# Lessons Learned Maturing Thermal Runaway Tolerant Lithium Ion Battery Designs

***S. Russell / E. Darcy***
***EP5/Power Systems Branch***

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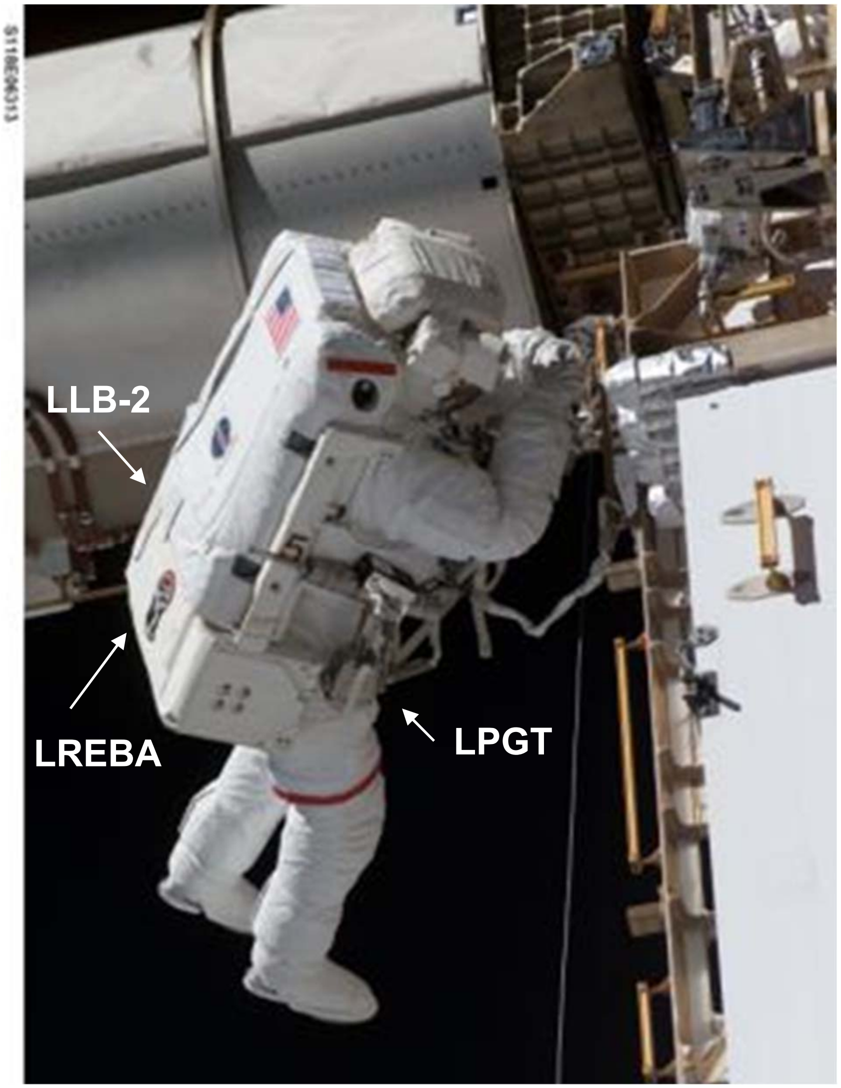
# Introduction



- This presentation provides lessons learned maturing three Passive Propagation Resistant Li-Ion battery designs from lab environment (TRL 3-4) to space qualified (TRL 8)
  - Lithium Ion Pistol Grip Tool Battery (LPGT), 89Wh
  - Lithium Ion Rechargeable EVA Battery (LREBA), 400Wh
  - Lithium Ion Battery for EMU (LLB-2), 670Wh
- Design decisions, materials and methods of construction, and unintended consequences are discussed



# Overview

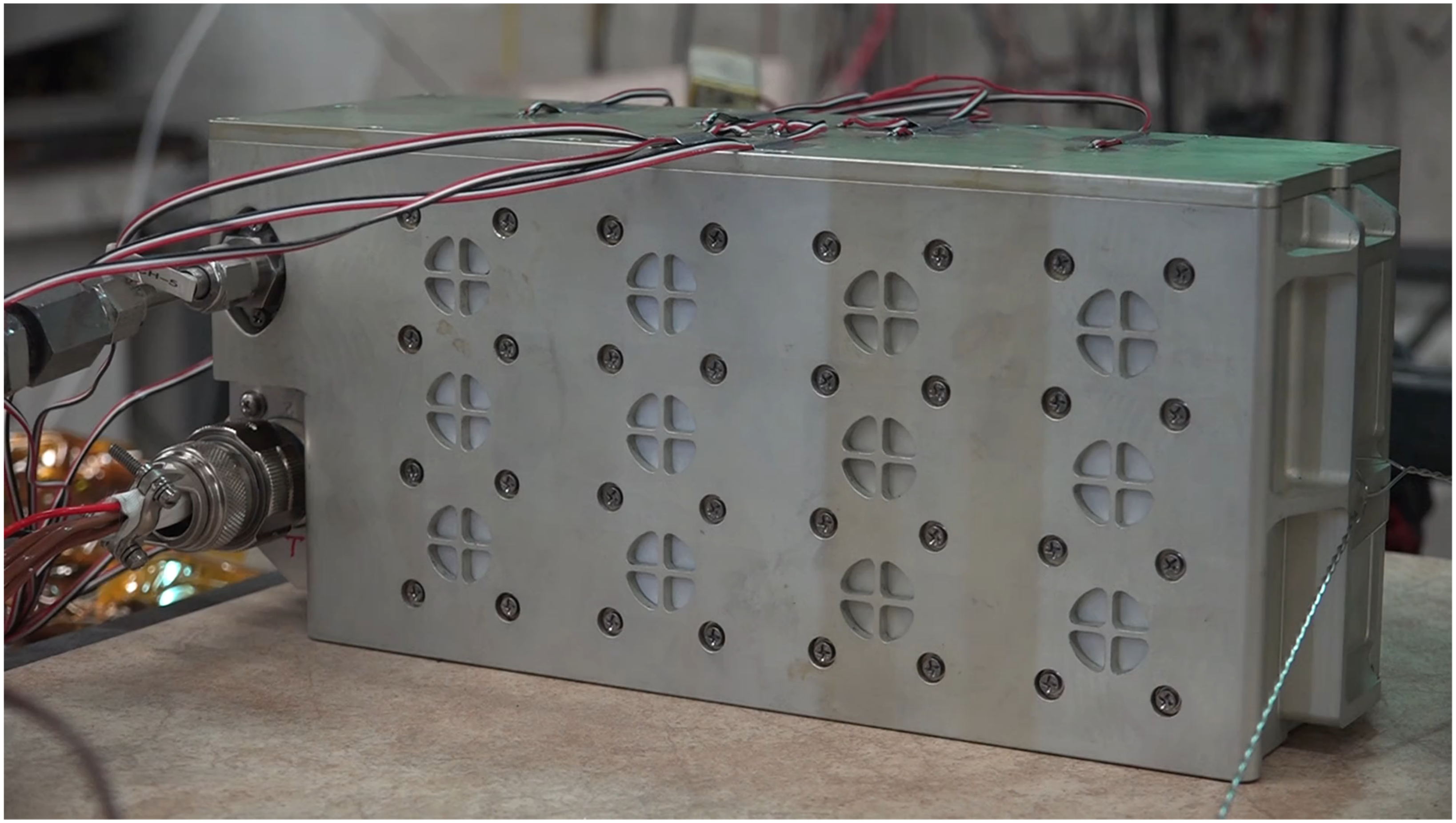


- Development activity provided a solution set for achieving PPR
- Each battery presented a unique development challenge
  - LPGT required gas flow and spark arresting screen development
  - LREBA required cell vent area material selection and design
  - LLB-2 required conductive interstitial development
- Designs were transitioned to flight development once PPR achieved
  - Mission specific feature sets were incorporated
  - Some solutions were challenged requiring PPR reverification
- Five key design drivers were satisfied
  - Side wall rupture prevented by cell selection
  - Adequate cell spacing maintained by cell capture plates
  - Cells/Wiring protected from hot gas by sleeving for large cell spacing or interstitial and sleeving for narrow cell spacing
  - Paralleled cells are individually fused by fusible links or fuses
  - Spark/Flame release prevented by tortuous path and vent screens

# Design Overview



## LLB-2 Thermal Runaway Propagation Mitigation Video

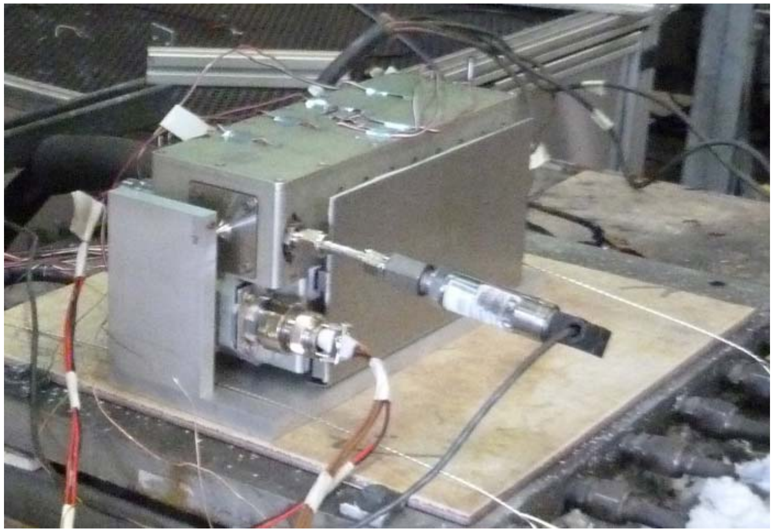


# Design Decisions



- **Effect of vented product exposure during single cell thermal runaway testing has been demonstrated**

**Test Article with Fabric Suspended in front of Housing Vent Ports**



**Effect of Garment Material Exposure to Externally Vented Product during Single Cell Failure**

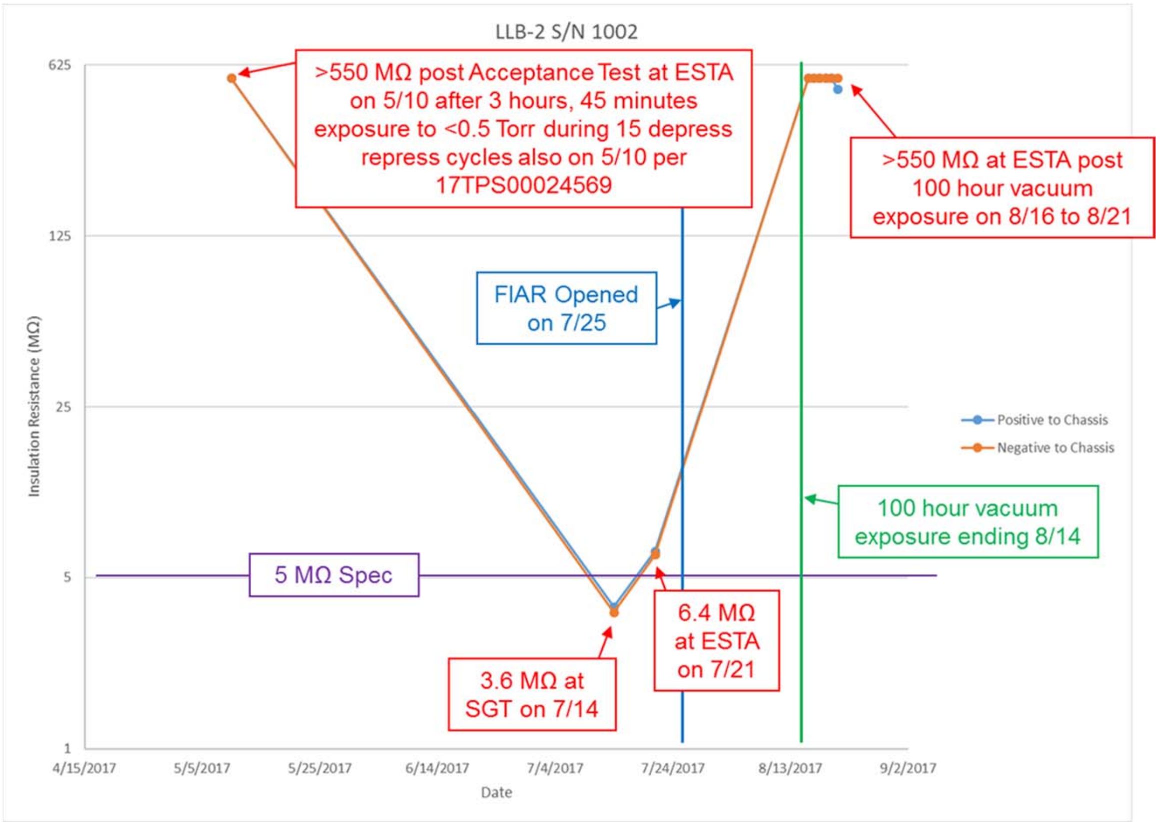
**Exposed** **Not Exposed**

# Decision Consequence



- **Selecting a conductive interstitial requires material selection rigor**
  - **State of the art, high temperature, high strength epoxy can form "amine blush" during cure which increases humidity sensitivity**

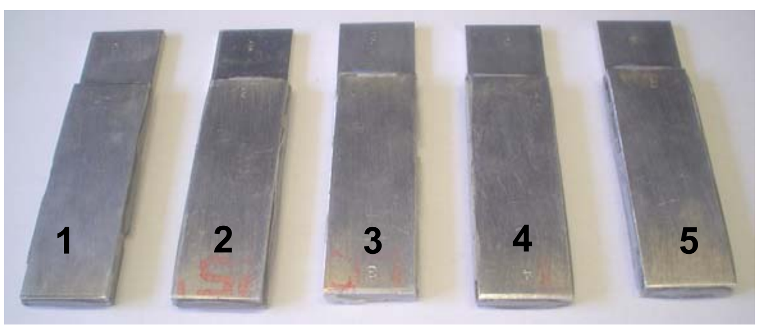
**500V Insulation Resistance Test Results**



# Decision Consequence



- Selecting a conductive interstitial requires material selection rigor
  - Electrical properties of high pot life material may not conform to specification data sheet values over all bond thicknesses
  - Coupon testing can verify stated performance values for volume resistivity of bonding materials
    - Coupons prepared using glass beads to maintain bond thickness
    - Can show effects of filler material in long pot life materials




Two aluminum plates separated by a narrow gap of epoxy when tested with a DMM:

1. $< 1\ \Omega$ – prepared using best practices
2. $< 1\ \Omega$ – using battery assembly method
3. $> 550\ M\Omega$ (500VDC IR) – no filler (different epoxy)
4. $< 1\ \Omega$ – low end of allowed hardener
5. $< 1\ \Omega$ – high end of allowed hardener

# PPR (Re)Verification



- Development team provided a repeatable, lab-scale solution
- Each solution was evolved to satisfy mission requirements
- Final design was assessed for applicability of lab-scale results
  - LPGT preserved development design and did not require retest
  - LREBA required retest due to ceramic bushing removal
    - Three tests were performed at different trigger locations
  - LLB-2 required PPR verification of final flight assembly
    - Initial test showed spark release
    - Short side fasteners and cover "lip" were added to secure joint and increase leak path tortuosity
    - PPR and spark retention verified with top corner cell tests
    - Reverification following epoxy selection is under assessment

# Future Considerations



- Develop methods to enhance LREBA-like solutions including
  - Impact tolerant thermal ground plane in flat pack designs
    - Initial heat spreader designs performed well, but LREBA has unique and severe external load case which must be tolerated without crushing cell or increasing battery thickness
    - Internal venting (head-to-head) may need to be considered
  - Reduce dependency on garment containment
    - Incorporate spark arresting features at housing exit or repackage/reorient cells to allow gas expansion within housing
- Reduce specific/gravimetric energy of battery designs
  - Assess external heating for unhoused heat sink design
  - Optimize dimensional recommendations for cell vent region
- Minimize reliance on adhesive bonding for structural integrity
- Assess scalability of energy PPR solutions to power designs

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