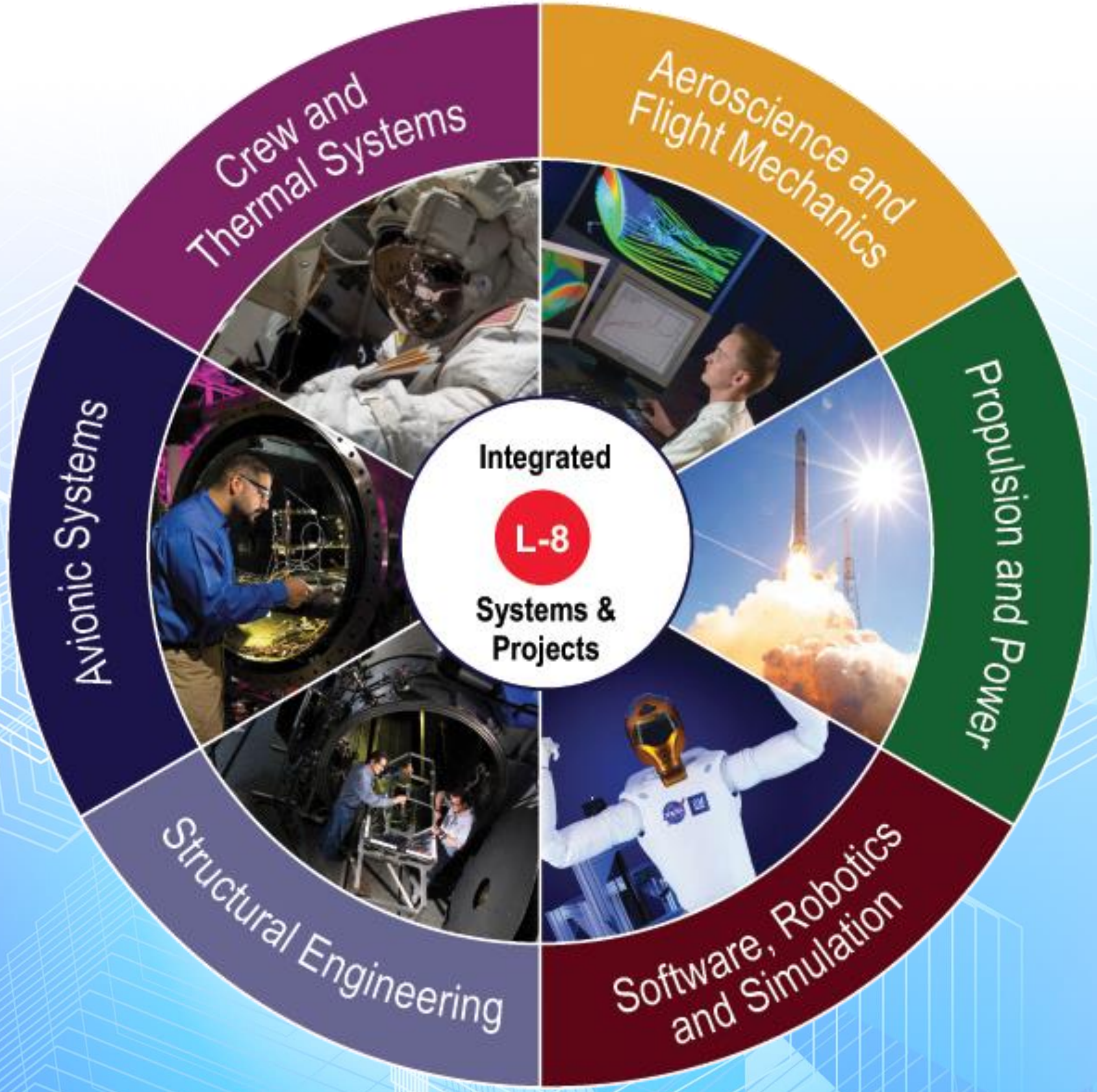
JSC Engineering: HSF Exploration Systems Development



- We are sharpening our focus on Human Space Flight (HSF) Exploration Beyond Low Earth Orbit
- We want to ensure that HSF technologies are ready to take Humans to Mars in the 2030s.
  - Various Roadmaps define the needed technologies
  - We are attempting to define <u>our</u> activities and dependencies
- Our Goal: Get within 8 years of launching humans to Mars (L-8) by 2025
  - Develop and Mature the technologies and systems needed
  - Develop and Mature the personnel needed
- We need collaborators to make it happen, and we think they can benefit by working with us.

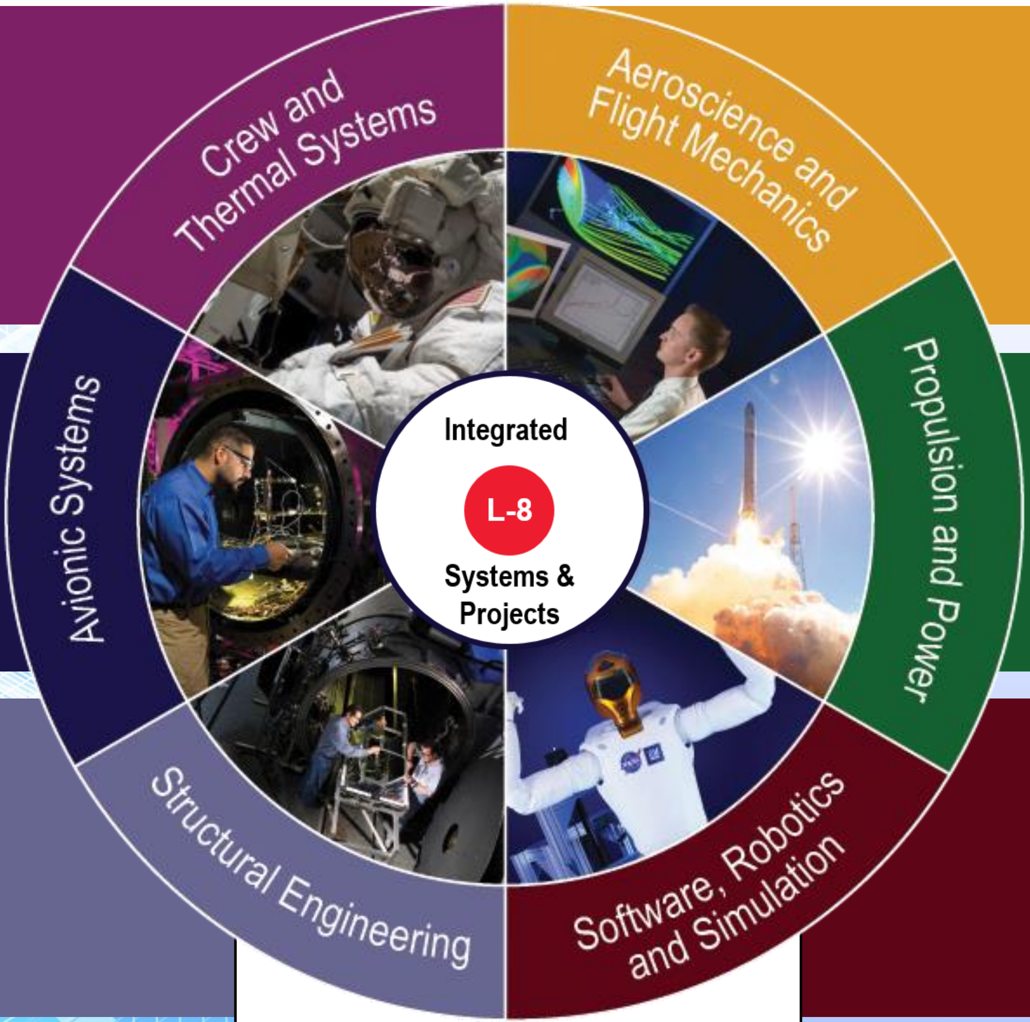
EA Domain Implementation Plan Overview

JSC Engineering: HSF Exploration Systems Development

- Life Support
- Active Thermal Control
- EVA
- Habitation Systems

- Human System Interfaces
- Wireless & Communication Systems
- Command & Data Handling
- Radiation & EEE Parts

- Lightweight Habitable Spacecraft
- Entry, Descent, & Landing
- Autonomous Rendezvous & Docking
- Vehicle Environments



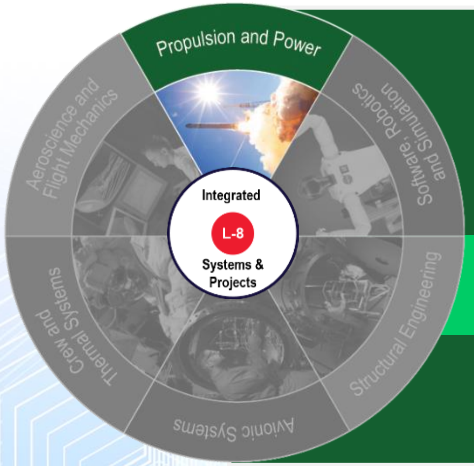
AA-2 | iPAS | HESTIA | Morpheus

Entry, Descent, & Landing -
Autonomous Rendezvous & Docking -
Deep Space GN&C -

Reliable Pyrotechnics -
Integrated Propulsion, Power, & ISRU -
Energy Storage & Distribution -
Breakthrough Power & Propulsion -

Crew Exercise -
Simulation -
Autonomy -
Software -
Robotics -

Propulsion and Power



- Integrated Propulsion, Power, & ISRU
- Reliable Pyrotechnics
- Energy Storage & Distribution
- Breakthrough Power & Propulsion

The Problem

- *Safe, high performing battery designs are need for human exploration to Mars*
- *Are 200 Wh/kg, 350 Wh/L battery designs possible that also are passively resistant to propagation of thermal runaway?*
- *Current SOTA safe battery is 120Wh/kg and 200 Wh/L*
- *We need increased production rate of reliable, consistent internal short circuit devices to enable battery safety verification testing with latest COTS cell designs achieving >275 Wh/kg, >730 Wh/L*

Safe Li-Ion Batteries

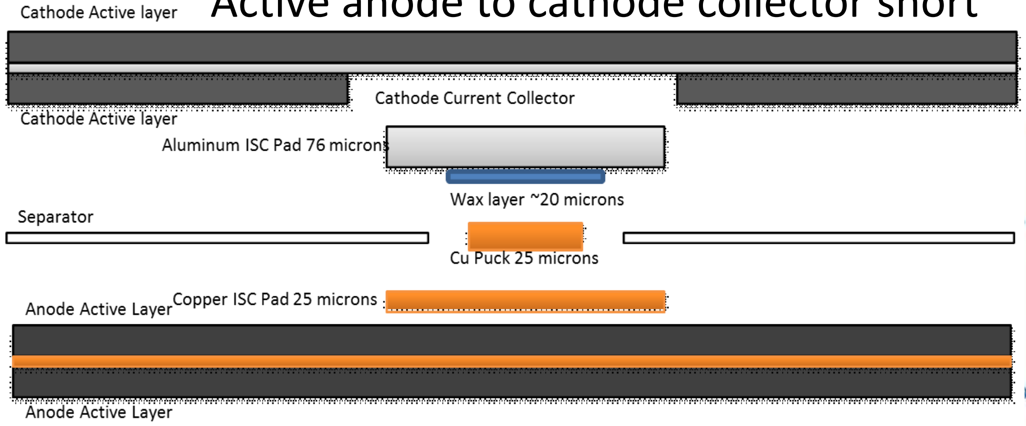
- *The NREL/NASA On-demand Internal Short Circuit (ISC) Device is a critical method for triggering thermal runaway (TR) for battery verification testing with minimal alterations to the battery design*
- *These devices are currently made by hand using a laborious wax spin coating and reflow process*
- *We are seeking partners that can automate the manufacturing of these devices to make them more consistent and available to cell manufacturers and battery designers*

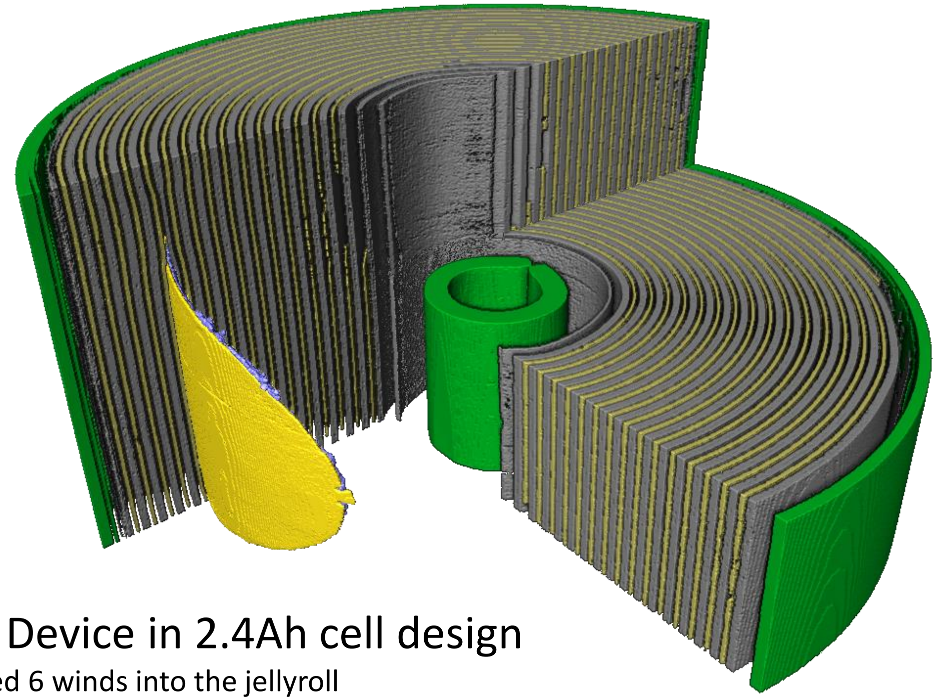
Background

- SOTA Li-ion cells provide very high specific energy > 275 Wh/kg and energy density > 730 Wh/L, but aren't safe enough to used in manned battery designs due to the risk of side wall rupture during TR.
- Side wall ruptures can lead to instant propagation of TR in tightly nested battery designs
- Despite extensive QC/QA, standardized industry safety testing, and > 25 years of manufacturing experience, incidents and recalls still occur (e.g. Galaxy Note 7)
- Many safety incidents that take place in the field originate due to an internal short defect that was not detectable and latent at the point of manufacture.

NREL/NASA ISC Device Design

Active anode to cathode collector short



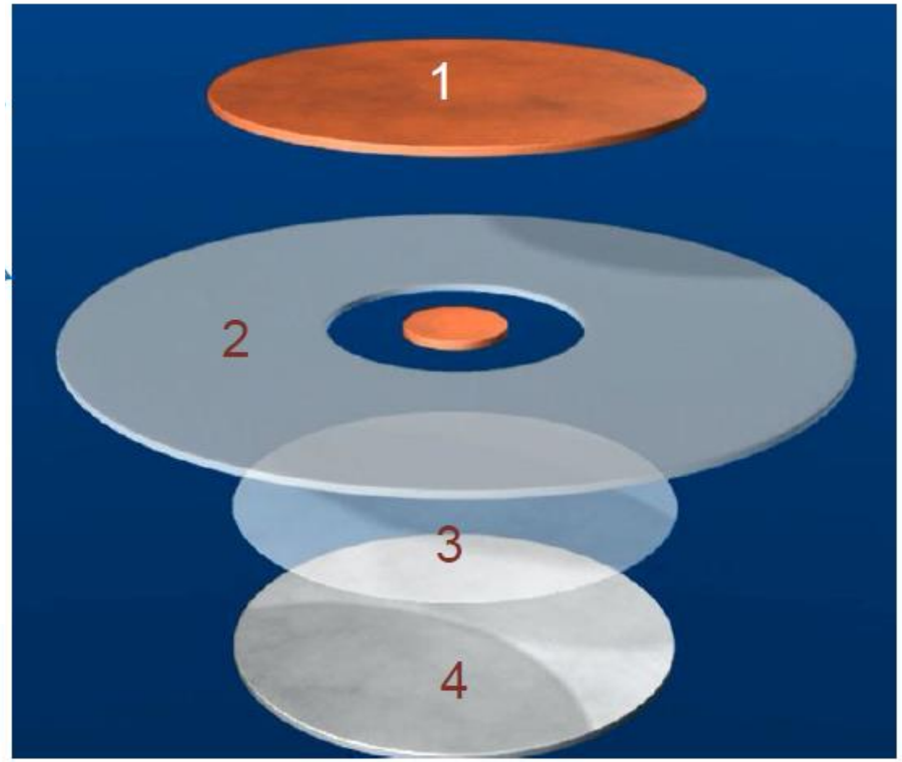


ISC Device in 2.4Ah cell design

Placed 6 winds into the jellyroll

5 mm

Tomography credits: University College of London



Graphic credits: NREL

Top to Bottom:
1. Copper Pad
2. Battery Separator with Copper Puck
3. Wax – Phase Change Material
4. Aluminum Pad

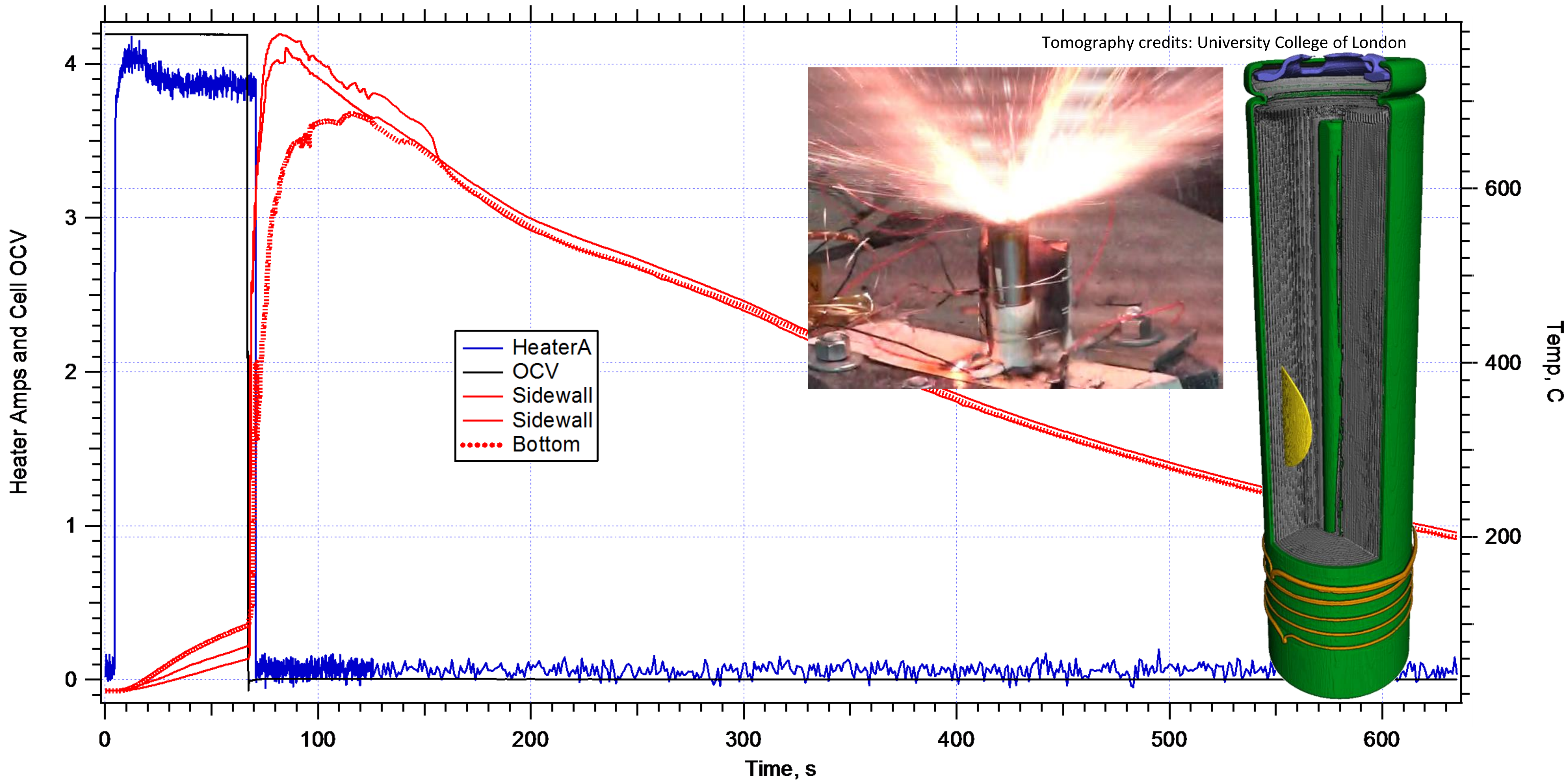
2010 Inventors:
- Matthew Keyser, Dirk Long, and Ahmad Pesaran at NREL
- Eric Darcy at NASA

US Patent # 9,142,829 awarded in 2015

Wax formulation used melts ~57°C

Thin (10-20 μm) wax layer is spin coated on Al foil pad

Single Cell TR – Moli 2.4Ah with ISC Device



Open air test with cell charged to 4.2V and with TCs welded to cell side wall (2) and bottom (1)

ISC Device Location Reveals Side Wall Rupture Risk

- 3.4Ah cell design
  - 165-175 microns can wall thickness
  - No bottom vent
- Unsupported oven heating test
  - No side wall ruptures (30 cells)
  - Slow external heating to TR
- Unsupported circumferential heater test
  - 1 side wall ruptures (8 cells tested)
- With ISC device (9 tested so far)
  - 6 sidewall ruptures
    - 5 unsupported
    - 1 supported by Al interstitial heat sink
  - 1 bottom rupture
    - Supported by Al interstitial heat sink
  - 2 vented through header (as designed)
    - Supported by Fe tubes

ISC device in 3rd wind

Circumferential heater near bottom of can wall

Photo credit: D. Finegan, University College of London

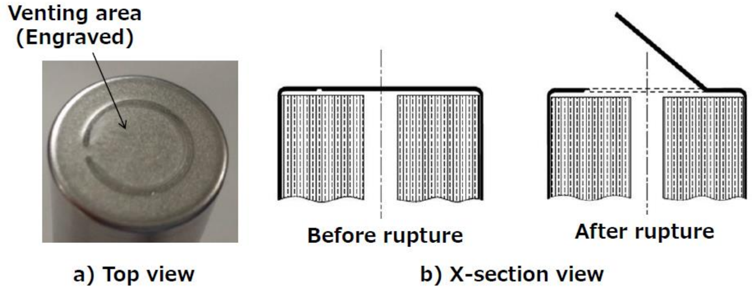
What has the device taught us so far? What do we hope it will teach us?

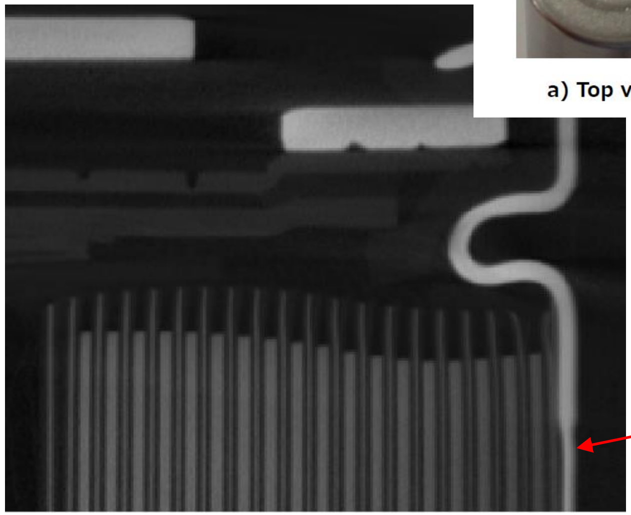
What has it taught us so far?

- With 2.4 Ah cell design
  - Trilayer shutdown separator works against collector-collector shorts
  - Doesn’t prevent TR with Al-anode shorts
  - With single layer polypropylene separator and Al-anode shorts, device was >80% successful in driving TR
- With 3.5Ah cell design
  - Sidewall rupture risk is > 80% with device in 3rd wind from the can wall
    - Even though external heating without device yields < 25% risk
  - 100% successful (14 activations so far) in driving TR

What do we hope to learn in future?

- Does the cell bottom vent design feature help reduce side wall ruptures?
- Or is a thicker can wall needed?



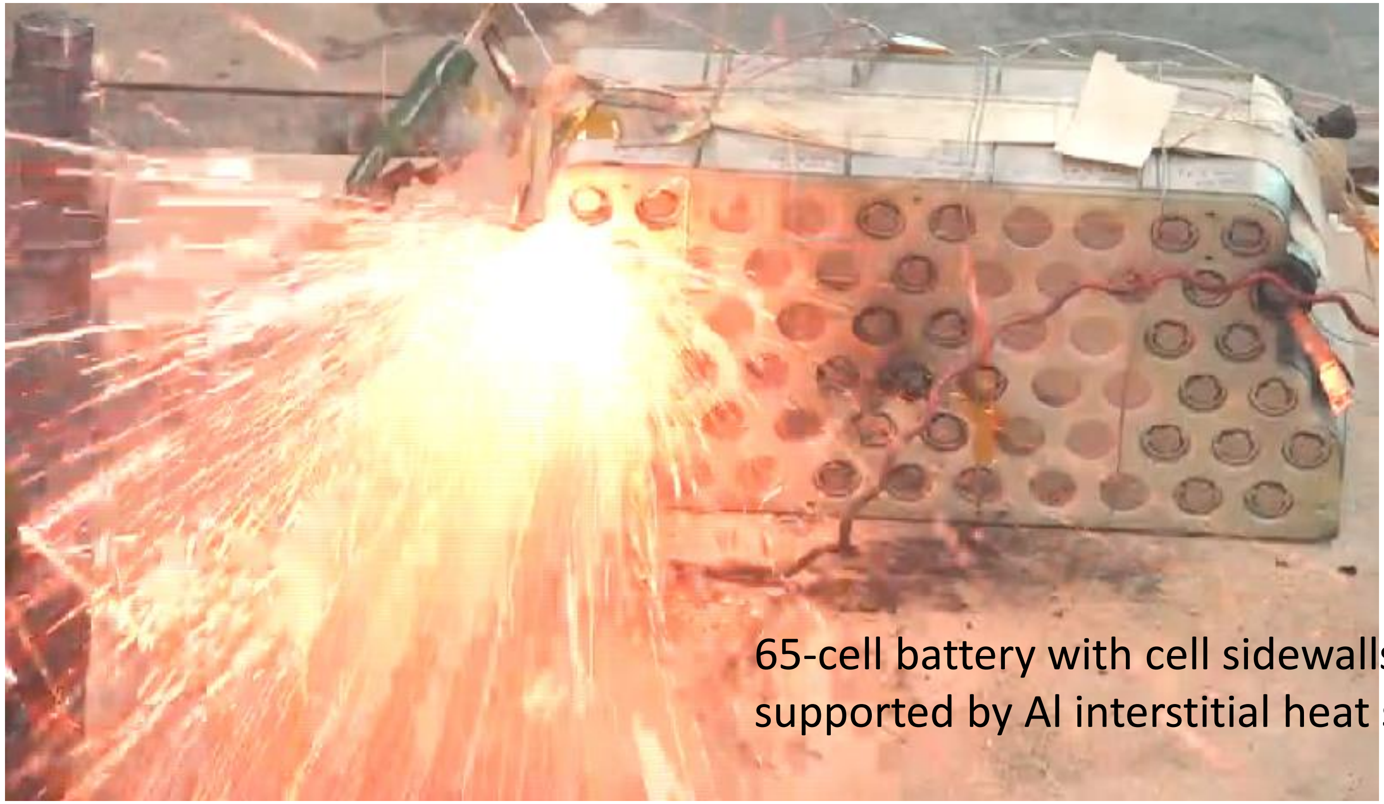


Thinning of can wall

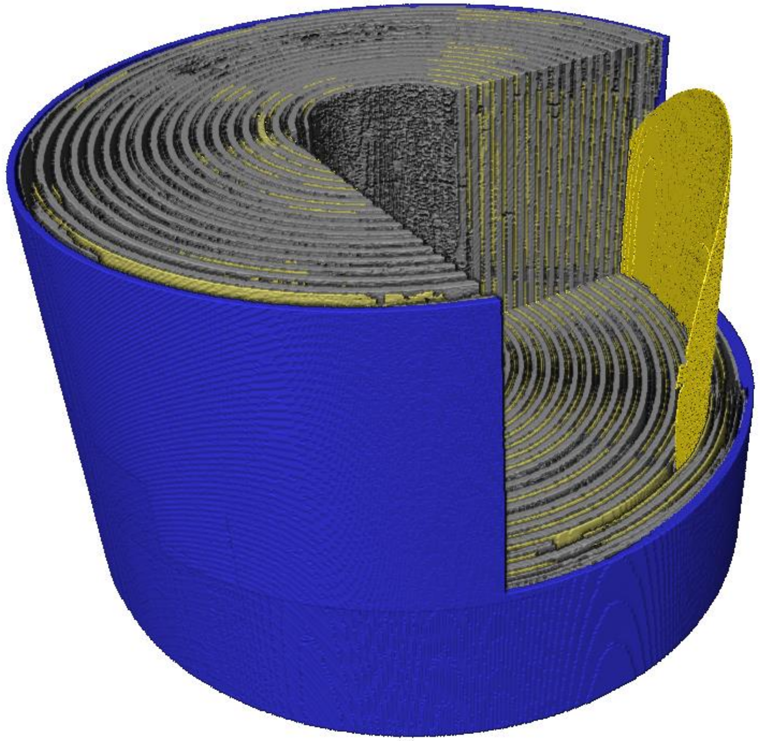
ISC Device Enables Key Cell & Battery Safety Verifications

Best trigger method of a cell internal short relevant to those that occur in the field (ie, Galaxy Note 7)

- No compromise of cell can required (as in nail penetration or crush)
- Can be triggered at any chosen state of charge (unlike overcharge)
- Requires minimal alterations of the test battery from mission use to heat trigger cell past wax melting temperature (57°C) vs cell onset of thermal runaway temperature (130°C), which minimizes temperature bias on adjacent cells within a tightly nested battery design and having to resort to over-test conditions
- Enables one to chose the type and location of the short inside a cell to assess cell design vulnerabilities

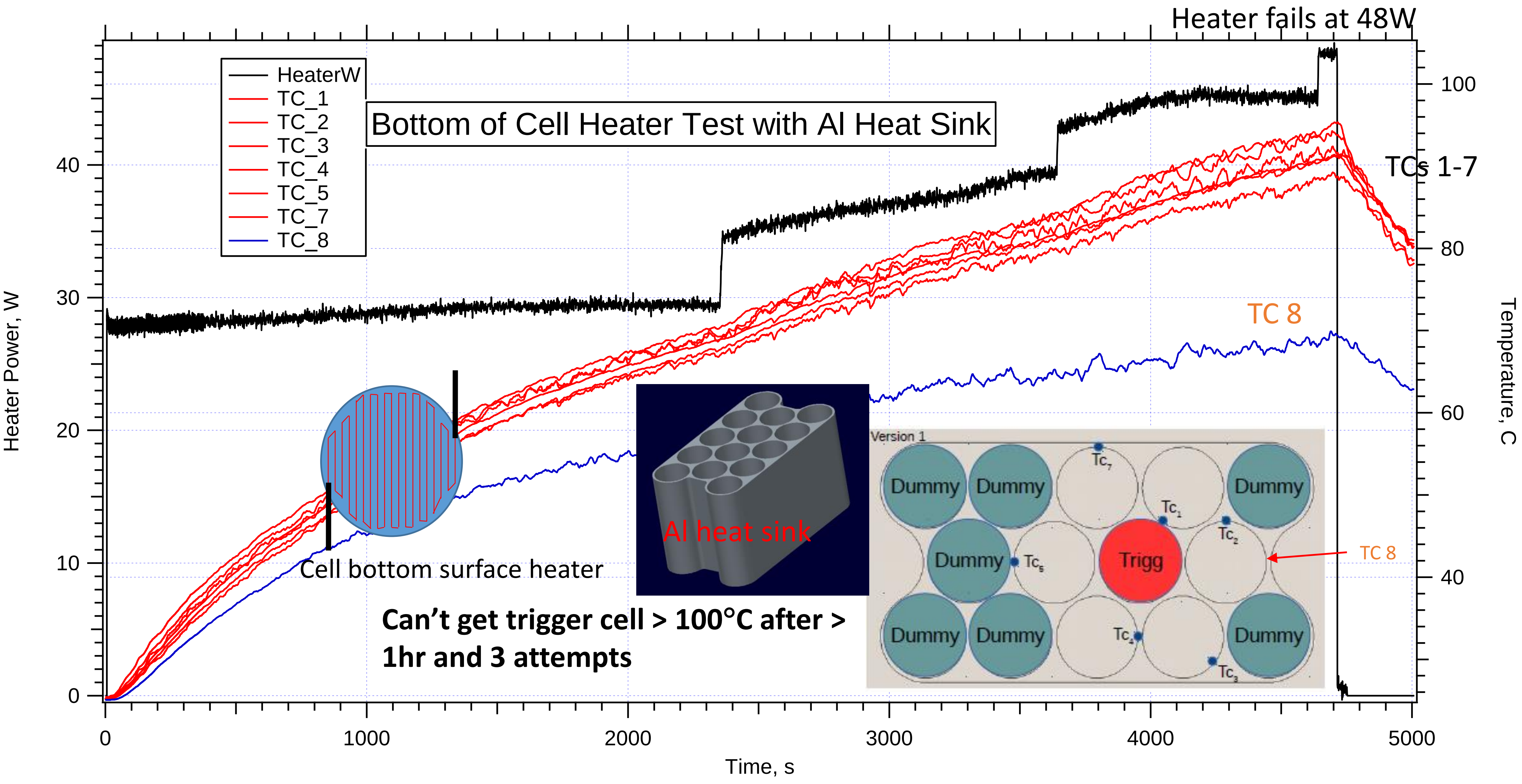


65-cell battery with cell sidewalls supported by Al interstitial heat sink



Tomography credits: University College of London

Attempts to Drive TR with Cell Bottom Heater Fails



Objective – Seek partners to automate fab of ISC devices

- Current manual process is laborious and not yielding very uniform results
  - Al pads are individually spin coated with wax
  - Then, reflow process in oven is needed to ensure uniform wax coverage under Cu puck
  - Manual handling of pads (Al & Cu) and Cu puck results in deformations
- Seeking an automated process that will achieve 10-20 micron wax coat and devices not warped by handling and enable
  - Use of other paraffin waxes to adjust melt point
  - Use < 25 micron Cu foils
  - Reduce the Cu puck diameter

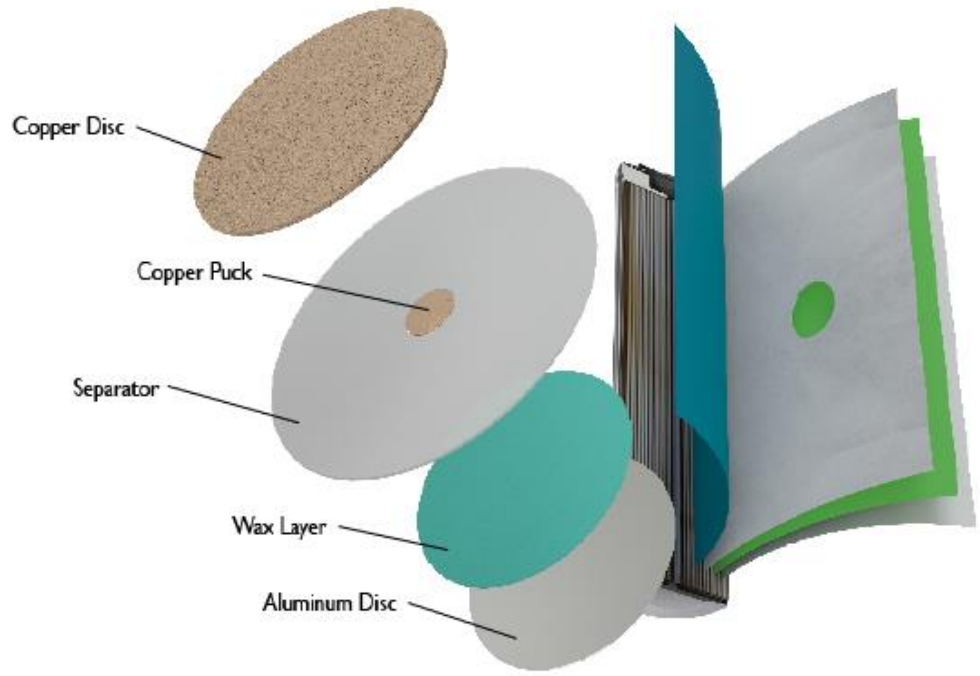


Diagram illustrating the components of the Battery ISC Device and its implantation in a battery cell.

Please contact Eric Darcy (713-492-1753) eric.c.darcy@nasa.gov with your ideas and proposals