Lithium Ion Technology: Balancing Increased System Capability with the Potential for Explosion

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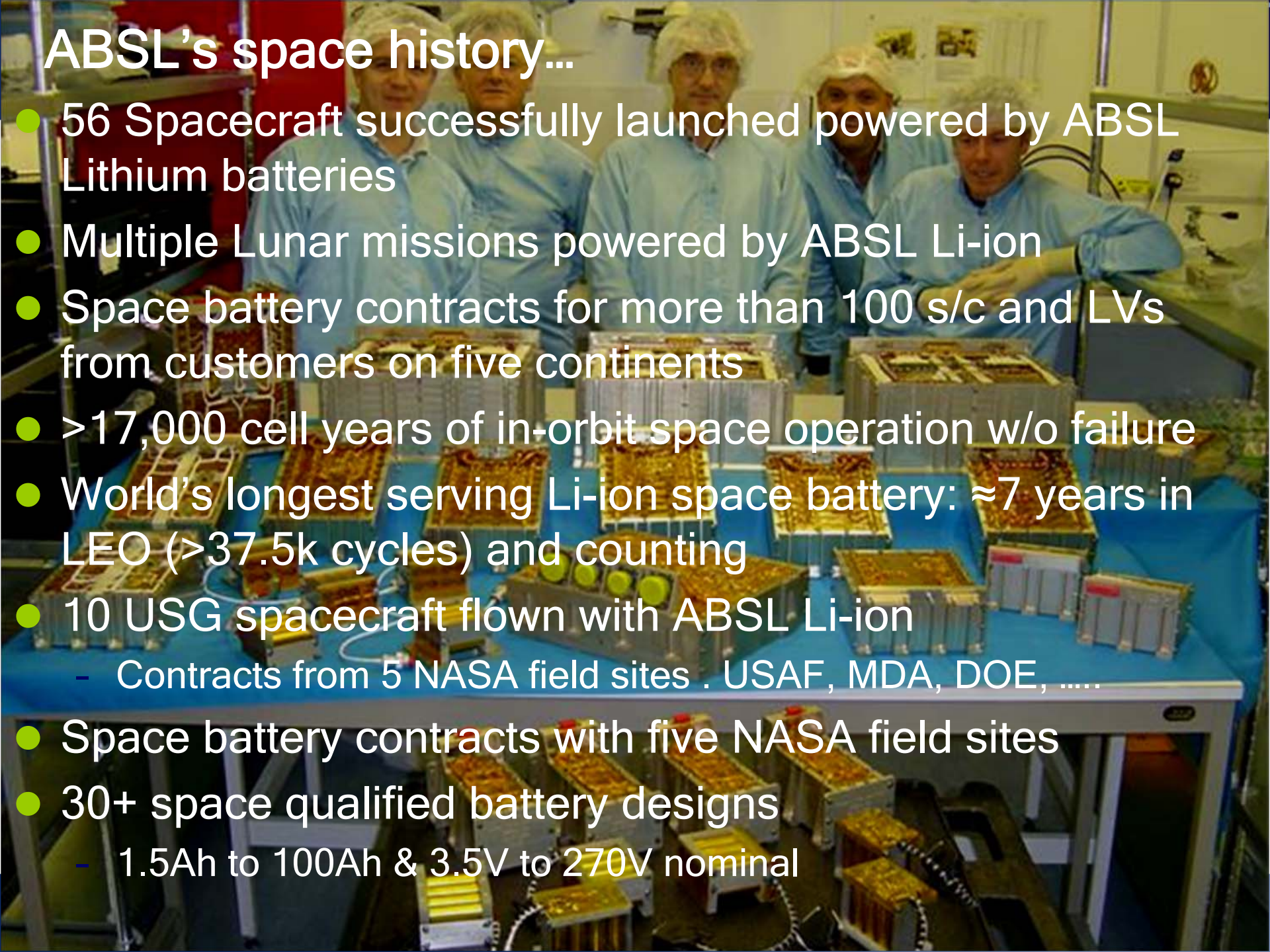
Advances in Battery Technology

NiCd
30 Wh/kg

NiH2
60 Wh/kg

Li-Ion
120 Wh/kg

- Today's Li-Ion chemistries are capable of extremely high energy and power density, and can provide long cycle and calendar life



ABSL's space history…

- 56 Spacecraft successfully launched powered by ABSL Lithium batteries
- Multiple Lunar missions powered by ABSL Li-ion
- Space battery contracts for more than 100 s/c and LVs from customers on five continents
- >17,000 cell years of in-orbit space operation w/o failure
- World's longest serving Li-ion space battery: ≈7 years in LEO (>37.5k cycles) and counting
- 10 USG spacecraft flown with ABSL Li-ion
  - Contracts from 5 NASA field sites . USAF, MDA, DOE, ….
- Space battery contracts with five NASA field sites
- 30+ space qualified battery designs
  - 1.5Ah to 100Ah & 3.5V to 270V nominal

Batteries Can Be Problematic

- A significant number of satellite failures are due to batteries
- Li-Ion batteries are capable of high amperage current spikes – extreme care must be taken to avoid short circuits
- Li-Ion battery failures can result in forceful venting, fire and even explosion

The Infamous Laptop Fire…

- Suspected Cause of Failure: internal contamination combined with aggressive battery management

FedEx Shipping Fire…

- Suspected Cause of Failure: loose tooling packed with shipment created a short circuit

Aftermarket Automotive Battery…

- Suspected Cause of Failure: improper assembly created a local hot-spot, causing extreme heating of nearby cells

What Is Thermal Runaway?

- A condition in which Li-Ion cells generate heat in a self-sustaining and self-accelerating manner.
  - **Phase 1** : Low self heating.
  - **Phase 2** : Increased self heating, venting.
  - **Phase 3** : Extreme self heating, possible fire or explosion.

Courtesy of pcpitsop.com

Courtesy of E.P. Roth, "Li-Ion Safety..", Space Power Workshop 2007

What Can Cause Thermal Runaway?

- High Environmental Temperature
- Overcharge
- External Short Circuit
- Internal Short Circuit
  - Mechanical deformation/penetration
  - Manufacturing defects

Many complex failure modes exist that can lead to a thermal runaway scenario

Thermal Runaway Protection

- Several approaches have been engineered to improve safety:
  - Active Protection Electronics
  - Current Interrupt Device (CID)
  - Controlled Vent Mechanisms
  - Positive Temperature Coefficient (PTC) Polyswitch
  - Shutdown separator
  - Thermal Management
- All of these approaches have limitations

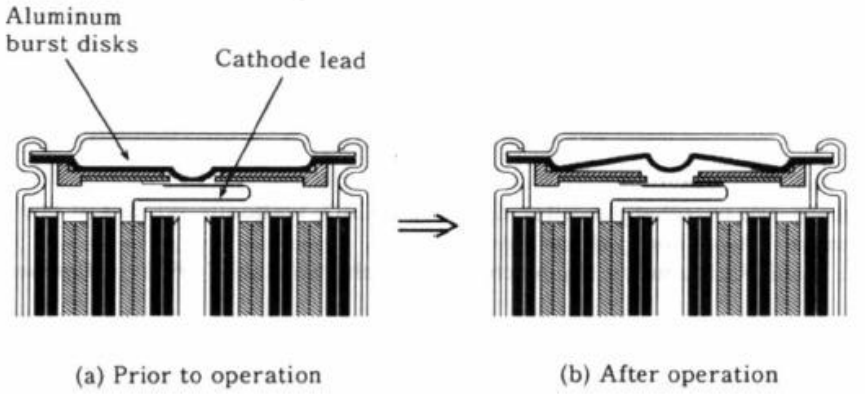
Custom vs COTS cells…

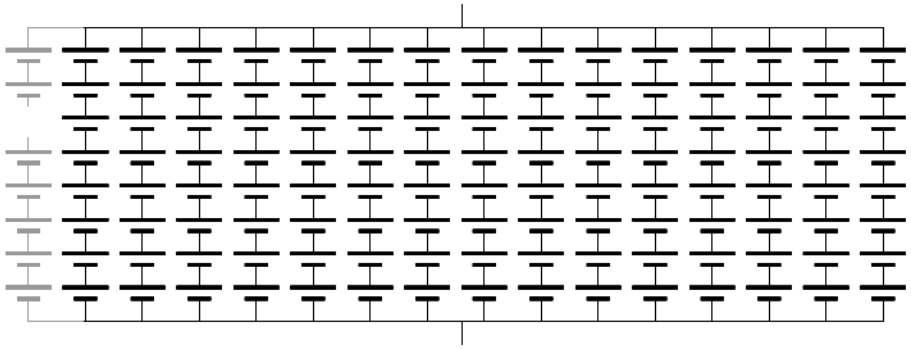
- Custom Cells:
  - Typically large capacity cells, difficult to isolate faults
  - Little to no built-in protection
  - Require external protection circuitry

- COTS Cells:
  - Typically small capacity cells – easier to isolate faults
  - Several built-in protection mechanisms
  - May not require external protection circuitry

Current Interrupt Device (CID)

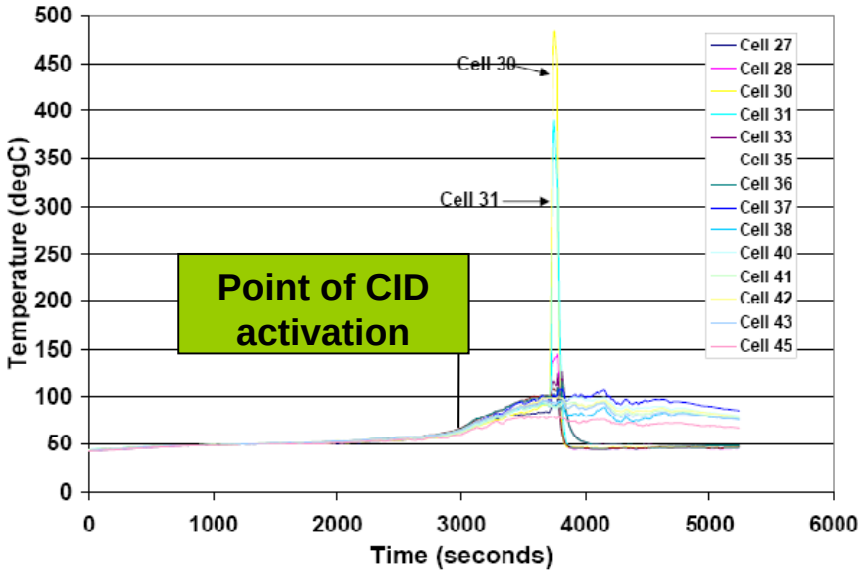
- On overcharge cells generate a gas that raises internal cell pressure.
- Eventually the burst disk will distort, disconnecting the cell open circuit to prevent further overcharge.
- At battery level, CID protection can be designed to be highly redundant

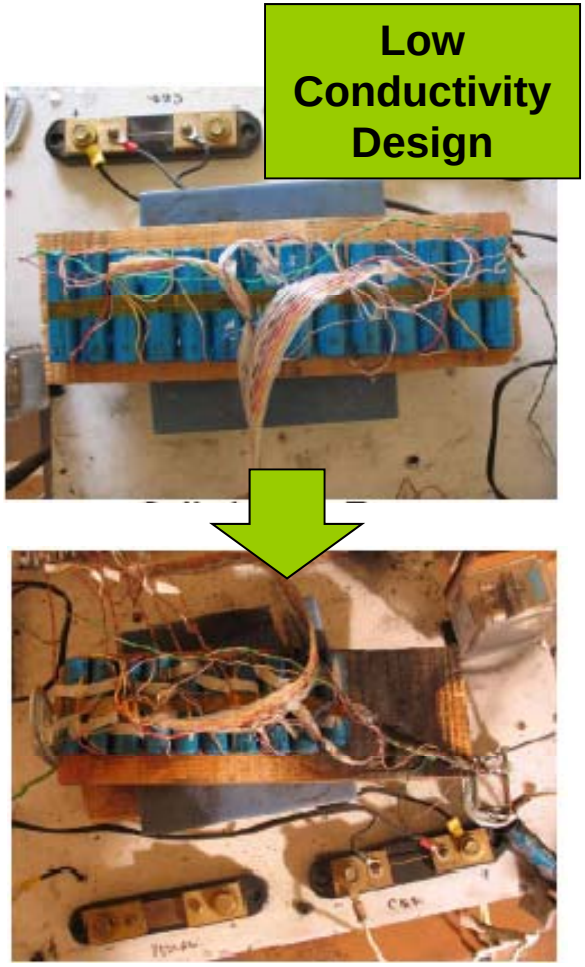




CID: When it doesn't work…

- A self heating reaction can continue after current flow is stopped
- In this test, high current, high environmental temperature, and low thermal conductivity led to venting, flame, and *forceful pack disassembly*

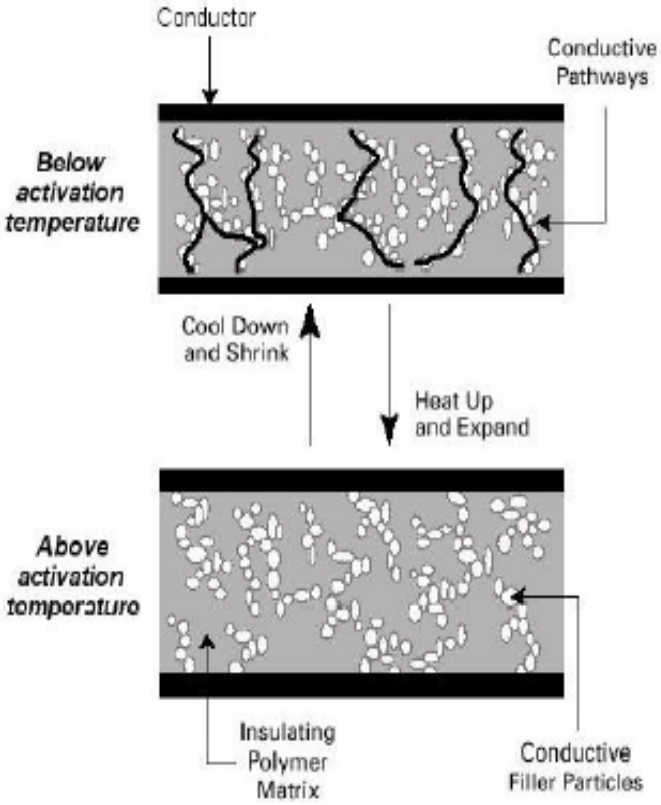




J. Jeevarajan, "Limitations of Internal Protective Devices...", NASA Battery Workshop 2007

Positive Temperature Coefficient (PTC) Polyswitch

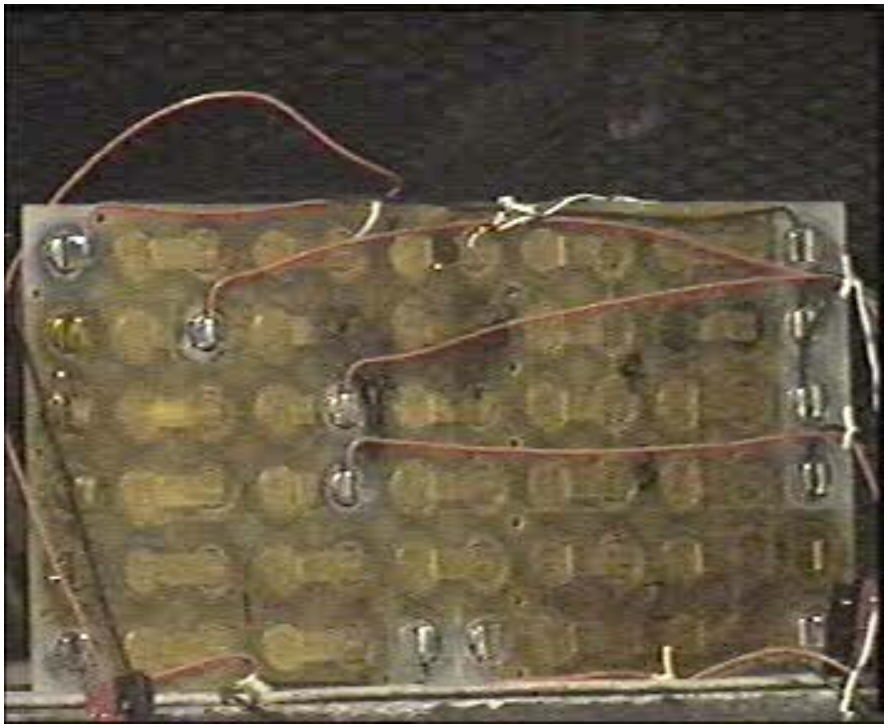
- PTC resistance increases nonlinearly with temperature, driven primarily by current flow
- The PTC acts as a short circuit protection mechanism
  - High current draws will heat the PTC and induce a several orders of magnitude increase in resistance.



PTC: When it doesn't work…

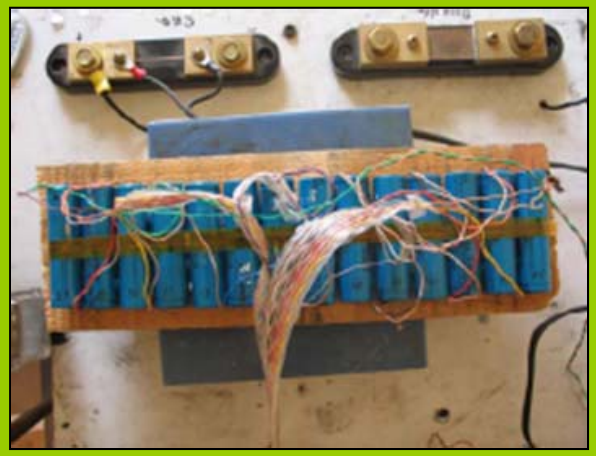
- PTCs may not activate on application of a 'smart short', allowing excessive heating of cells
- Activated PTCs may generate excessive heat that cannot be adequately dissipated
- PTC's can suffer an insulation breakdown at high voltage and revert to low resistance state

Example of PTC Breakdown



- PTCs broke down on activation in this 12s high voltage string
- Different model cells have different breakdown voltages
- Engineering solutions exist

Thermal Management



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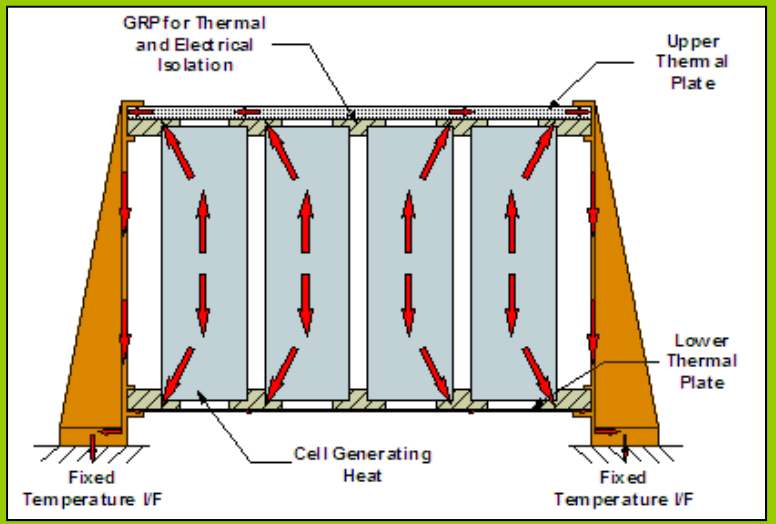

- Proper thermal management is critical to address limitations of protection devices
- ABSL engineers optimize flight battery thermal designs for safety and performance

Lessons Learned

- It is essential that safety is of prime consideration during battery build, spacecraft AIT, launch and on-orbit operations when employing Li-ion

- There are many approaches to protect a battery, but they all have limitations. The 'safety envelope' of a design must be considered, proven, and respected.

- Testing of ABSL battery designs has shown robustness to an array of off-nominal conditions through life

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