The NASA EMU Battery Program and Progress

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Agenda

- Background
- Design development
- Manufacturing development
- Testing accomplishments
- On-going and near term plans

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Background

- Astronaut life-support during EVA is presently provided by Silver-Zinc batteries
- NASA wishes to replace these batteries with Li-Ion batteries for improved performance and simplified handling logistics
- To minimize changes to the Extravehicular Mobility Unit (EMU) program, mechanical interface to the battery housing is unchanged
- JSC identified two COTS 18650 Li-Ion cells to be evaluated with a later down select following cell screening and engineering unit testing

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Background Cont.

- After competitive procurement, ABSL placed under initial contract to perform:
  - Screening of approximately 6000 cells of each candidate cell type
    - JN cells screened at ABSL's US facility, LV cells at ABSL's UK facility
  - Perform preliminary and detail design of battery 'brick' that will be assembled into NASA provided battery housing
  - Fabricate and acceptance test 12 'bricks', 6 of each cell type
  - Fabricate 8 battery assemblies, called LLBs
  - Perform engineering unit testing with 6 LLBs
    - Qualification type environmental testing with 2 LLBs
    - Abuse/safety testing with 2 LLBs
    - 100 cycle mission simulation testing with 2 LLBs
- Following successful CDR, contract option placed with ABSL to fabricate 35 flight 'bricks' and perform qualification testing with 2 LLBs
- Note: this was the first major hardware contract at ABSL's Colorado facility, but have now demonstrated similar capability as ABSL's UK facility with multiple flight batteries delivered for various customers

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Design Development

- Goal to maximize capacity within existing housing geometry and voltage range of 16.0 to 20.6 volts
  - Minimum acceptable capacity: 26.6Ah
- Optimization was a 16p5s topology with meshed cell matrix
  - Not using ABSL traditional approach because NASA will be using custom charger with integrated 'bank' balancing if required
- Typical ABSL design features and EMU specifics
  - Cells electrically & mechanically screened for any defects or out-of-family characteristics
  - Cells are bonded into counter bored capture plates
  - Redundant cell welds using common bus pads
  - Robust electrical insulation
    - For additional safety against FOD, isolation barrier placed between cell banks
  - Aluminum side panels for thermal dissipation and mounting to battery housing

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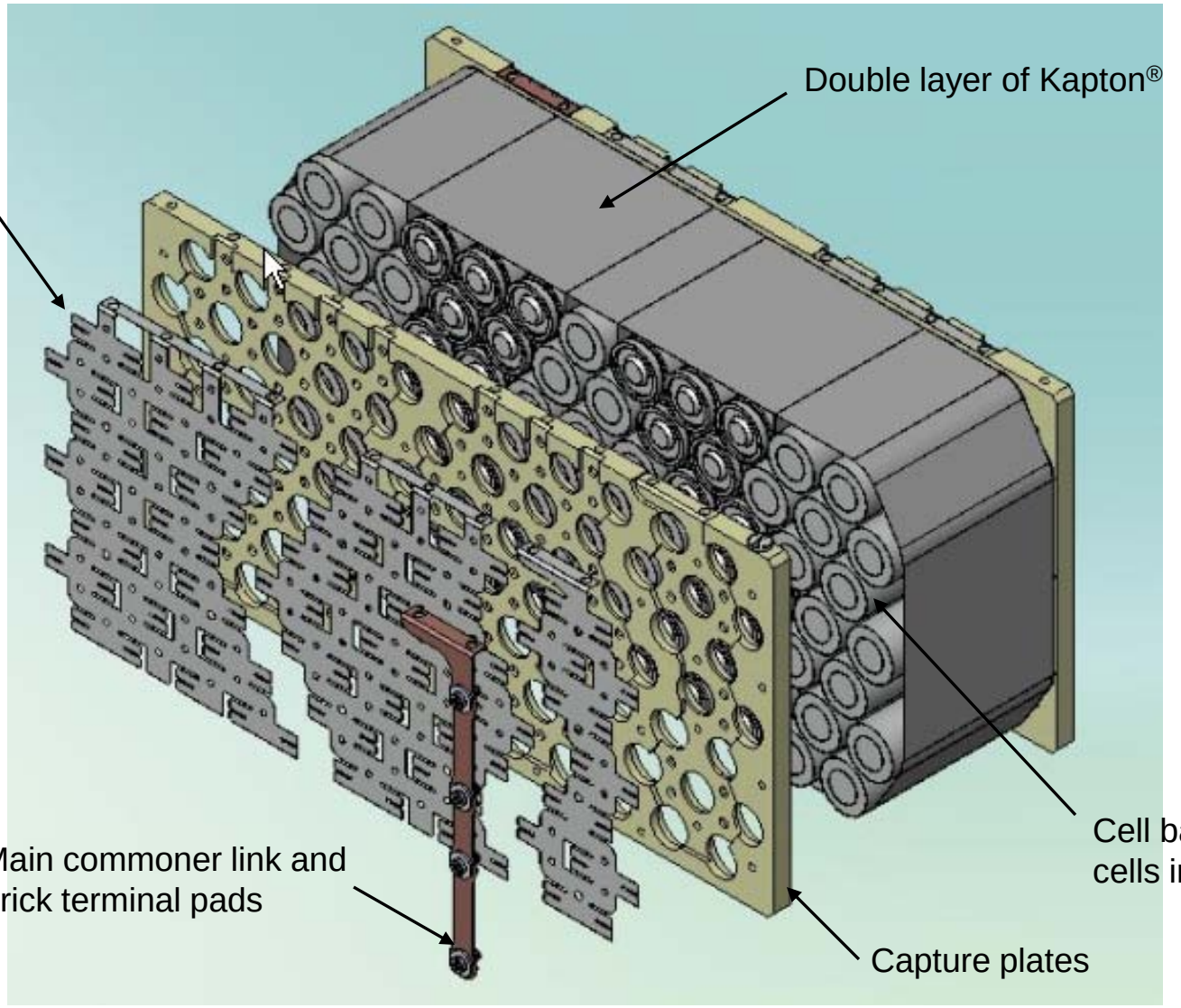
Brick Design



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Manufacturing Development

- In parallel with design development, assembly processes developed
  - Weld schedules
    - Modified from heritage schedule for Sony HC cells
    - After 100s of welds that were achieving consistent high pull strengths, thought we were successful, but cross-sections revealed additional refinement needed
    - Agreed to use existing weld schedule for engineering units while further weld schedule refinement performed
    - Additional weld schedule development was successful and weld schedule is now fully qualified for flight hardware
  - NASA certifications
    - Manufacturing and Inspection Personnel were NASA certified for application and inspection of soldering, conformal coating, and crimping
  - Detailed assembly 'travelers' and supporting manufacturing documentation released

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Welding per 60010A WI
(Macgregor M2 welder with Multitest 2.5X Pull Tester)

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Cells Installed Into Lower Capture Plate with Insulating Block Dividers

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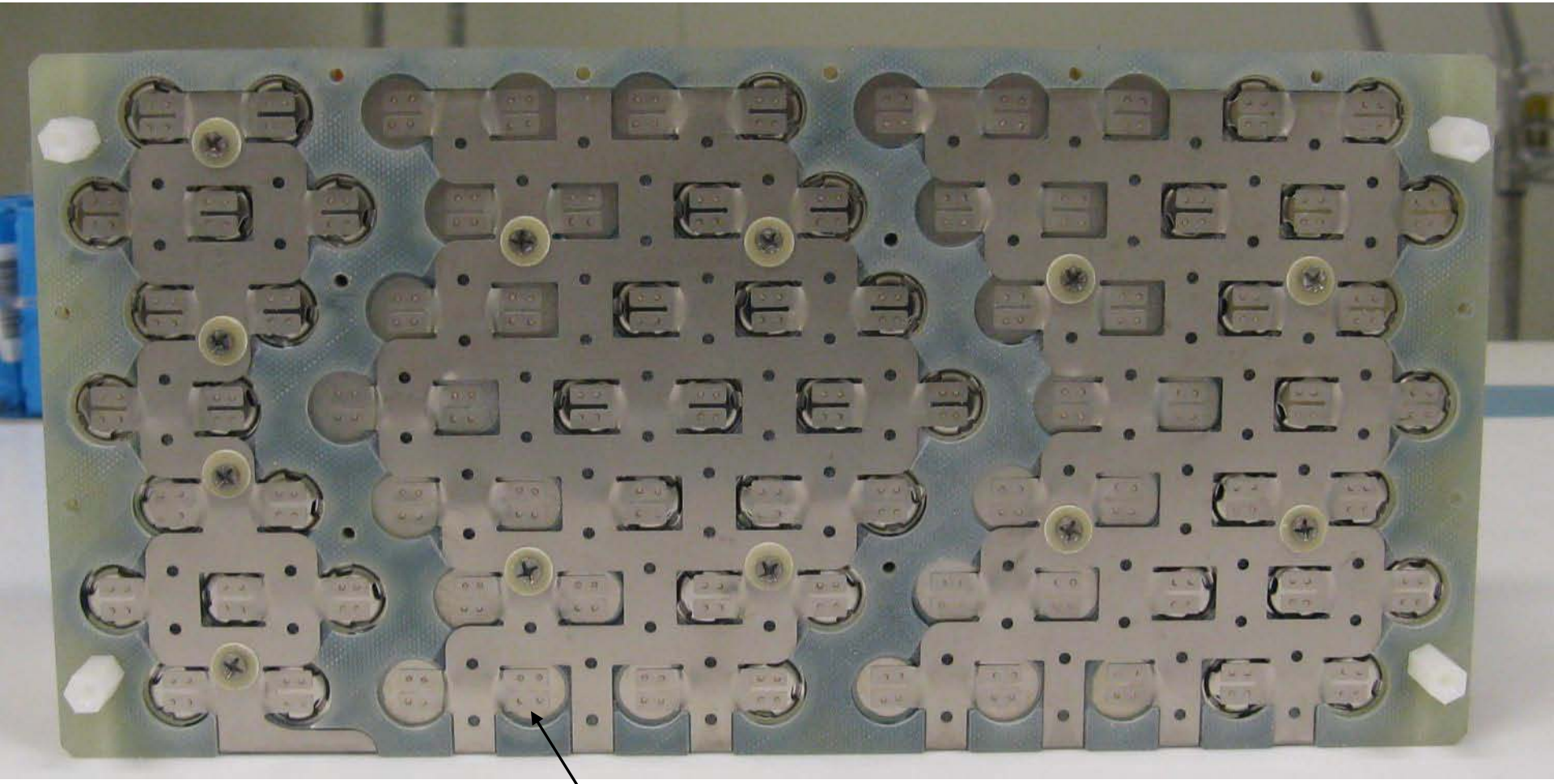
Post Welding



4 welds per cell anode or cathode

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Final Brick Assembly

Kapton® insulating wrap

Side panels

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Brick Acceptance Test

- Each brick undergoes post fabrication acceptance testing
  - Visual inspection
  - Mass measurement
  - Electrical isolation
  - Dimensions and housing fit check
  - Functional performance (OCV, 9A pulse at 30% SOC)
  - 4 vacuum cycles and 3 day +35°C vacuum dwell
  - 5 thermal cycles (-14°C to +45°C)
  - Individual bank capacity measurements
    - 1st cycle: 19.2A (C/2) charge to 4.2V with 9.6A (C/4) discharge to 3.0V
    - 2nd cycle: 5A charge to 4.12V with 3.8A discharge to 3.2V (mission conditions)
  - Repeat functional, mass, and visual exam
- No mechanical or performance issues with any bricks
  - Bank capacities 34.8Ah to 35.3Ah for JN cells and 31.0Ah to 31.3Ah for LV cells under mission conditions

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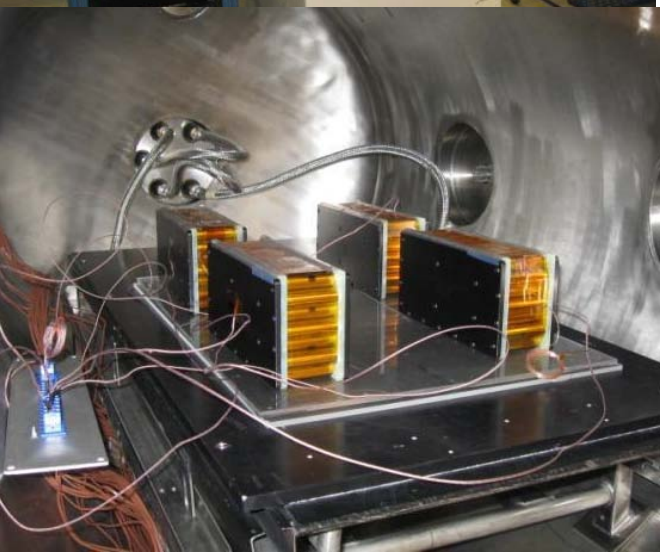
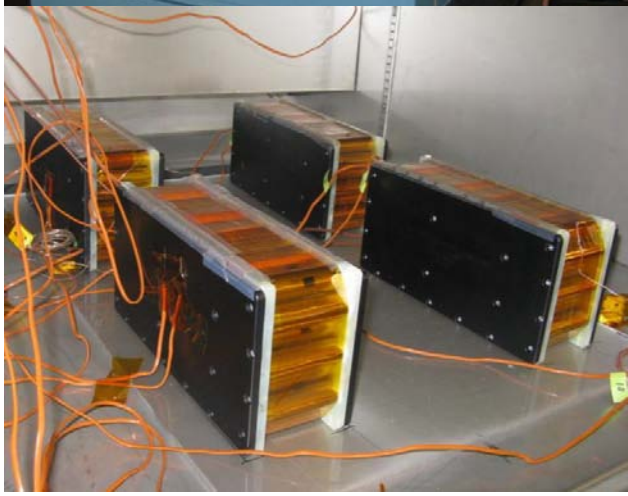
Bricks Acceptance Testing

Vacuum cycling and heated vacuum dwell

Ambient pressure thermal cycling



Bank capacity testing with Maccor 4000 cycler



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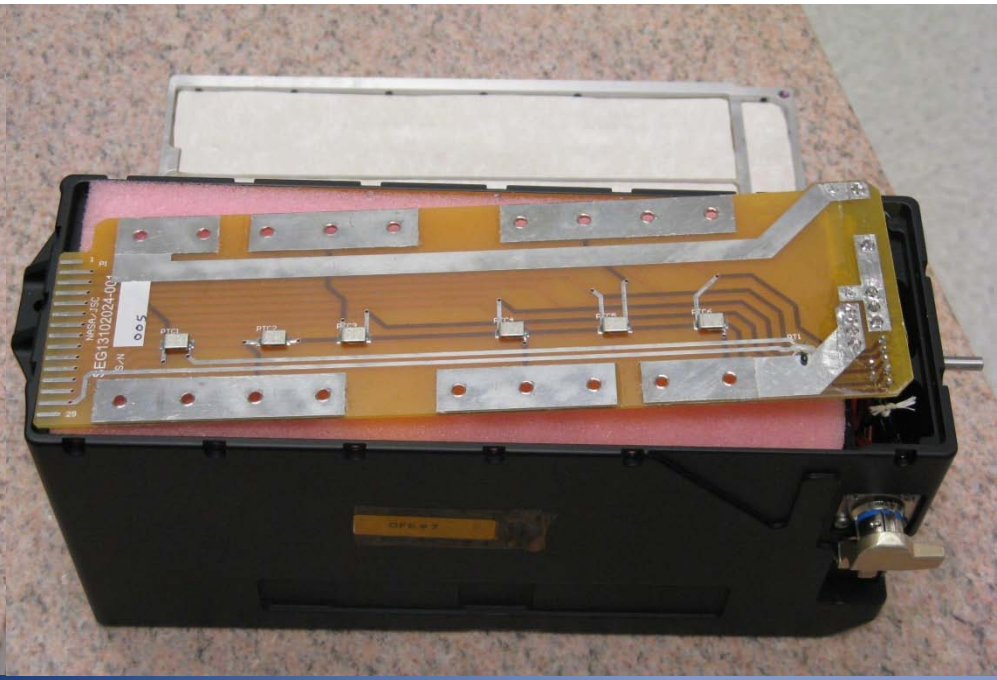
LLB Assembly

- Following successful completion of brick acceptance testing, 4 bricks of each cell type were integrated into NASA's GFE housing kits
  - Housing kit includes mechanical housing, PCB board with bank level PTCs, in-line fuse, thermistor, and wiring into two connectors



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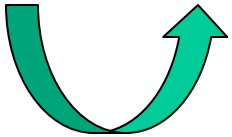
LLB Assembly

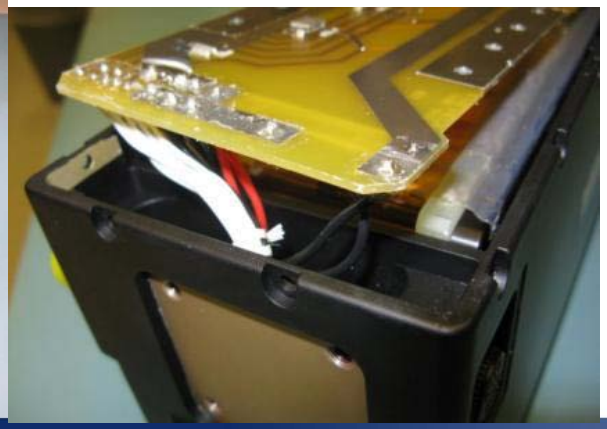
With brick upside down, housing inserted over the top and secured with fasteners into side panels

Completed assembly is weighed , QA inspected and 'bought off'



Lid installed and fastened to housing

PCB aligned and fastened to brick terminals with fasteners into capture plates



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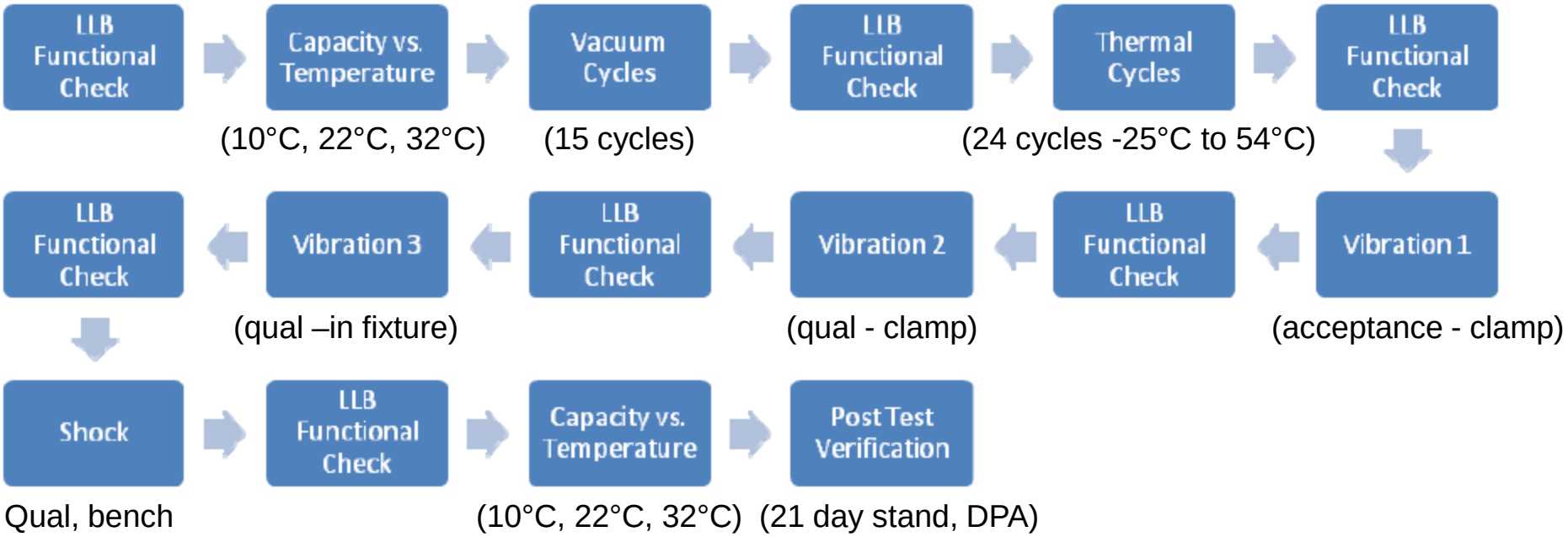
Environmental Tests

- One LLB of each cell type exercised through extensive environmental campaign



- Both LLB survived with no mechanical issues, no evidence of vibration or shock induced degradations, and only mild (<2%) capacity fade)

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Pre/Post Performance

Temp.	006703 0002 (JN) Pre (Ah)	Post (Ah)	Delta (Ah)	Delta (%)	006803 0001 (LV) Pre (Ah)	Post (Ah)	Delta (Ah)	Delta (%)
10C	34.04	33.59	-0.45	-1.3%	30.43	29.95	-0.48	-1.6%
22C	34.30	33.86	-0.44	-1.3%	30.47	30.06	-0.41	-1.3%
32C	34.49	34.13	-0.36	-1.0%	30.54	30.26	-0.28	-0.9%

Vibration Testing Functional Checks					
PN, SN	When Completed	OCV (V)	CCV (V)	AC Imp* (mΩ)	Result
6803, 0001	Pre Vibe	18.878	17.841	24.6	Pass
	Post Vibe 1	18.881	17.821	N/A	Pass
	Post Vibe 2	18.878	17.827	N/A	Pass
	Post Vibe 3	18.834	17.775	N/A	Pass
	Post Shock	18.830	17.779	23	Pass
6703, 0002	Pre Vibe	18.834	17.781	31.4	Pass
	Post Vibe 1	18.836	17.780	N/A	Pass
	Post Vibe 2	18.835	17.781	N/A	Pass
	Post Vibe 3	18.773	17.713	N/A	Pass
	Post Shock	18.771	17.718	30.06	Pass
*at brick terminals					

- DPA found all fasteners still at torque values, no signs of abrasion, or other discrepancies

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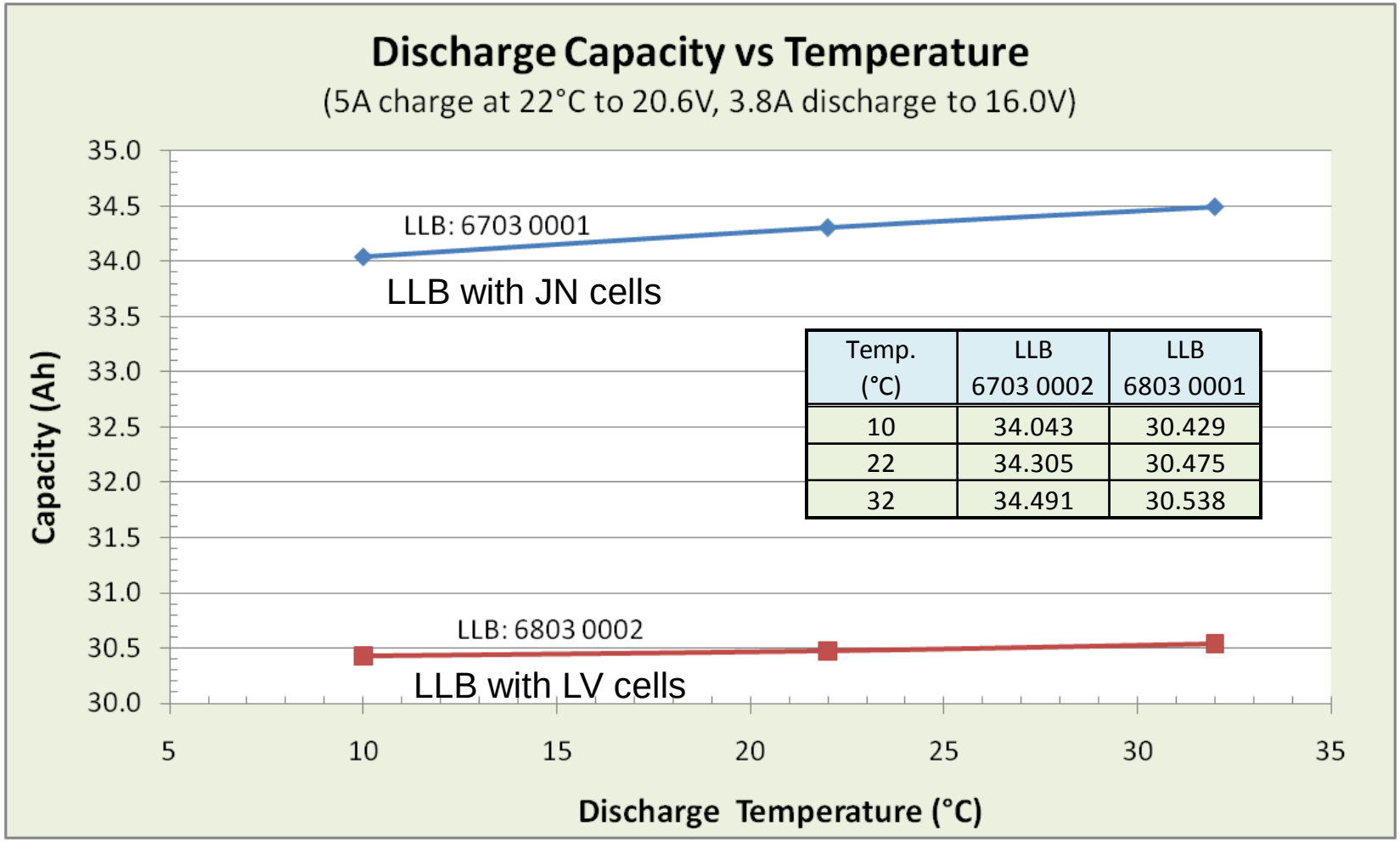
Capacity vs Temperature



Temp. (°C)	LLB 6703 0002	LLB 6803 0001
10	34.043	30.429
22	34.305	30.475
32	34.491	30.538

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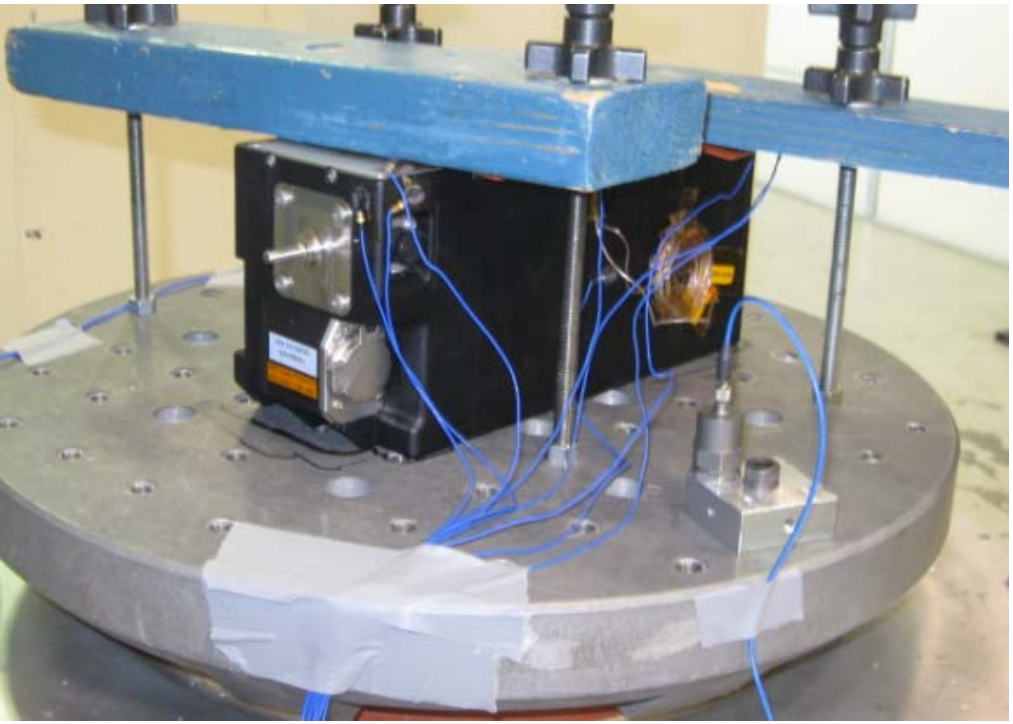
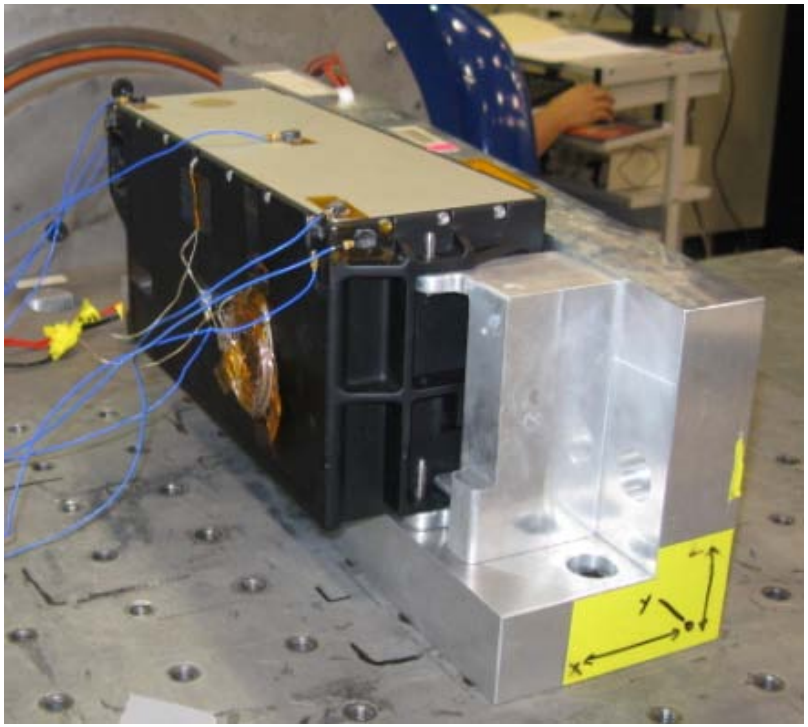
Vibration/Shock Testing



LLB in ‘clamped’ restraint for locker storage
Acceptance level: 7.43grms
Qualification level: 9.89grms



LLB in GFE fixture for shuttle stowage
Qualification level: 6.48grms

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Mission Simulation Testing

- One LLB of each cell type is undergoing a mission simulation test that combines thermal, vacuum, and electrochemical cycling to reproduce EVA conditions
  - Charge at 5A to 20.5V in ambient pressure
  - Discharge at 3.8A while in vacuum starting from +32°C
  - Charge at 5A to 20.5V in ambient pressure
  - Discharge at 3.8A while in vacuum starting from +14°C
  - Repeat for total of 100 cycles
    - To expedite test duration, full discharges only required every 10 cycles
- Testing being performed in ABSL's UK facility
  - Currently around cycle 80, expect to complete test in late December
  - No issues so far, just a very long test – started last June

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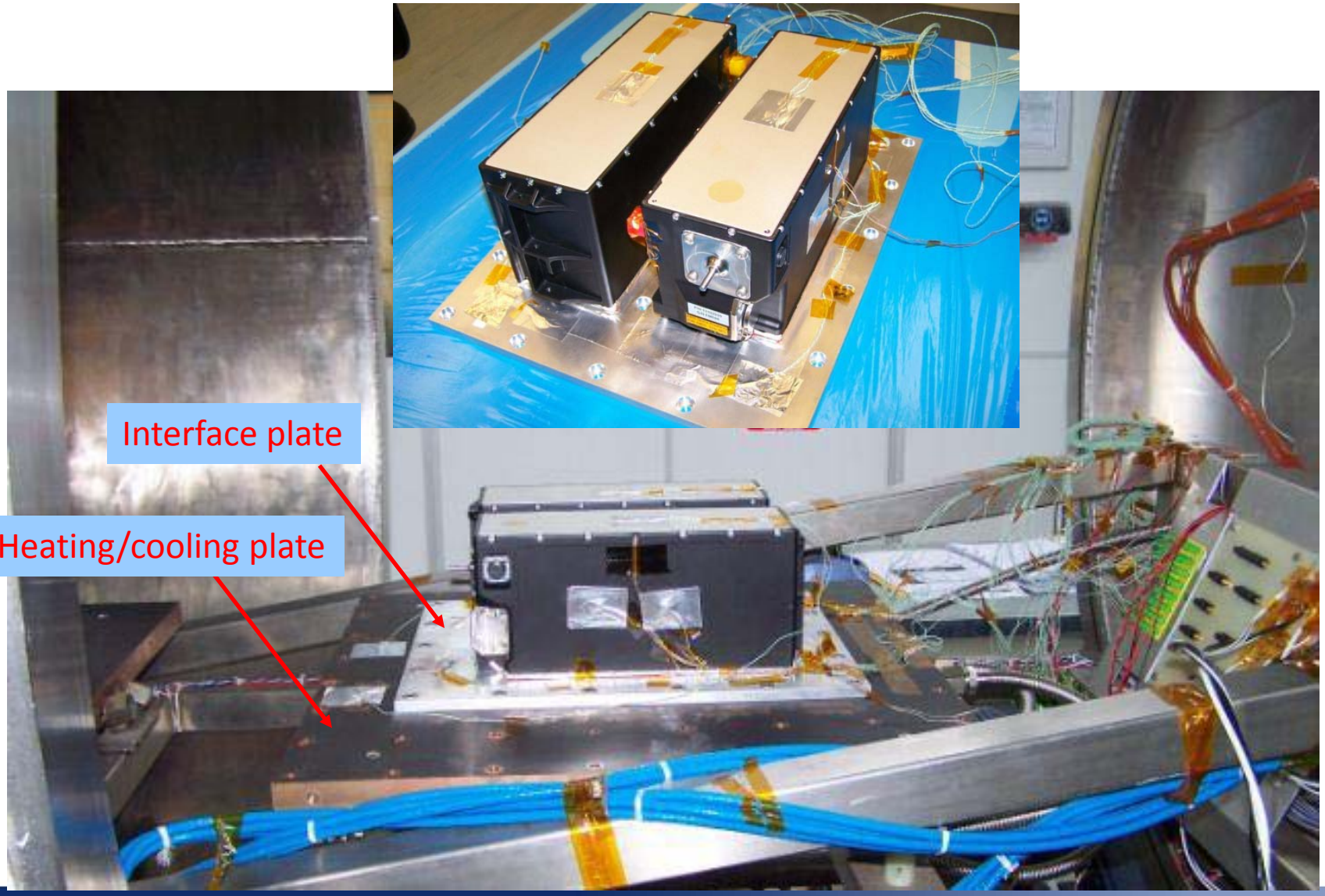
Test Set-Up



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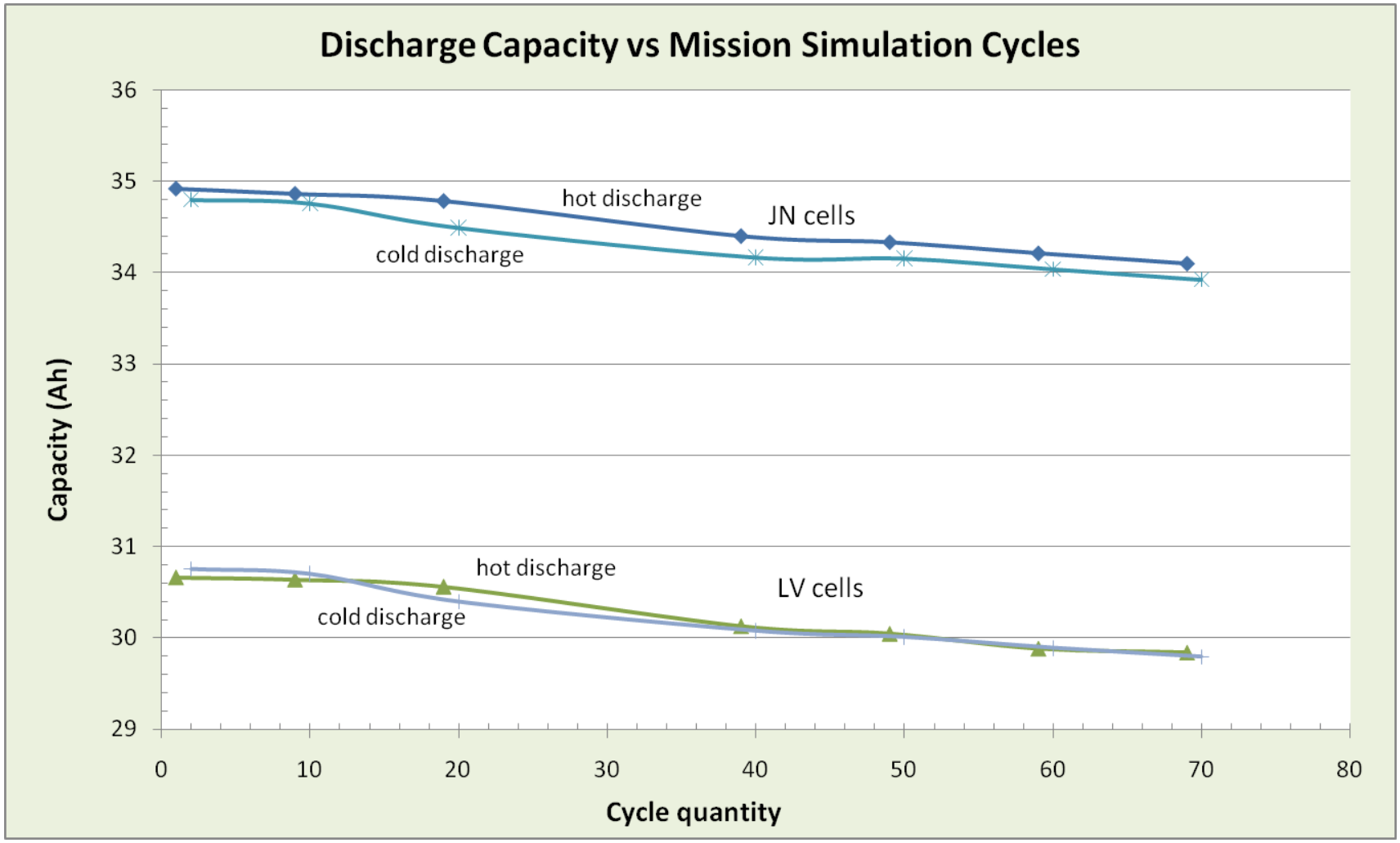
Mission Simulation Results



- Smooth graceful capacity fade observed so far

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Safety/Abuse Testing

- One LLB of each cell type underwent safety/abuse testing
  - Over-charge
    - With banks balanced, charge LLB at 1.55A to 21.9V for 48 hrs (cell banks at 4.38V on average)
    - With 1 bank charged to 4.2V and remaining 4 banks at 3V, LLB charged at 1.55A to 21.9V
  - Over-discharge
    - One bank resistively discharged to 0V then continued discharge in reverse by discharging remaining banks that were fully charged – results in approximately 100% SOC reversal
  - Short-circuit
    - 63mΩ short circuit with 1 bank – PTC un-activated case
    - 6.5mΩ short circuit across 1 bank – PTC activated case
- All safety/abuse tests resulted in benign degradation

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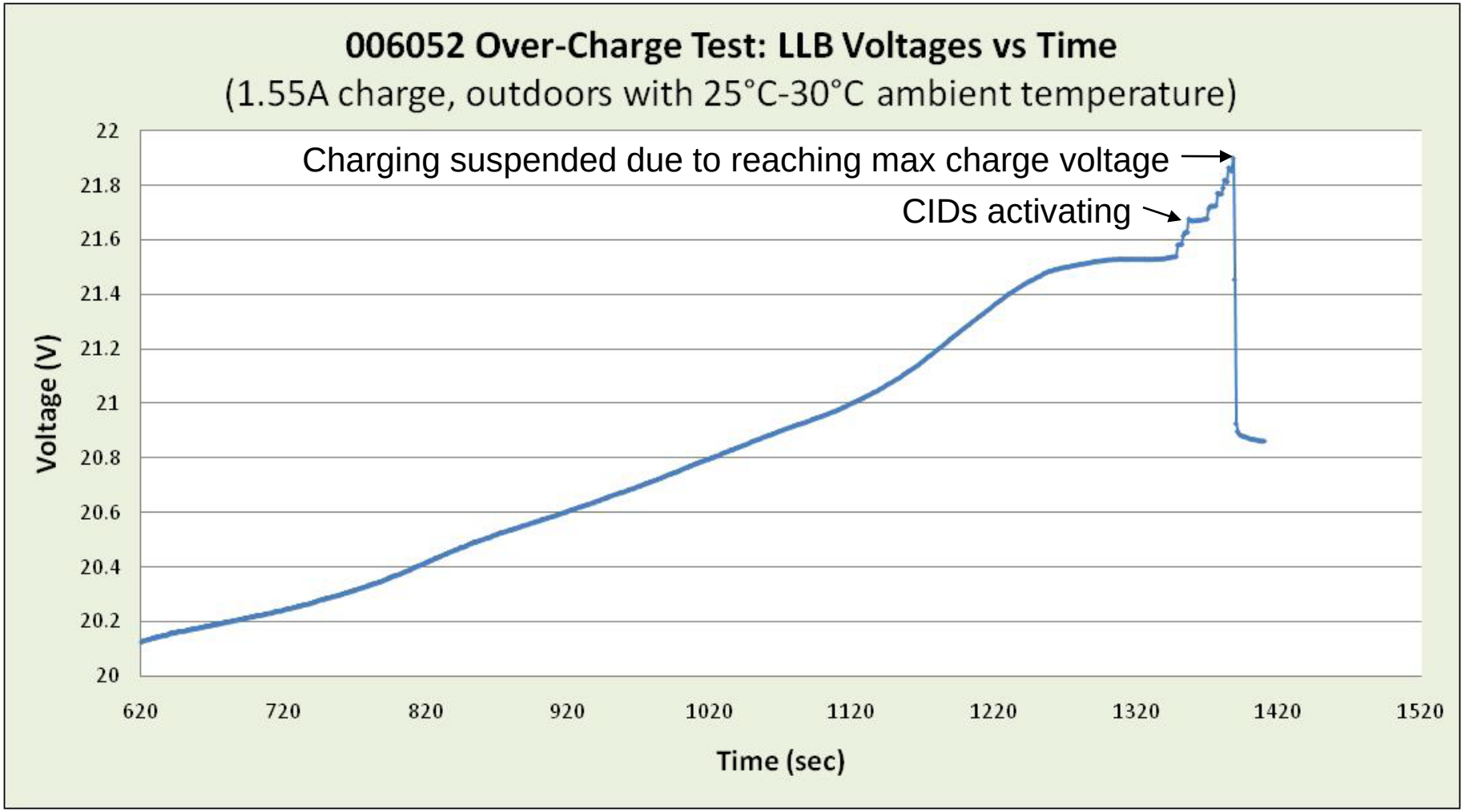
LLB Overcharge



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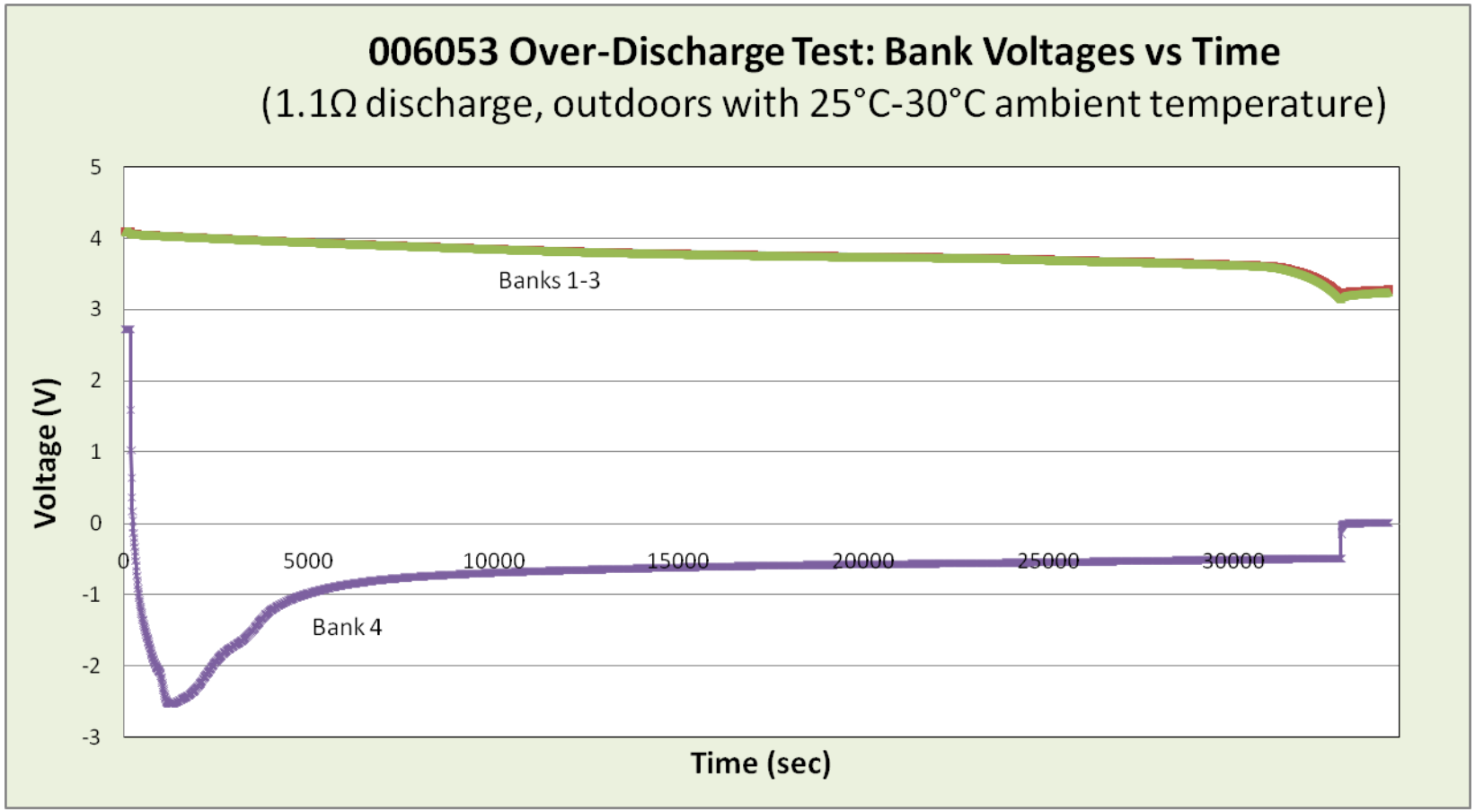
LLB Over Discharge



- Bank 4 was driven into reverse approximately 100% SOC
- No anomalous results were witnessed.

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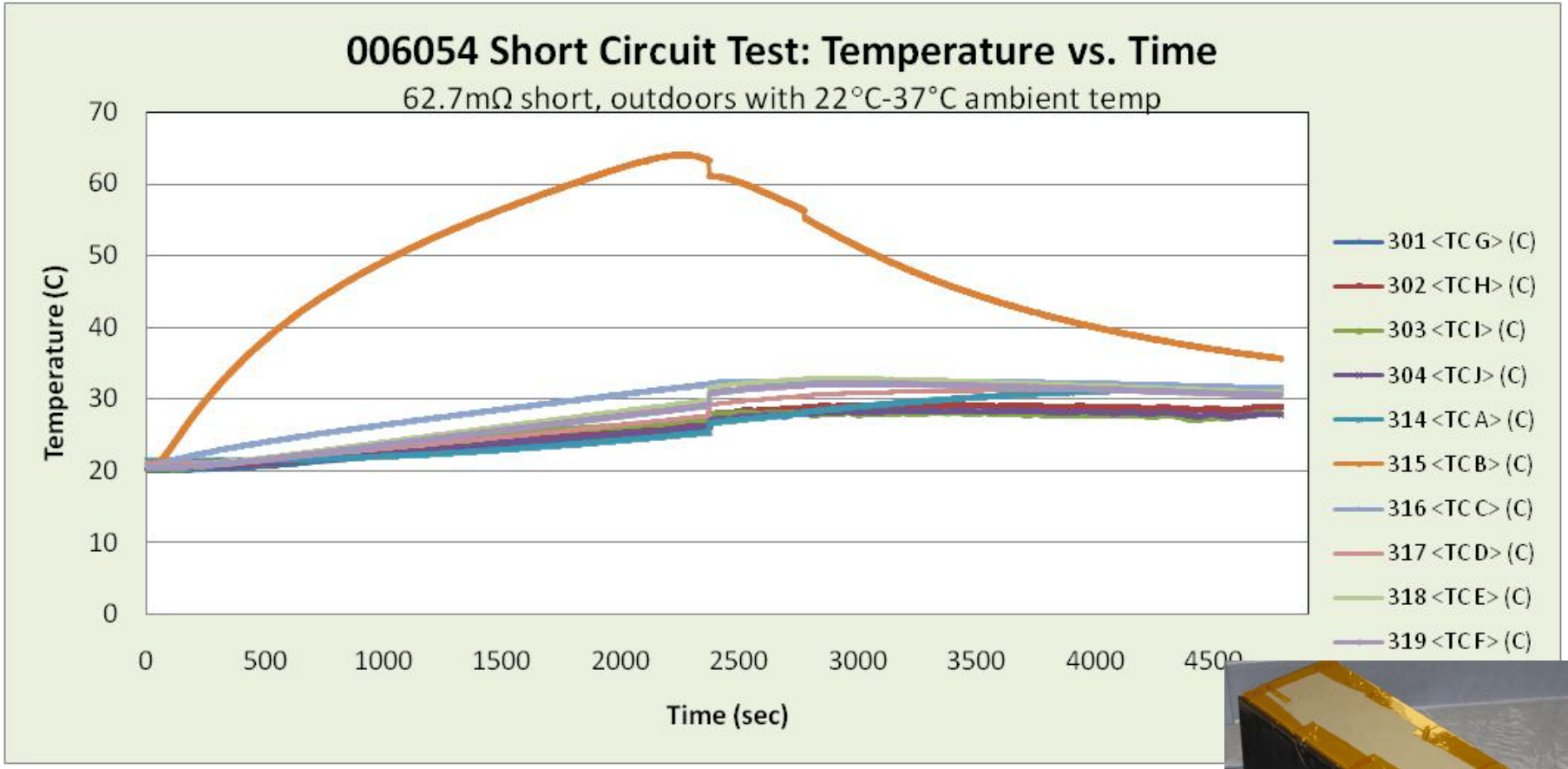
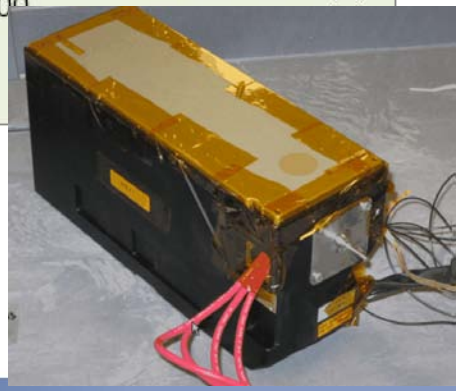
LLB Short Circuit Testing





- 61A in-rush current measured
- Maximum temperature: 63.96°C
- Throughout test, no smoke or venting observed

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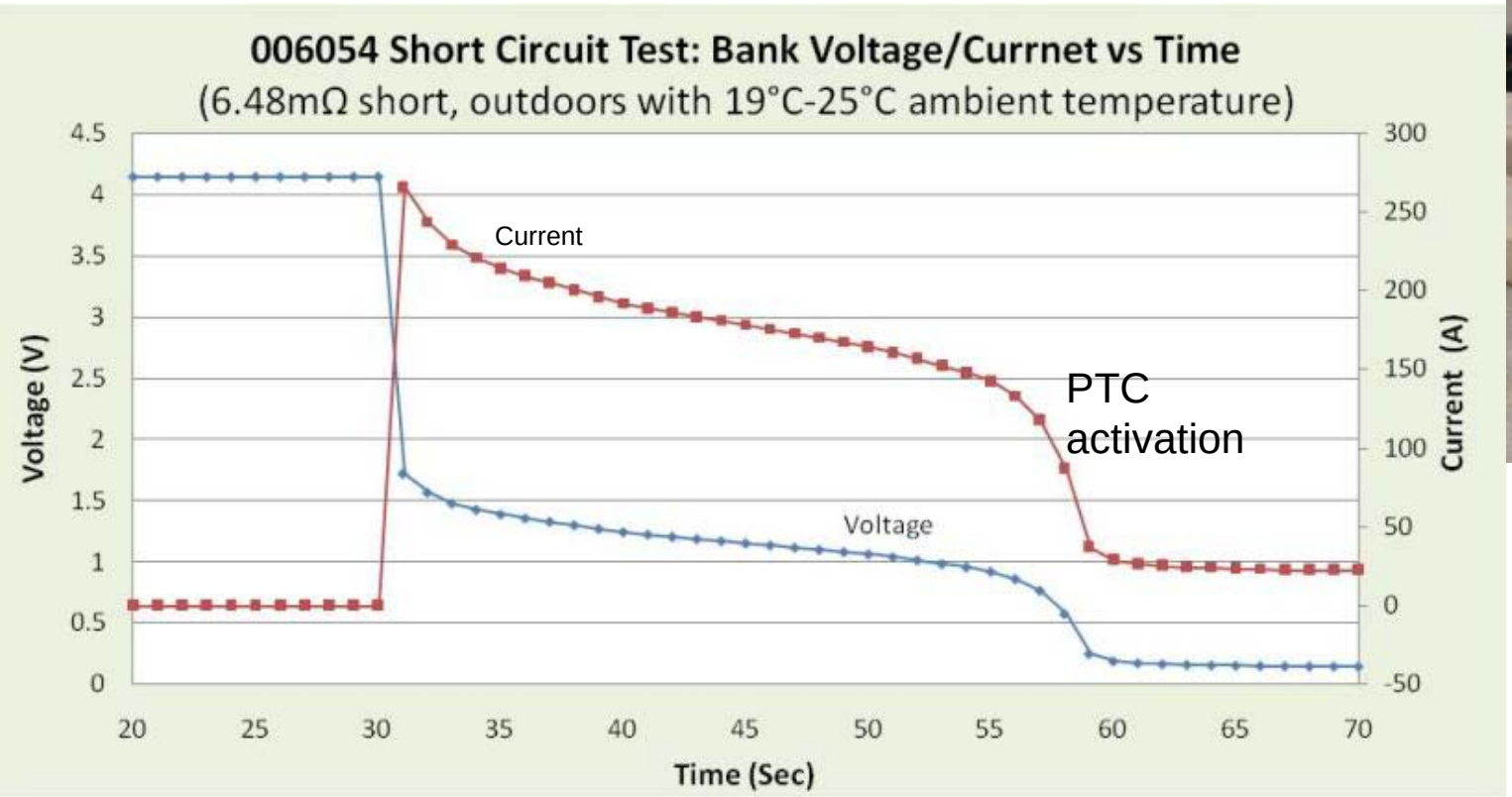
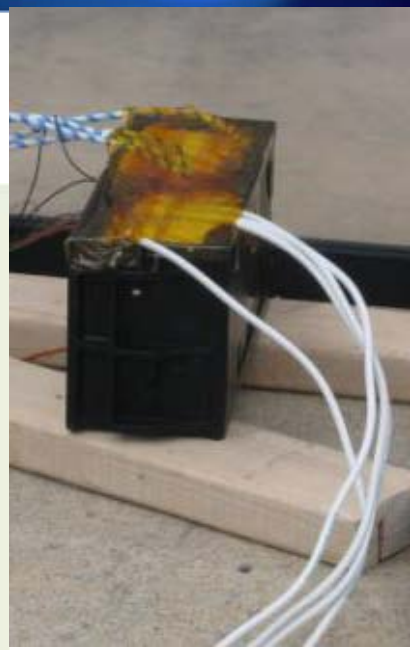
LLB Short Circuit Testing





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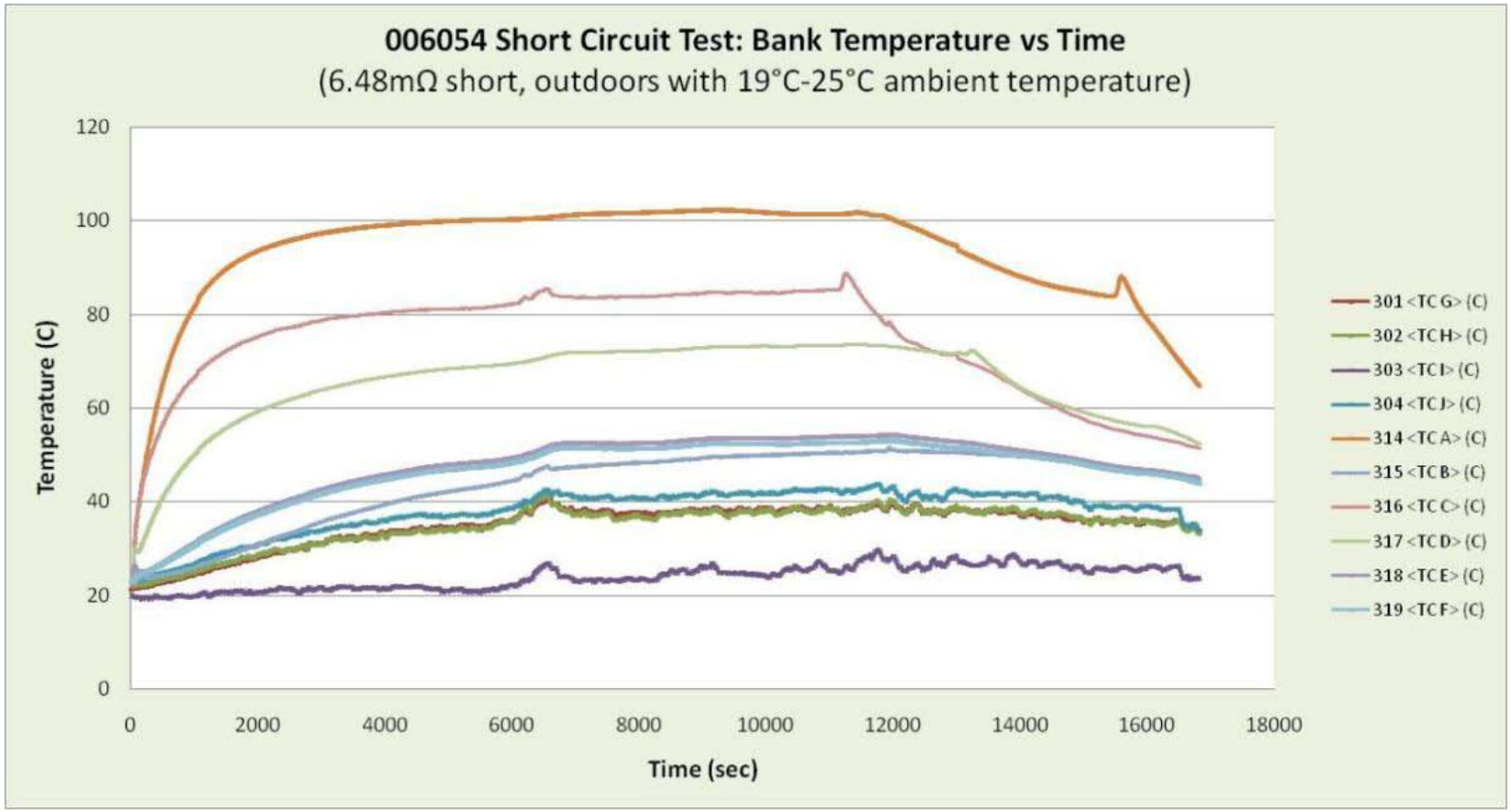
LLB Short Circuit Testing



- Maximum temperature: 102.3°C, measured on top of shorted bank
- Throughout test, no smoke or venting observed

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Present and Near Term Activity

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- NASA has now down-selected to JN cell
- Following review of engineering brick and LLB test data at CDR, authorized ABSL to proceed with Option 2 of EMU contract
  - Produce 35 flight bricks
  - Fabricate 3 LLBs with GFE housing kits
  - Conduct LLB acceptance testing
  - Perform formal qualification testing with 2 LLBs
- Flight bricks are now in full production with 8 bricks complete and 4 more in-work
  - Production rate is currently four bricks every 2 weeks
  - Acceptance test rate is four bricks every 4 weeks
- Preparing for LLB fabrication in early December following by acceptance testing and then qualification testing
- Anticipate near-term contract with Hamilton-Sundstrand for fabricating and acceptance testing additional LLBs for flight delivery
  - 4 LLBs scheduled to launch July 29 aboard shuttle Discovery to support ISS EVAs

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Acknowledgement

- Thanks to Sam Russell and Eric Darcy, NASA Johnson Space Center, for their excellent contract support and technical guidance

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