Consideration of Internal Shorts for the Spacesuit Li-Ion Battery

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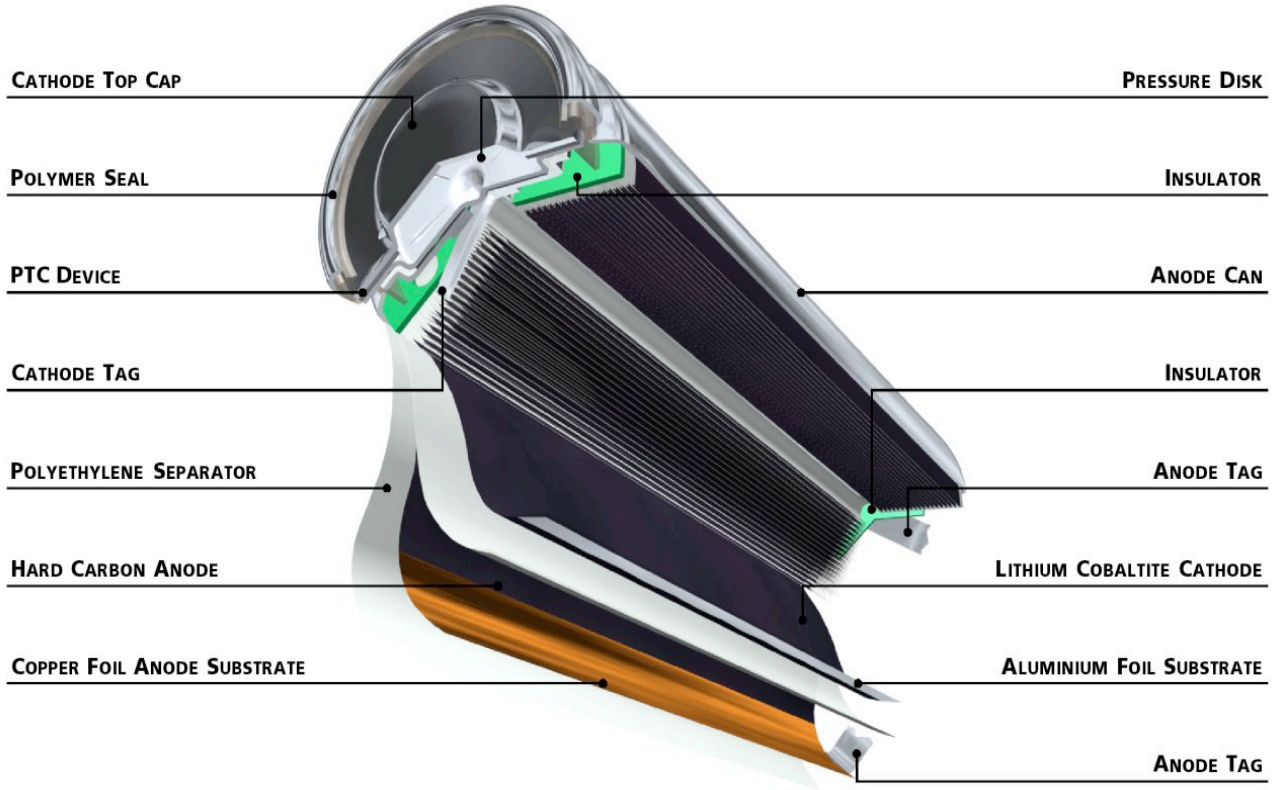
EMU Introduction

- Extravehicular Mobility Units (EMUs) need a rechargeable, high energy, long life battery for servicing the ISS
- Li-ion is necessary for the required performance, but concerns exist on safety
- **As a critical manned space application, safety is top priority!**

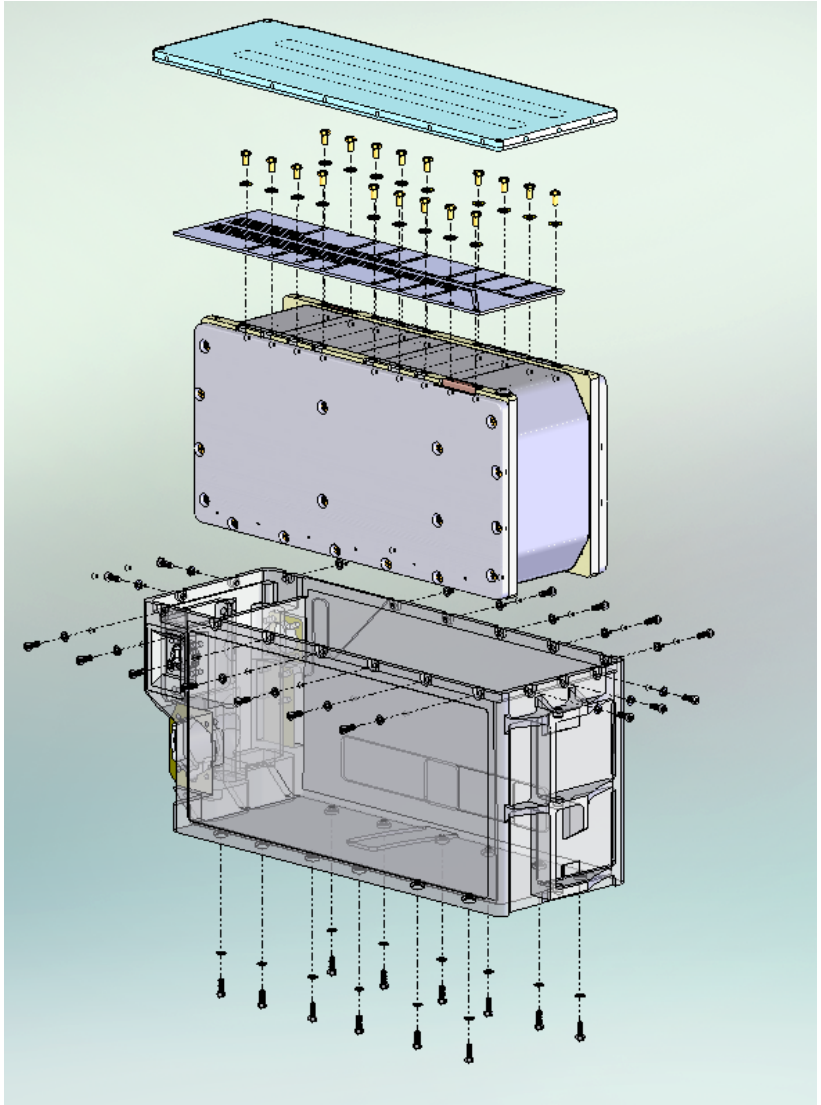
EMU COTS Cells

- Two different 18650 format COTS cells under evaluation
- Both are higher energy cells than the ABSL 18650 HC



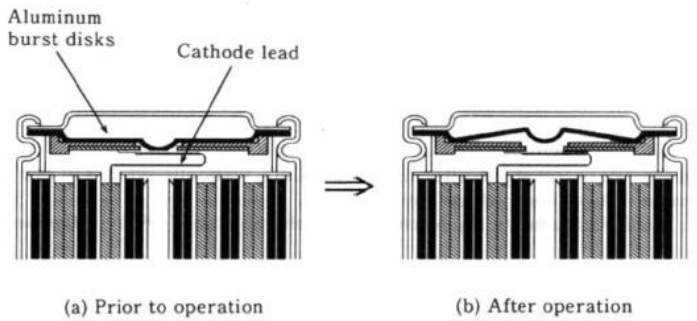
EMU Battery Design

- Quick Stats
  - ~20 V
  - > 36 Ah
  - > 130 Wh/kg
- Accommodates either cell
- Replaceable cell brick
- Designed for safety



Risks: Overcharge

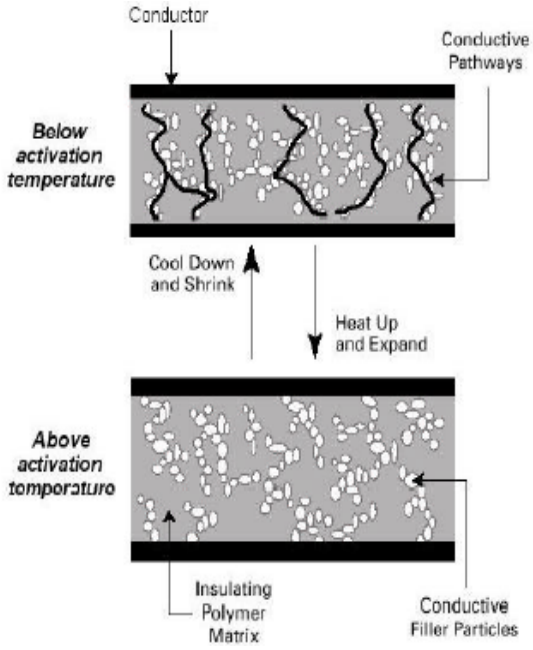
- Li-Ion is highly sensitive to overcharge, and results can be catastrophic
- Relatively well understood
- Protection:
  - Cell level CIDs
  - Battery level thermal conductivity
  - Two-fault tolerant charger



CIDs built into COTS cells offer a simple, reliable cell disconnect on overcharge

Risks: External Short Circuit

- Li-Ion is capable of extremely high discharge rates, the results of which can be catastrophic
- Relatively well understood
- Protection:
  - Redundant insulation
  - Cell level PTCs
  - Battery level fuse
  - Battery level thermal conductivity



PTCs built into COTS cells provide resettable short circuit protection

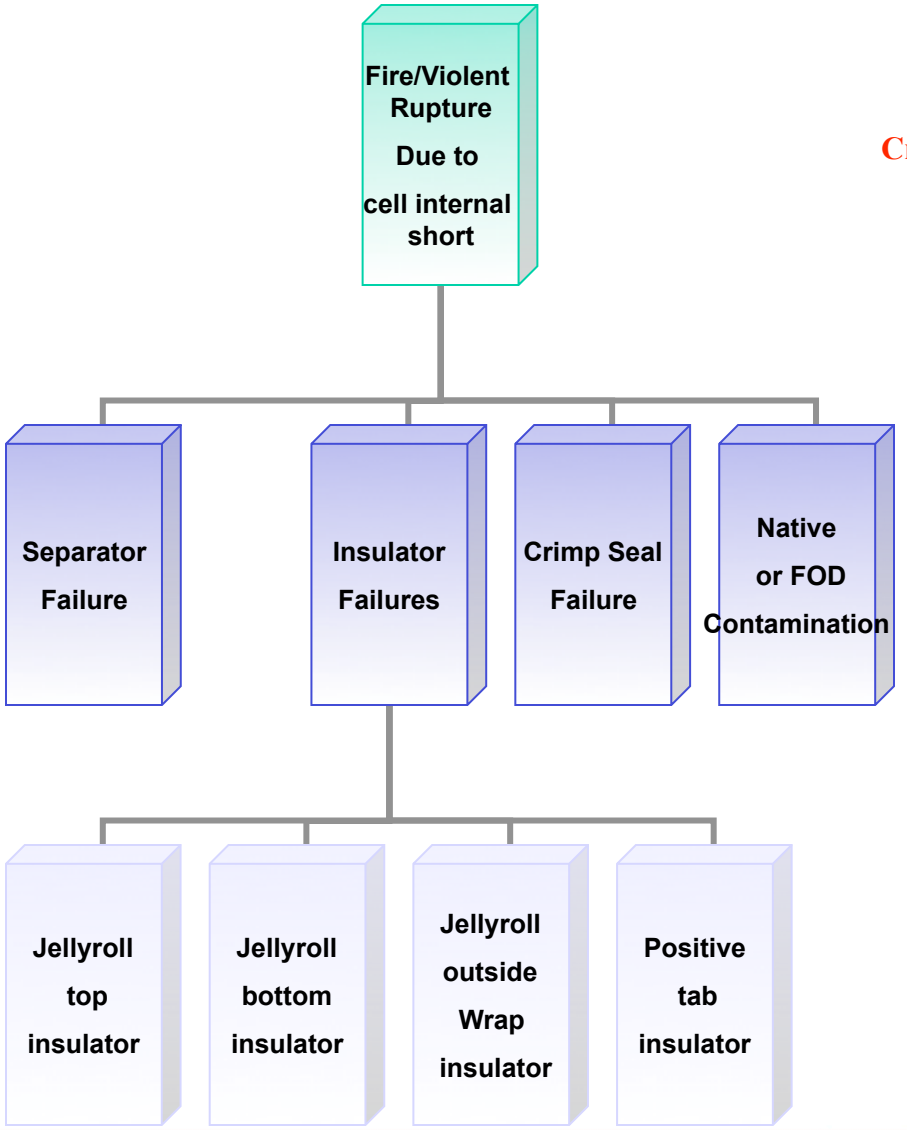
Risks: Internal Short Circuit

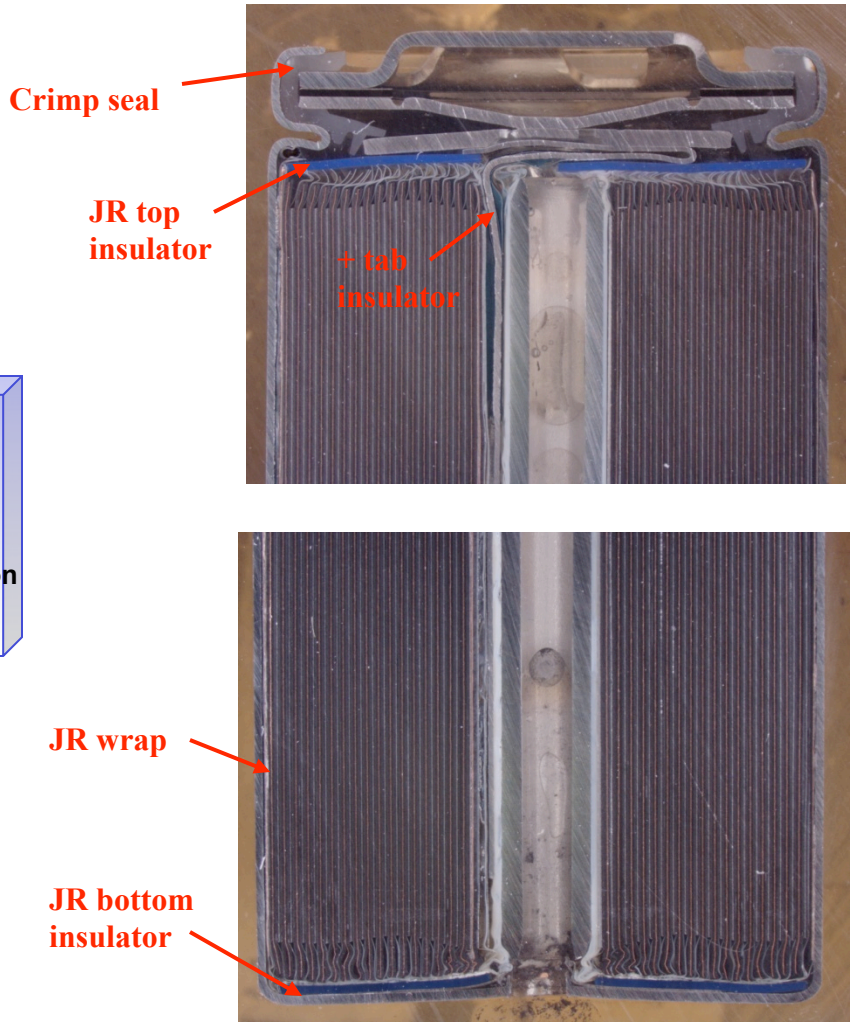
- Cell-internal short circuits have been blamed for sudden catastrophic battery failures

- Such incidents are poorly understood

- **Why does it happen, and how do you protect against it?**

Internal Short Fault Tree





Pick the Right Cells

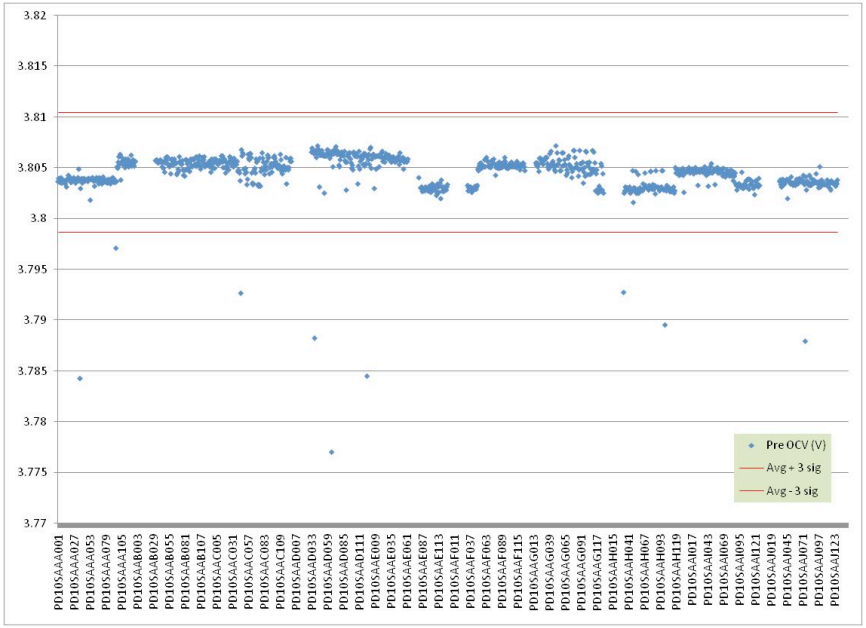
- Highly automated & uniform mass production (>1M cells/month)
- Mature cell designs (circa 2003 for EMU) with excellent track records
- Reasonable energy density, internal separator, and safe insulators
- **Does it work?**
  ~1 in 235,000,000 COTS cells fail catastrophically from internal shorts

Screen Your Cells

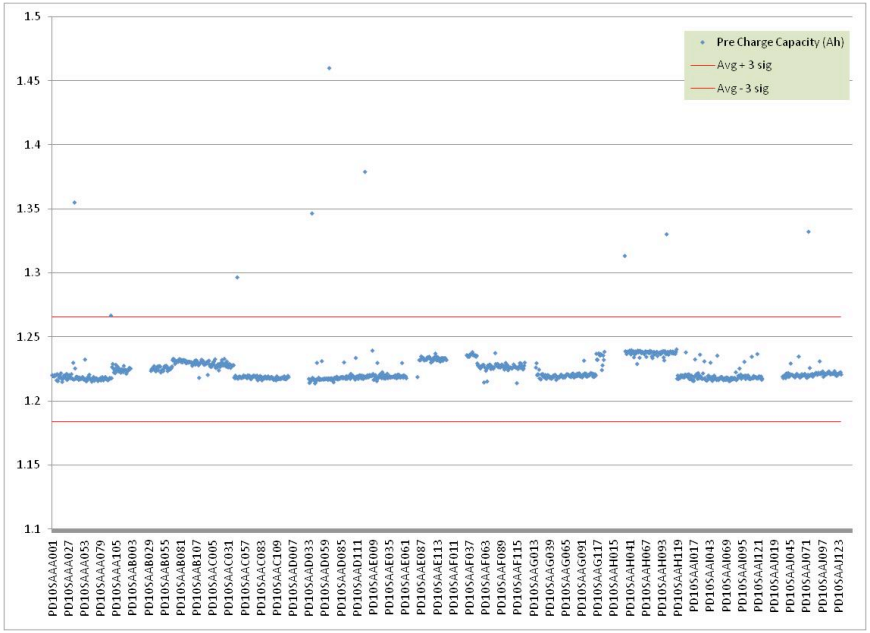
- Check for anomalous things…
  - Dents, scratches, rust, etc.
  - Self-discharge rates
  - AC and DC impedance
  - Charge and discharge capacity
- An extensive EMU cell screening program includes these factors and more… **but does it work?**

Does Cell Screening Work?

EMU Cell 1: OCV Pre-Screening
σ = 0.05% of average



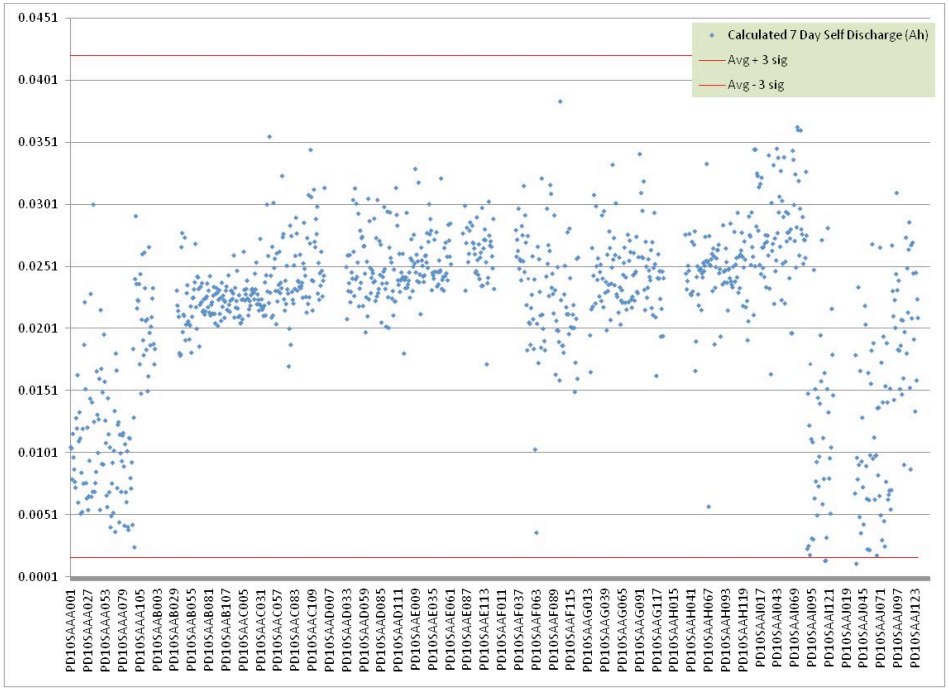
EMU Cell 1: Initial Charge Capacity
σ = 1.14% of average



- Long duration (~17 month) self discharge tests have identified out-of-family cells

Does Cell Screening Work?

EMU Cell 1: 7 Day High SOC Self Discharge Capacity



- Shorter self discharge measurements appear less useful
- Capacity & impedance measurements have not yet identified any suspicious cells

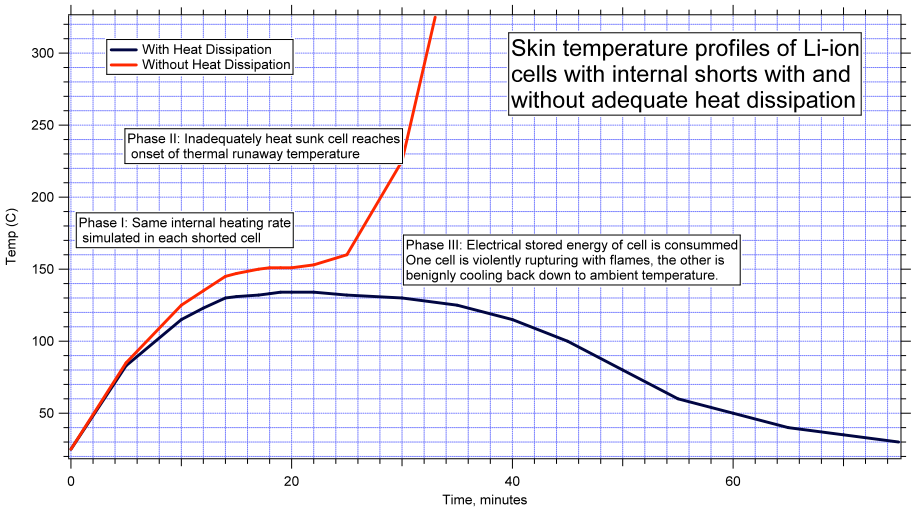
Does Cell Screening Work?

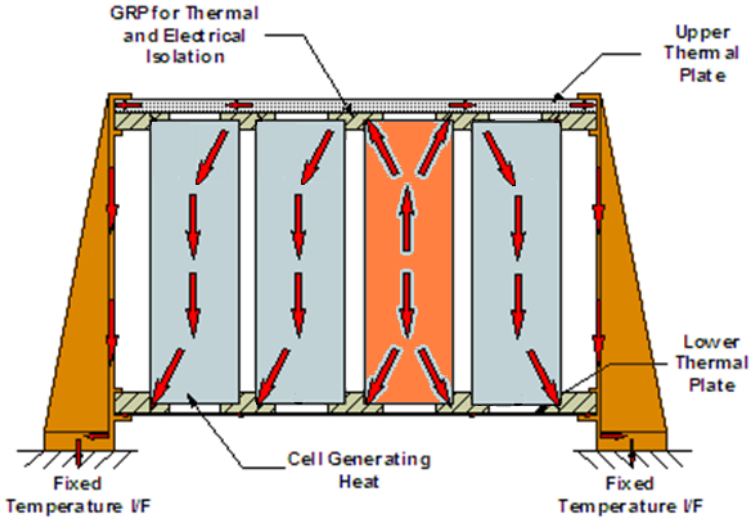
- Do these ‘suspicious’ cells pose a real risk?
- Did we miss cells that do pose a risk?

- **Ongoing Work:** Test anomalous and accepted cells to try to induce a hard internal short via…
  - High level vibration testing
  - Extreme thermal cycling
  - High rate & DOD electrical cycling

Build a Safe Battery

- Manage thermal effects of the short to prevent escalation to catastrophic failure
- **Using small cells is key** to limiting propagation and ultimate magnitude of the effects
- **Does it work?** Has been proven effective for overcharge, but hard to prove for internal shorts





Screen Your Batteries

- Attempt to identify batteries containing susceptible cells pre-flight
- The EMU program includes rigorous battery level screening, like…
  - Visual, Mass, OCV, CCV, AC impedance, insulation resistance, bonding, etc.
  - Random vibration
  - Thermal cycling
  - Depress/repress cycling
  - 3 day, high temperature vacuum hold
  - High rate and mission rate electrical cycling
- **Does it work?** ABSL has employed similar screening on more than 45 launched batteries without failure

Don't Abuse the Battery

- Restrict to low stress operations, like…
  - Tighter voltage window
  - Lower charge/discharge rates
  - Lower max temperature exposure
  - Lower cycle life

	EMU	Typical Consumer Application
Voltage	3.2 to 4.12 V	3.0 to 4.2 V
Rate	< C/8	C/2 and higher
Temperature	10 to 40° C	20 to 55° C
Cycle Life	~50	>500

- **Does it work?** Couldn't hurt…

What we think we know

- Picking the right cell matters
  - Look for consistency & quality
  - *Odds of failure can be reduced to less than 1 in 235,000,000*
- Screening cells on self discharge identifies suspect cells
  - Long periods, not short ones
- Battery features can control effects
  - Thermal management and the use of small cells is key
  - Low stress operation could help

What we're not so sure about…

- Does screening catch or miss risky cells?
  - Are "suspicious" cells actually a risk?
  - What's the value of different screening?
  - Stay tuned for result of future testing…
- How well does battery level protection work?
  - Internal short variability makes testing difficult
  - What operating conditions are most dangerous?
  - How much performance are we willing to sacrifice?

Addressing Internal Shorts

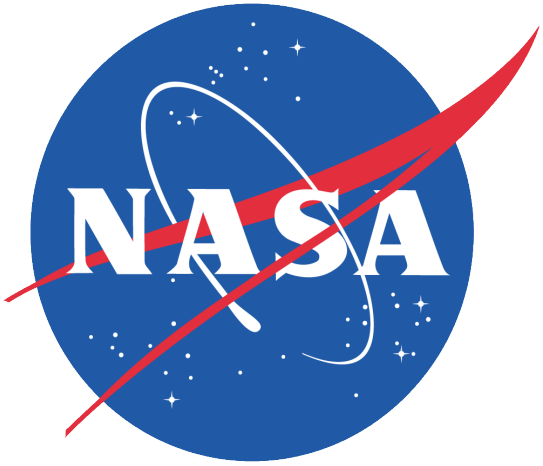
- EMU is moving forward and taking every reasonable precaution to minimize risk
- Continuing ABSL/EMU efforts will investigate value of cell and battery screening
- More efforts needed to accurately gage effectivity of battery level protection methods

Addressing Internal Shorts

- With small COTS cells, risk can be extremely low… but visibility in the commercial market is high
  - *If all the satellites since 1957 had been built with COTS cells, the chance of an internal short induced failure having occurred to date would be ~2%*

R. Spurrett, " The Future of Lithium-Ion Batteries: A Supplier's Perspective"

Acknowledgements



- NASA Johnson Space Center
  & Everyone on the EMU LLB team

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