ABSL Performance Comparison

SONY 18650 Hard Carbon Cell and SONY 18650 Hard Carbon Mandrel Cell

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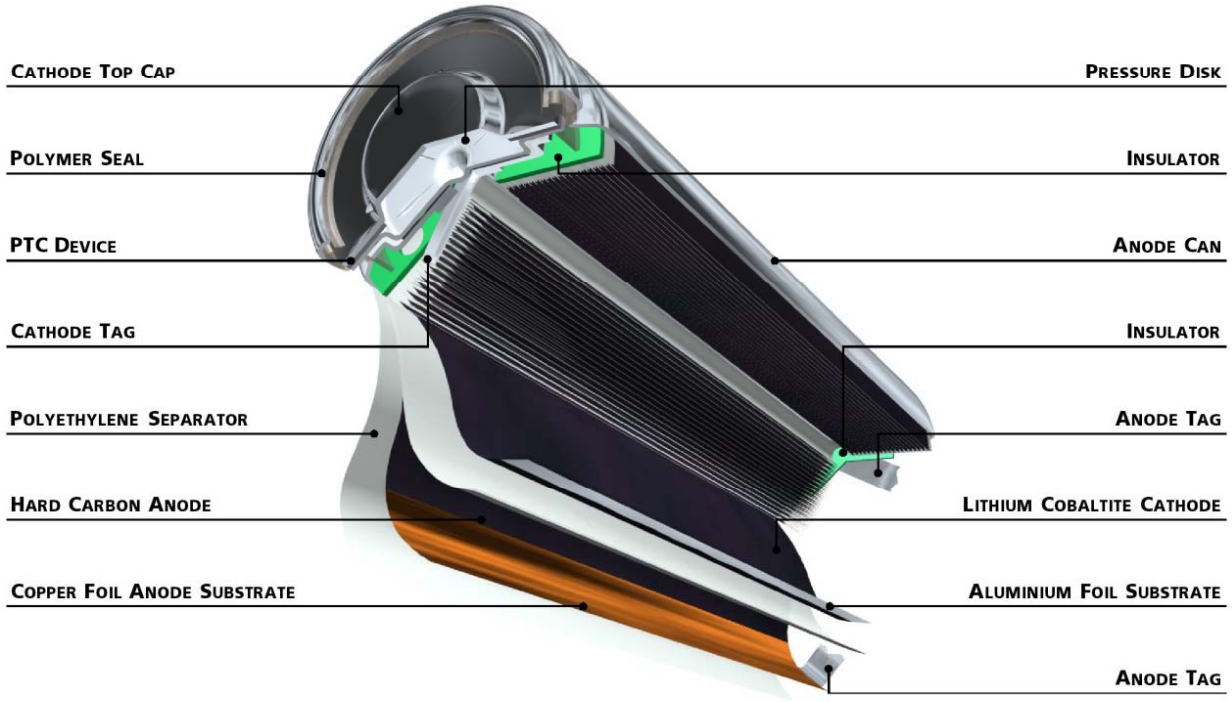
Overview

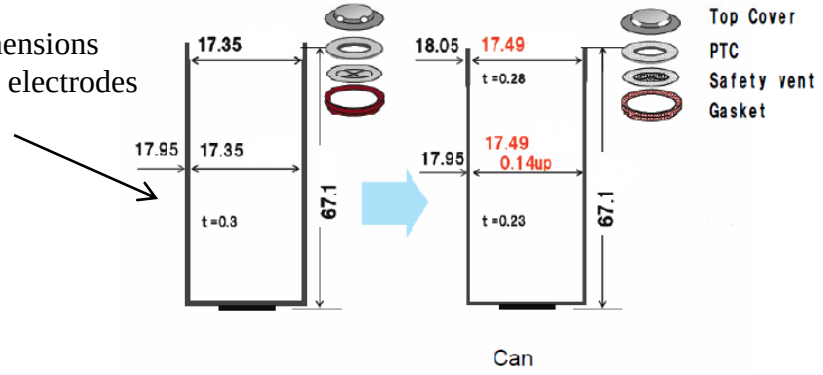
- ABSL Space Products extensively uses the Sony 18650 hard carbon cell within its battery designs.
  - 1.5Ah, 2.5V to 4.2V, rolled cylindrical design
  - Hard carbon anode with lithium cobaltite cathode

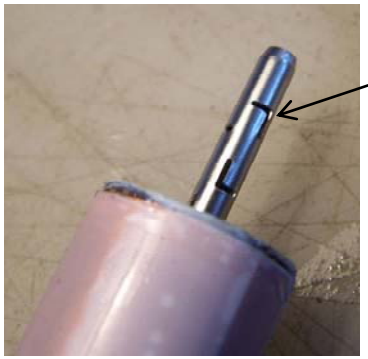


Design changes to 18650 Hard Carbon Cell

- Sony notified ABSL of design modifications necessary to the 18650 hard carbon cell.
  - Design modifications were a result of failure incidents regarding Japanese lithium ion cells in terrestrial applications such as laptops.
  - To improve design safety Sony implemented several changes to the basic design of the 18650 hard carbon cell
    - Improve vent path within cell to the safety vent
  - Identical voltage and capacity characteristics between cells

•Cell can construction
•Top cap component dimensions
•Width of cathode/anode electrodes
•Length of foils





•Mandrel

Performance of Hard Carbon Mandrel

- Question: Does the modified hard carbon cell perform similar or identical to the standard hard carbon cell?
- If not, what is different and why?
  - Identical materials
  - Identical chemistry
  - Identical safety features
  - Identical manufacturing process/procedures
  - Change in dimensions/size
  - Addition of the mandrel component

Testing Status

- Extensive testing has been performed as part of the overall cell qualification process to characterize the hard carbon mandrel cell and to identify any performance differences to the hard carbon cell.
  - All critical performance criteria has been tested an determined to be acceptable for space applications
    - Critical parameter performance similar or better than the previous hard carbon cell.
  - Further cell characterization testing beyond that required for cell qualification is on-going
    - Expanded vibration testing to determine extreme limits of the cell design
    - Life testing performed with varying operational parameters

Endurance Testing

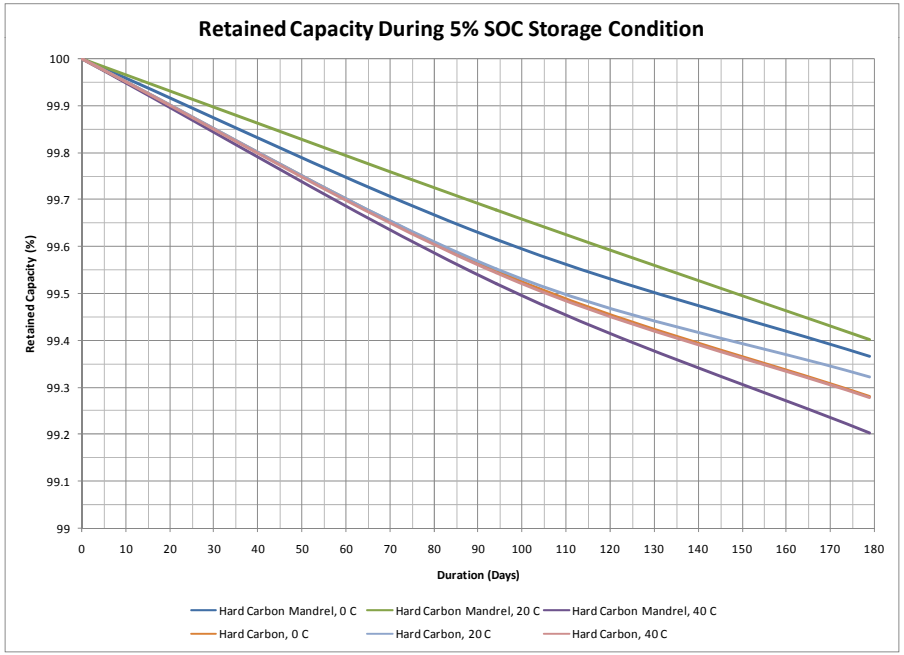
Storage and Life Cycling

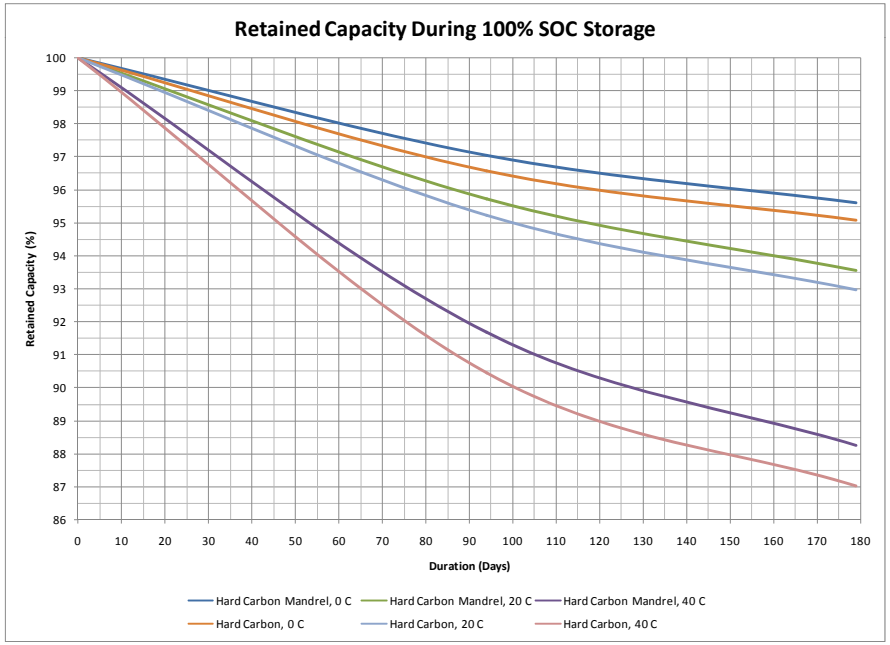
Modified Hard Carbon Cell Performance Testing

- Endurance Testing: Storage
- Capacity degradation during storage is dependent upon 3 major factors:
  - Temperature environment of the stored cells
  - Capacity (state of charge) of the cells
  - Storage duration
- 18650 hard carbon mandrel cells were stored at various levels of SOC and also in several temperature environments
  - Temperatures and SOC levels identical to those used for 18650 hard carbon cell storage tests
- Testing period of 179 days analyzed for hard carbon mandrel to hard carbon cell performance comparison.
  - 4 cells stored at each SOC condition and their average capacity retained is plotted.
  - All cells tested are from the same cell batch

Modified Hard Carbon Cell Performance Testing

- Retained Capacity is a function of SOC, duration, and temperature
- Typical hard carbon performance with minimal capacity degradation at low temperatures / low SOC levels and increased capacity degradation at high temperatures / high SOC levels.
- Overall the Hard Carbon Mandrel cells show slightly better storage performance



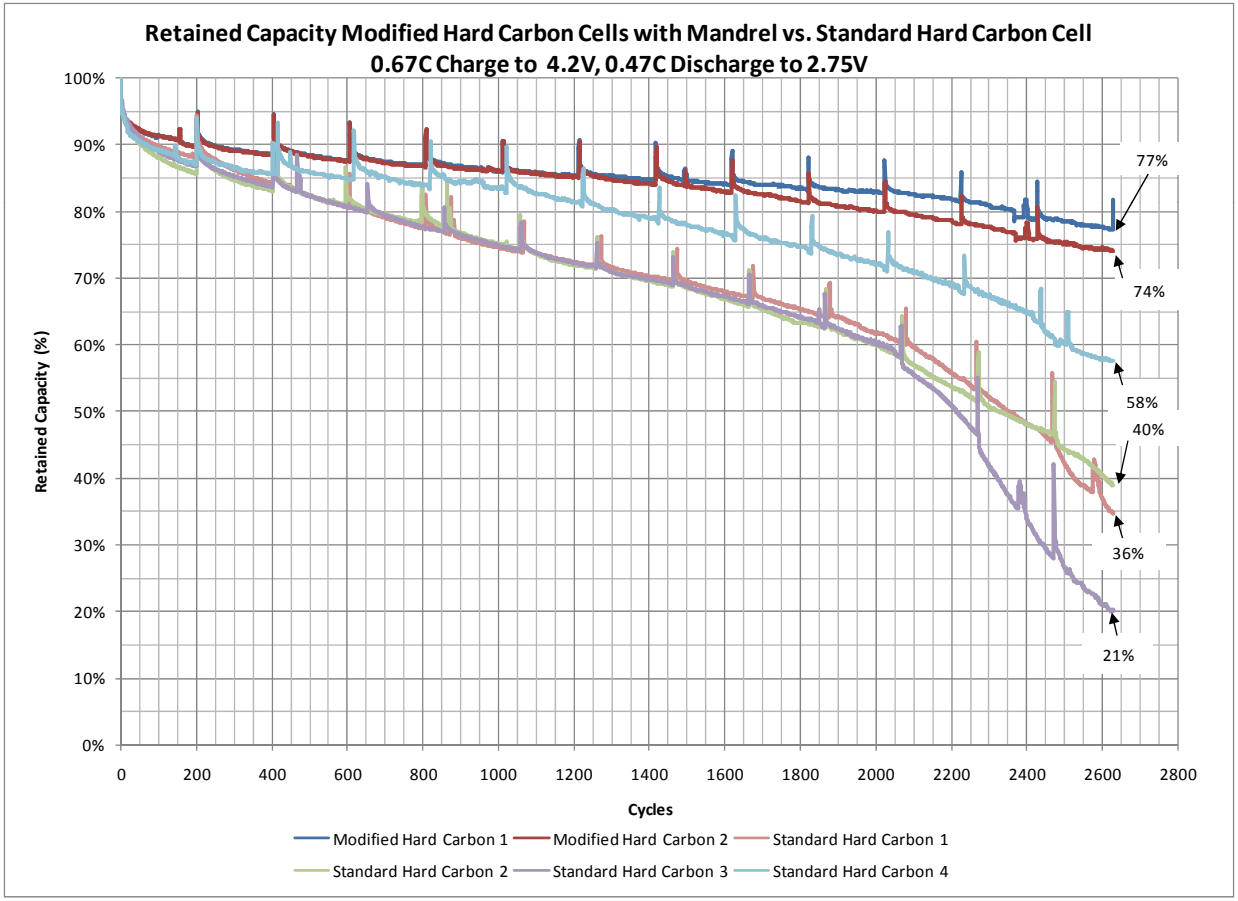


Modified Hard Carbon Cell Performance Testing

- Endurance Testing: Life Cycle
- Life cycling endurance testing of the 18650 hard carbon mandrel cell is on-going
  - Approximately 2700 cycles performed to date by ABSL
    - Generic Cycling: ABSL testing performed at 20°C and discharge/charge profile of 0.47C discharge current to 2.75 and 0.66C charge current to 4.2V/cell
      - Roughly 90% DoD cycles
    - Standard Capacity Measurements every 200 cycles
      - C/10 discharge to 2.5V, C/10 charge to 4.2V
  - Testing is on-going at other organizations (Northrop Grumman)
  - NASA GSFC currently having 2 – 8S13P hard carbon mandrel cell modules built by ABSL for cycle life testing to be performed by CRANE.

Modified Hard Carbon Cell Performance Testing

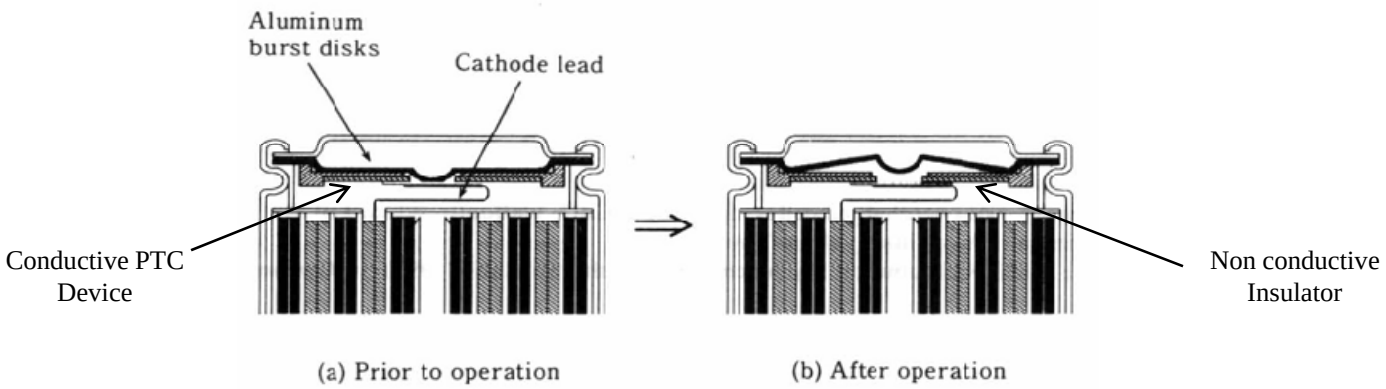
- Hard Carbon Mandrel cells show improved performance versus the hard carbon cells with retaining capacity over cycle life.
- Trend is expected to continue with increased cycle life



Safety Device Performance

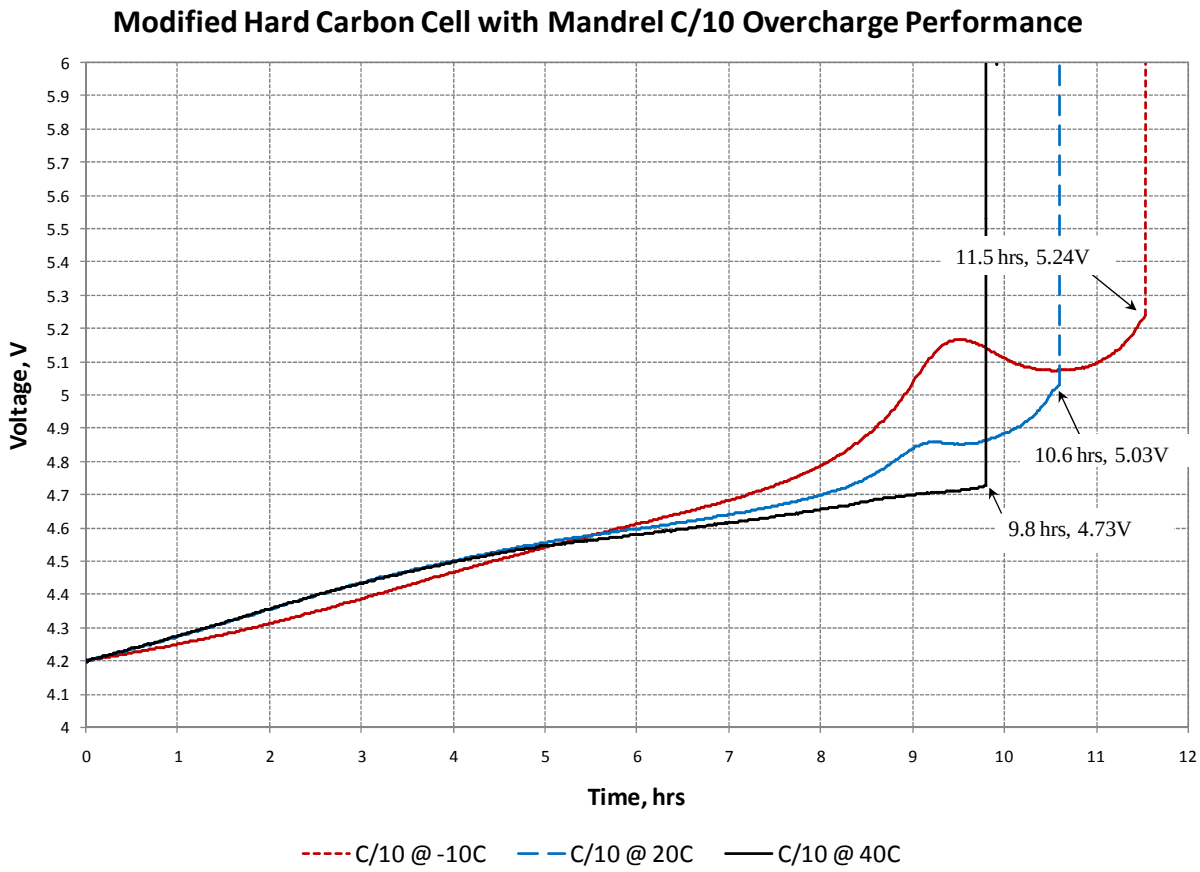
Modified Hard Carbon Cell Performance Testing

- Safety Testing: Overcharge
  - Cell incorporates Current Interrupt Device (CID) to protect against overcharge to an unsafe condition
  - CID operates based on pressure conditions of the cells.
    - Also, the pressure increases due to generation of gases cause by decomposition of lithium carbonate.
      - Li_2CO_3 decomposes above 4.7V with rapid pressure increases seen around 5.0V.
      - Testing results show a phase change (bump in voltage) at roughly the same time the pressure ramps up.
    - The CID will activate when a maximum pressure is reached (typically at 200% SOC)
    - CID activation results in a disconnect of current flow within the cell



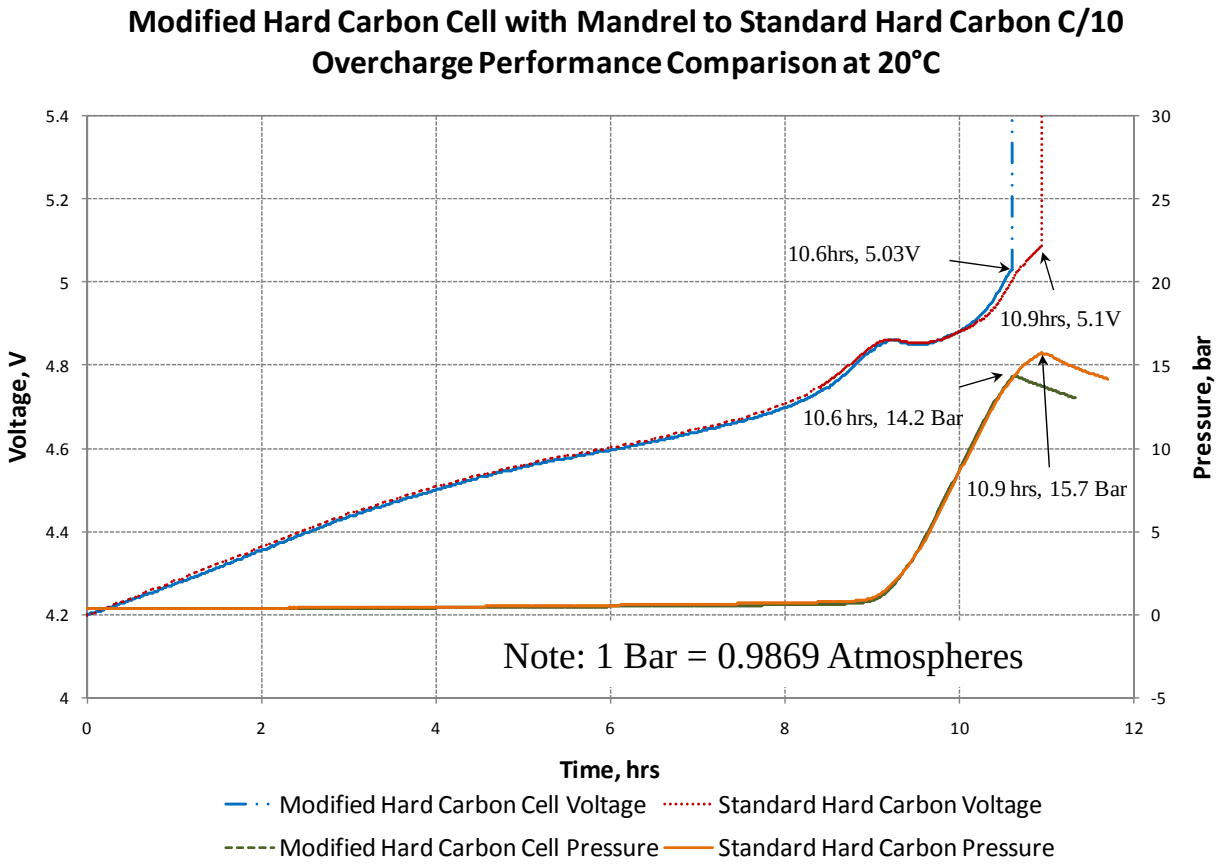
Modified Hard Carbon Cell Performance Testing

- Temperature effects on CID operation during C/10 charge
- Greater overcharge current results in shorter CID activation time.



Modified Hard Carbon Cell Performance Testing

- Modified Hard Carbon with Mandrel cell CID operates very similar to the Hard Carbon cell.(10% delta in pressure, 3% delta in activation time, and 1% delta in activation voltage)
  - Same C/10 charge current applied

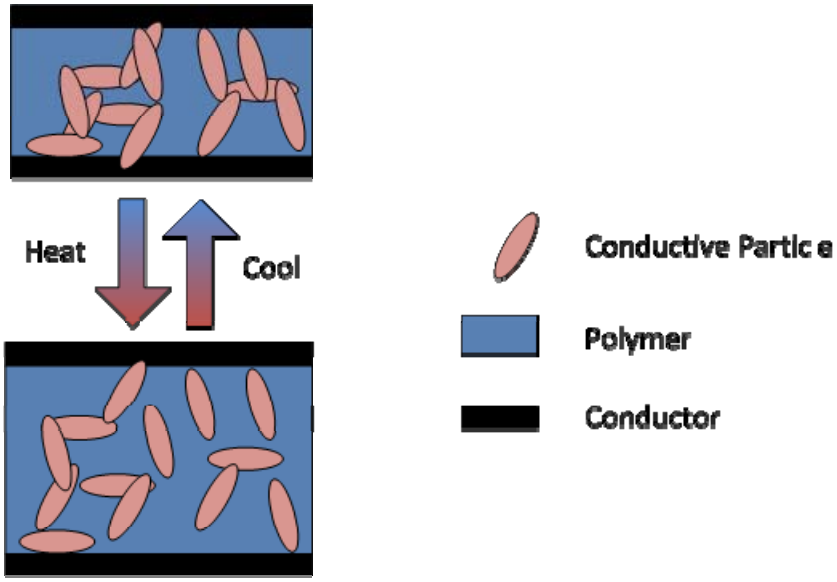


Modified Hard Carbon Cell Performance Testing

- Safety Testing: Over-current (short circuit)
  - Cell incorporates Positive Temperature Coefficient (PTC) Safety Device to protect against short circuit conditions external to the cell.
    - Excessively high discharge currents greater than capability of the cell under safe operating conditions
  - PTC operates based on a temperature caused by extremely high discharge currents.
    - As a short is applied on the cell, the discharge current level increases and the temperature of the PTC device rises.
    - As the PTC heats up its resistance increases thereby decreasing the discharge current
  - PTC returns to a resistance value close to its pre-activation resistance following the removal of the short circuit condition

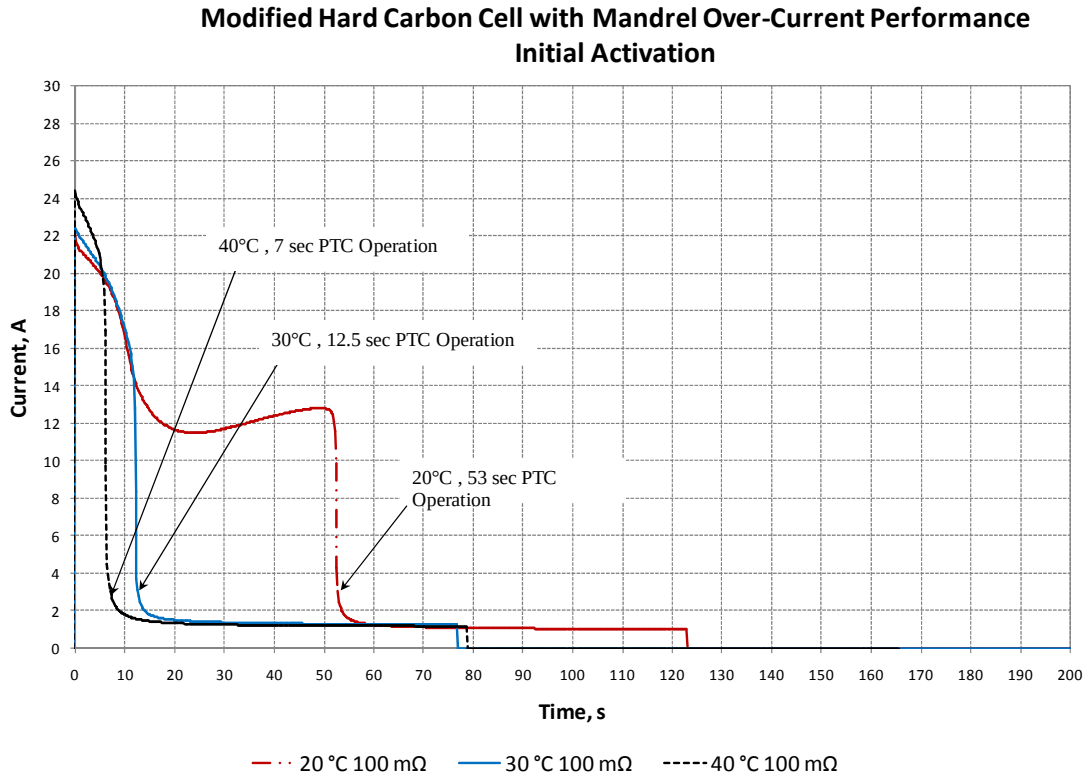
Modified Hard Carbon Cell Performance Testing

- **Safety Testing: Over-current PTC operation**
  - The PTC is a semi-crystalline polymer impregnated with conductive particles.
  - A high currents heats the PTC causing the polymer to expand as the crystalline phase melts.
  - As the polymer expands the conductive particles are separated resulting in a large increase in resistance of the PTC bringing the current under control



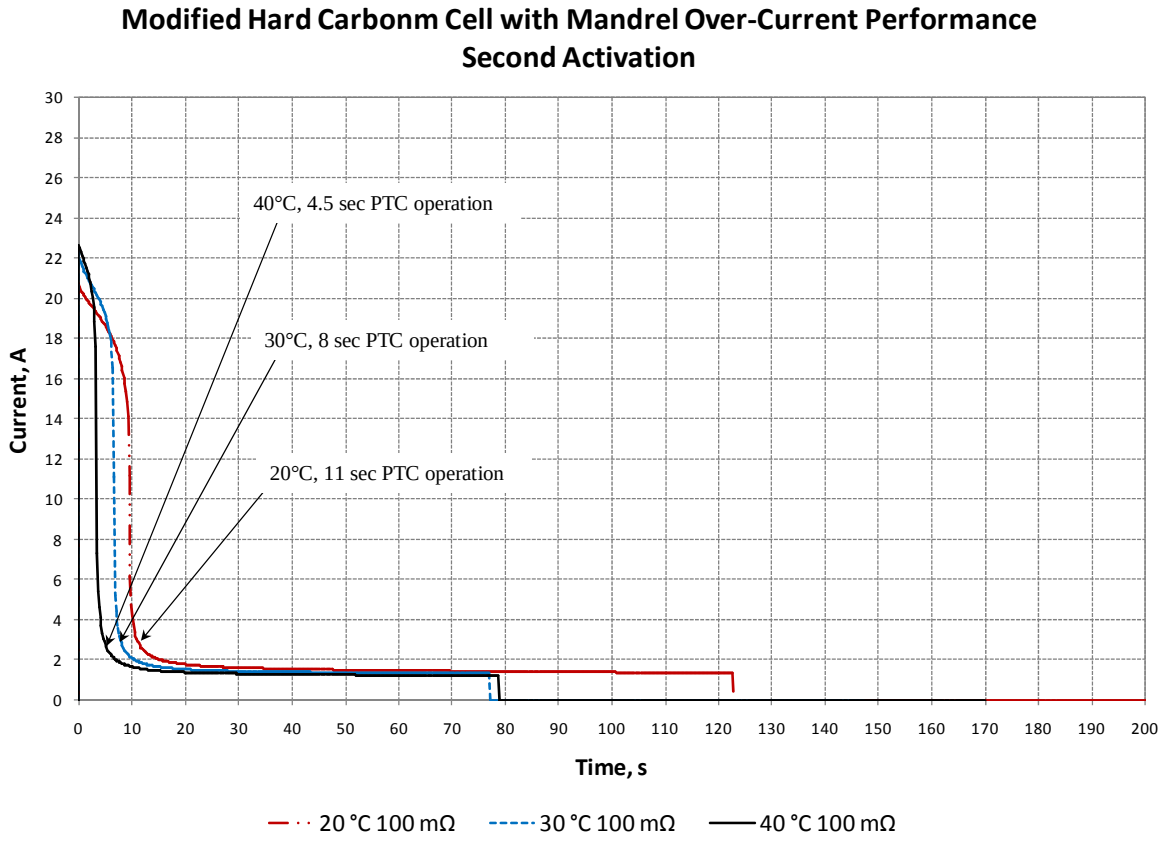
Modified Hard Carbon Cell Performance Testing

- Temperature effects on PTC operation.
  - PTC has a lower resistance at colder temperatures
  - Lower resistance results in less heat generation and longer PTC activation times
  - 53 second time period required prior to PTC activation under 100mΩ load.
    - With load continued all venting, fire, or thermal runaway conditions controlled by the PTC



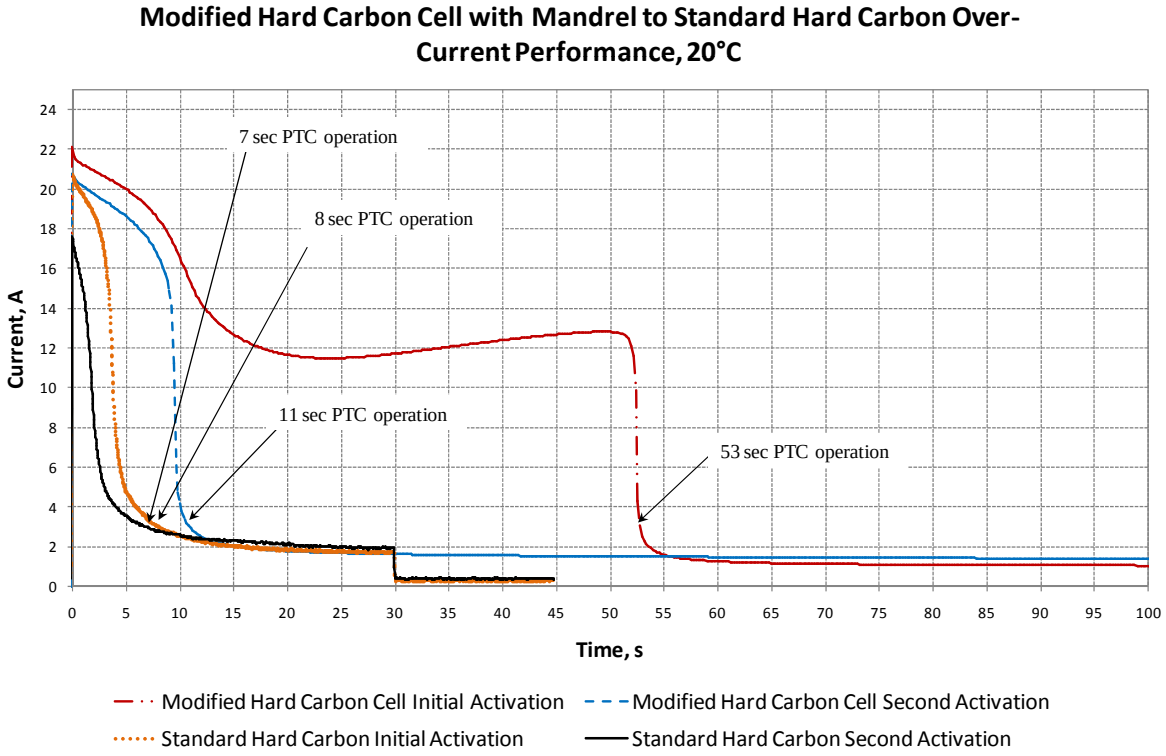
Modified Hard Carbon Cell Performance Testing

- Temperature effects on PTC operation during second PTC activation event.
  - PTC resistance is similar over the range of temperatures following initial activation.



Comparison of Modified Hard Carbon Cell and Standard Hard Carbon Cell

- Examining the 20C condition the modified hard carbon cell with mandrel PTC activation time is longer than the standard hard carbon cell due to an initial lower PTC resistance
- Hard carbon mandrel PTC resistance changed from 14mΩ to 20mΩ
- Hard carbon PTC resistance changed from 23mΩ to 38mΩ



Environmental Performance

Random Vibration Testing

Modified Hard Carbon Cell Performance Testing

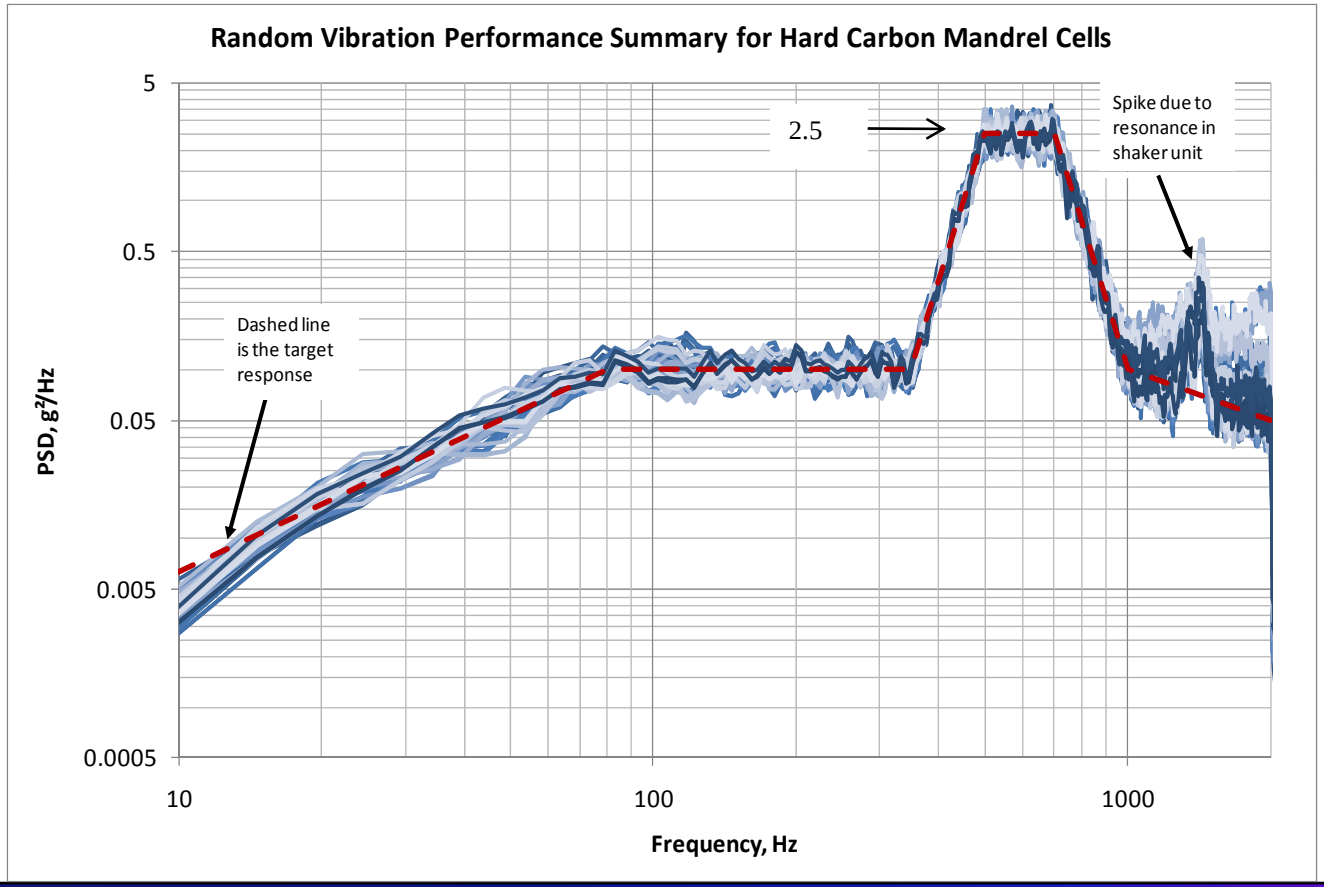
- The concern of the modified hard carbon cells with mandrel during environmental testing was the potential movement of the mandrel during a vibration event.
- The modified hard carbon cells were subjected to a random vibration environment consistent with that used during the nominal acceptance testing for the standard hard carbon cells.

Level	Frequency (Hz)	Notes
+4dB/oct	10 - 80	Total Acceleration: 30.4 g_{RMS} Duration: 240 seconds per axis
0.1 g^2/Hz	80 - 350	
2.5 g^2/Hz	500 - 700	
0.1 g^2/Hz	1000	
-3dB/oct	1000 - 2000	

- Random vibration testing results showed the response of the modified hard carbon cell with mandrel was well within acceptable limits of expected response levels.
- Destructive Physical Analysis (DPA) of the cells following test showed no signs the mandrel component had moved during the vibration testing.
  - No scraping on the center of the coil pack or impact markings on the anode or cathode tags.

Modified Hard Carbon Cell Performance Testing

- All modified hard carbon cells with mandrels tested showed performance results within expected response levels
  - Spike at 1280Hz is associated with the shaker unit and was measured during calibration runs with dummy load on the table.



Modified Hard Carbon Cell with Mandrel Summary

- The Modified Sony 18650 Hard Carbon Cell with Mandrel is currently demonstrating similar or improved performance over the Standard Sony 18650 Hard Carbon cell in key performance areas.
  - Hard Carbon cell test results remain relevant
- At this time there appears to be little to no technical risks to the space flight use of the Modified Sony 18650 Hard Carbon Cell with Mandrel.
  - ABSL will continue to examine the characteristics of the 18650 Hard Carbon Cell and the modified hard carbon cell with mandrel.
  - ABSL will be delivering its first Modified 18650 Hard Carbon Cell with Mandrel battery for spaceflight in the 2nd quarter of 2012.