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Lithium Cell Calorimetry for Safety Evaluation

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Navy's Lithium Battery Needs

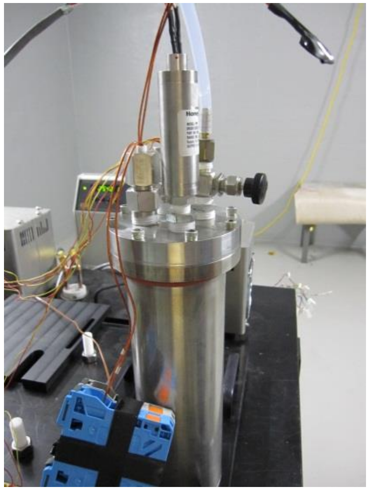
- Performance (Higher Energy Density):
  - Energy/Power needs driven by increasing mission and operational requirements and innovative technologies
  - Navy requirements ally unique to commercial industry
- Affordability (Development & Integration):
  - Battery system requires a rigid technical certification process
  - Safety evaluation costs and schedules are significant
- Safety (Warfighter Lives):
  - People, ships, and/or facilities at risk
  - Must consider host platform/vehicle
  - Requires high reliability and well characterized failure for mitigation development

Isothermal Calorimetry Evaluation

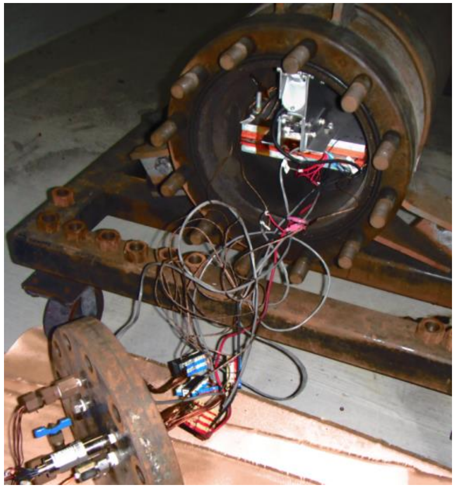
- Goal is develop a new process to obtain additional safety characterization for Lithium cells
  - Heat generation during a cell failure event
  - Data can be used to develop mitigation strategies, modeling efforts, and risk analysis
- Evaluate the feasibility of Isothermal Calorimetery for safety and abuse evaluations
  - Characterize a cell's heat generation during a failure event
  - Minimize testing requirements by capturing multiple parameters at one time
  - Compare results to standard testing processes
- Isothermal Calorimetry vs. Accelerated Rate Calorimeter (ARC)
  - ARC – sample is heated through a series of heat/weight steps to identify the thermal runaway point and monitor the heat generation through the event.
    - Sample item is usually bulk material and not a full cell and is cannot be under load
  - Isothermal Calorimetry – sample enclosure temperature is tightly controlled in order to monitor heat generation from the cell during operation
    - Believe that this processes allows for more realistic failure modes
    - Sample item can be full cell and item should be under load
- Efforts based on Navy Lithium Battery Safety Program
  - NAVSEA S9310-AQ-SAF-010, Technical Manual For Batteries, Navy Lithium Safety Program
    - Establishes safety guidelines for the selection, design, testing, evaluation, use, packaging, storage, transportation and disposal of lithium batteries for the Navy and Marine Corps

Testing Methodology

- Overcharge Abuse Test Comparison
  - Cells charged at nominal charge currents until an event.
  - Enclosures used to contain the event and resulting gases
  - Tests instrumented with temperature and pressure sensors
  - Calorimetry testing provides total thermal energy release
  - Identical samples tested in the standard method (Bullet Enclosure)
    - Bullet enclosure is a well defined test processes for abuse testing
    - Enclosures used to contain the event and resulting gases
    - All tests instrumented with temperature and pressure sensors
    - Same charging and monitoring processes as Calorimetry testing
- Calorimetry Test Setup Overview
  - Cell and placed in enclosure.
  - Cell enclosure placed in Aluminum fixture inside NSWC Crane patented calorimetry measurement chamber
  - System is placed in water bath that is maintained at set temperature
    - Water bath maintained at 25°C
    - Constant ambient temperature allows for accurate data collection of heat flow during charging and event.



Calorimetry Enclosure



Bullet Enclosure

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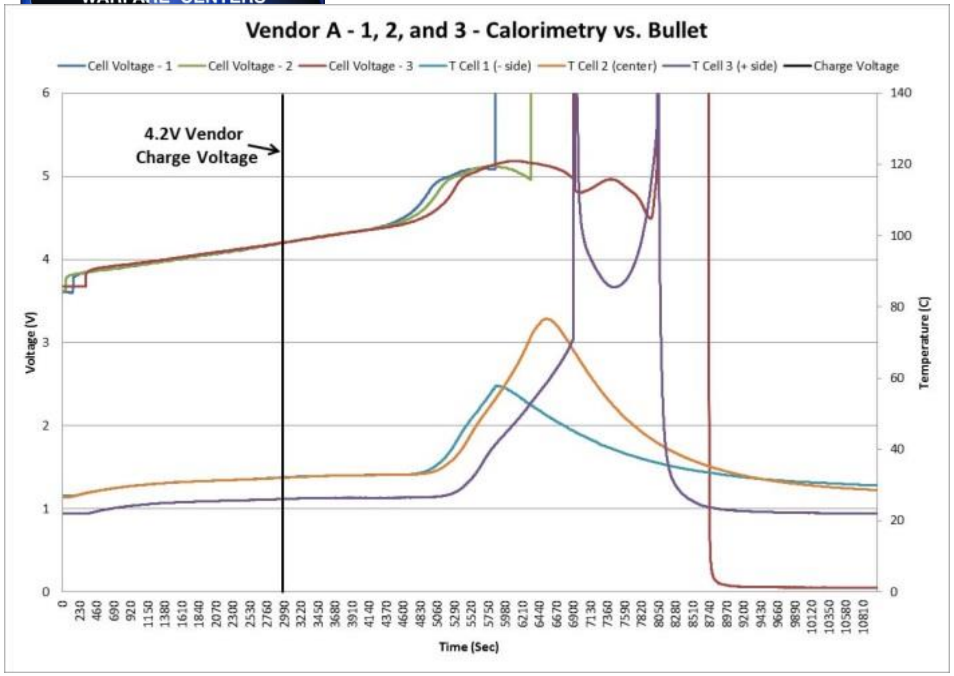
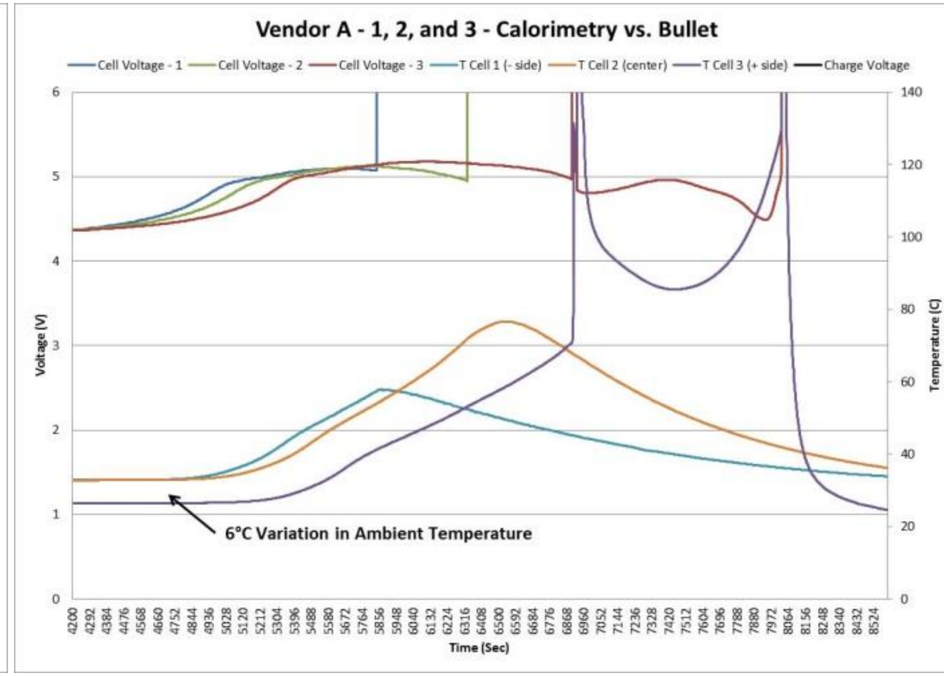
Samples

Testing conducted on commercially available cells

	Test	Charge Rate (Amps)	Cell Type	Cell Size	Capacity (AmpHrs)	Condition
Vendor A – 1	Calorimetry	1.6	Rechargeable: Lithium Ion	18650	3.2	New
Vendor A – 2	Calorimetry					
Vendor A – 3	Bullet					
Vendor B - 1	Calorimetry	5	Rechargeable: Lithium Iron Phosphate	26650	2.5	Aged
Vendor B - 2	Bullet					
Vendor C - 1	Calorimetry	2	Primary: Lithium Sulfuryl Chloride	D	15	New
Vendor C - 2	Bullet	2 (3)				

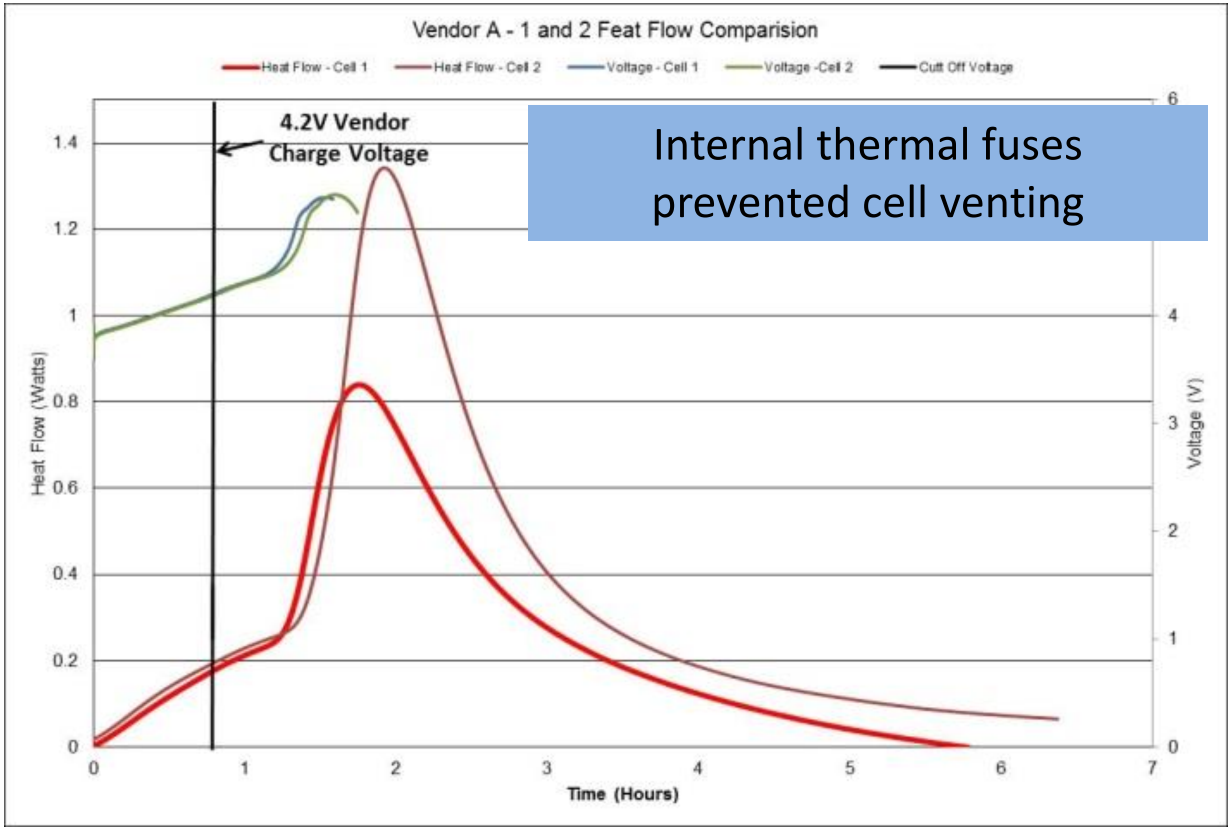
Vendor A – Rechargeable / 18650 (3.2AHr)





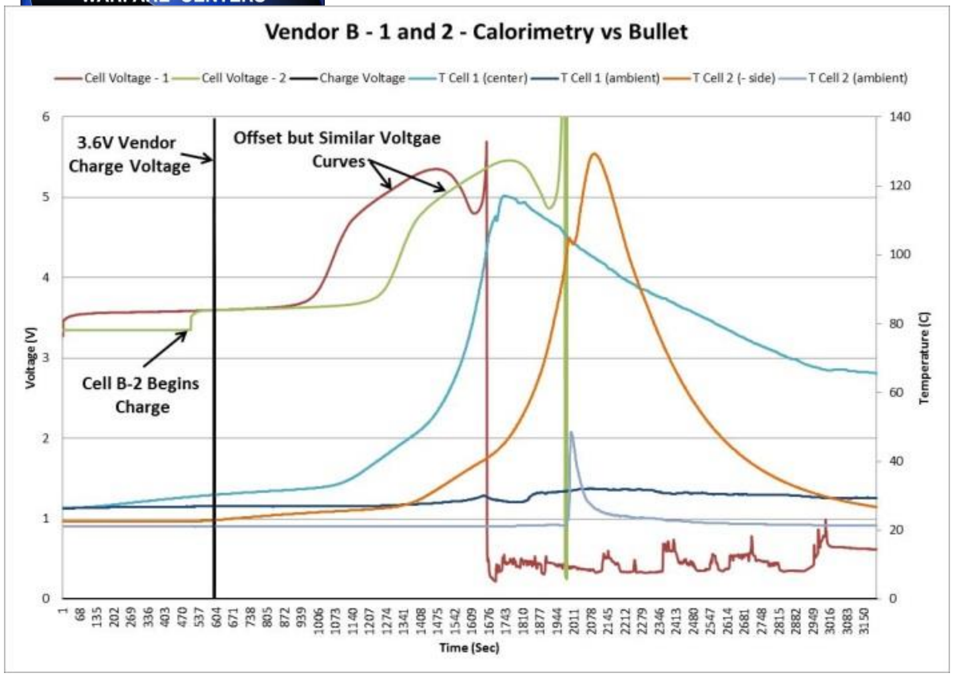
- Vendor A Observations (Calorimetry 2 Cells / Bullet 1 Cell)
  - Calorimetry tested cells did not vent due to internal thermal fuses
    - Fuses opened at different temperatures, 57.9°C and 76.6°C
    - Slight variation in overcharge voltage curves
  - Bullet tested cell did vent;
    - 6°C variation in ambient temperature
  - All test results show similar voltage, temperature, and heat flow trends
    - Suggests repeatable process that is similar to established processes

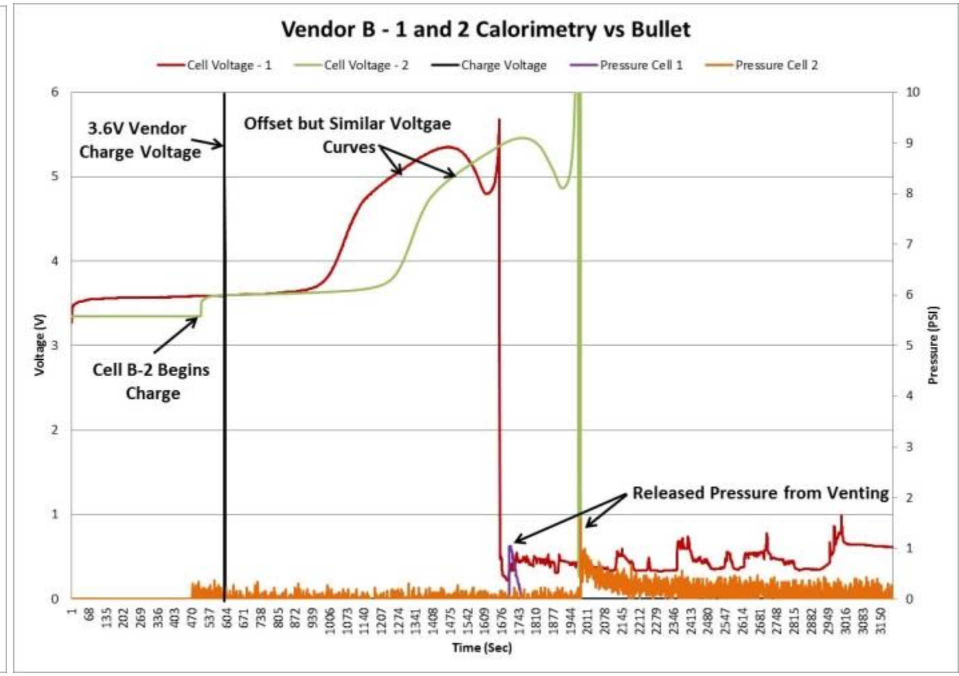
Vendor A – Rechargeable / 18650 (3.2AHr)



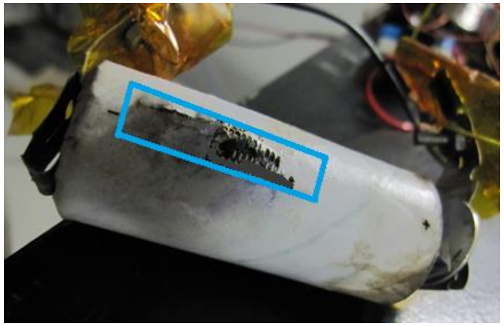
	Vendor A - 1 (Lithium Ion)	Vendor A - 2 (Lithium Ion)	Vendor A - 3 (Lithium Ion)
Peak Heat Flow	0.839 W	1.342 W	N/A
Raw Energy Released	5.087 kJ	7.609 kJ	N/A
Input Energy	39.114 kJ	43.811 kJ	N/A
Net Energy	-34.027 kJ	-36.202 kJ	N/A

Vendor B – Rechargeable / 26650 (2.5AHr)

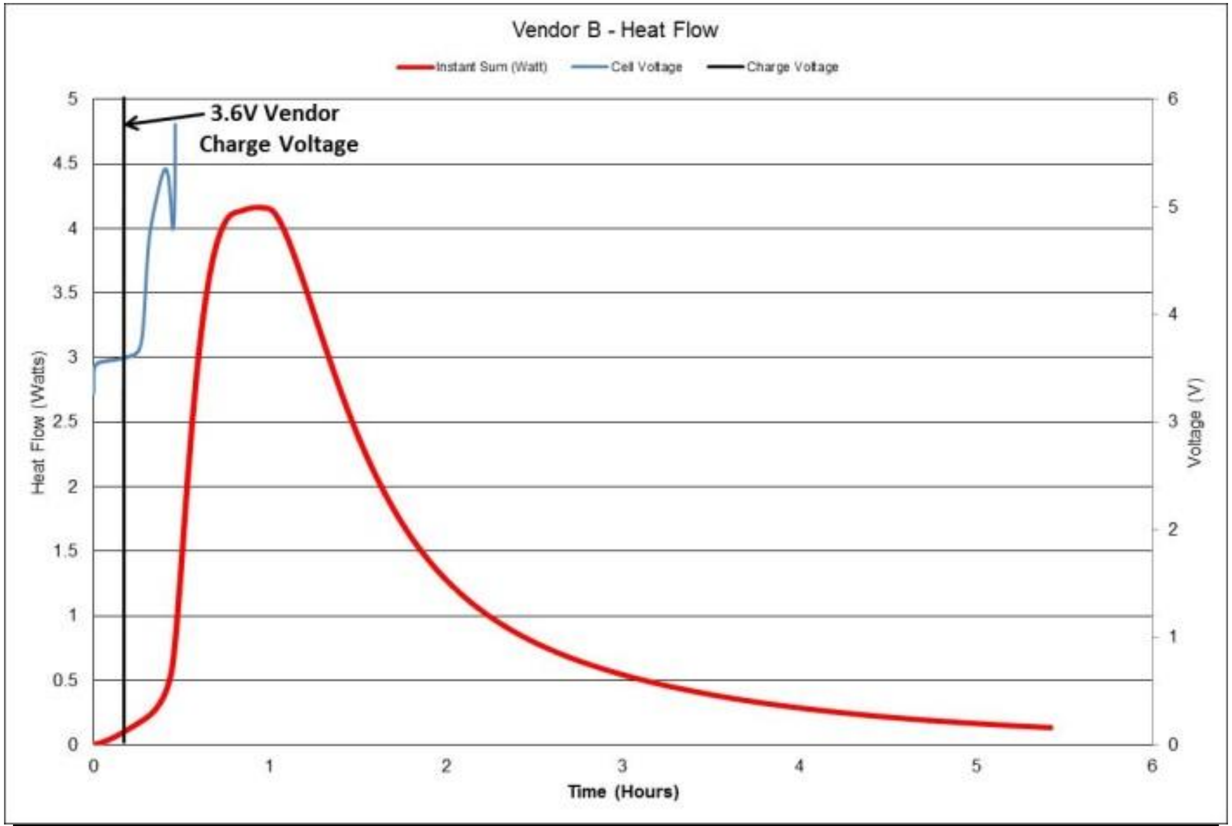




- Vendor B Observations (Calorimetry 1 Cell / Bullet 1 Cell)
  - Both cells showed a destructive event but in different ways
    - Calorimetry showed a rupture along the side
    - Bullet showed an end cap released
  - Testing showed similar charge and temperature curves but offset
    - Variation in state of charge and possible cycle life
  - Testing showed very similar pressure curves between the two tests

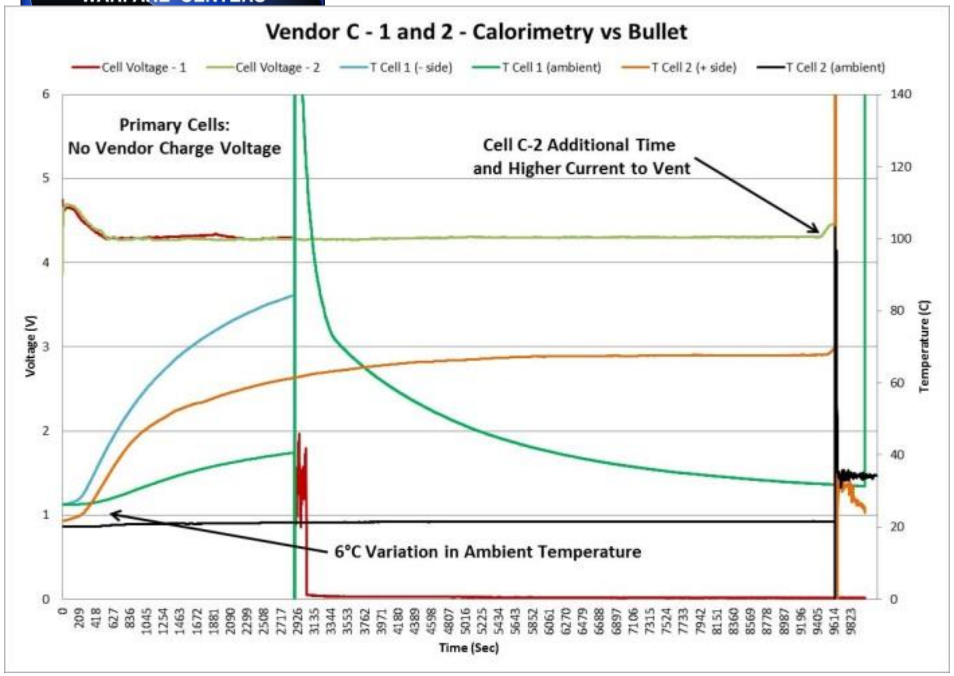


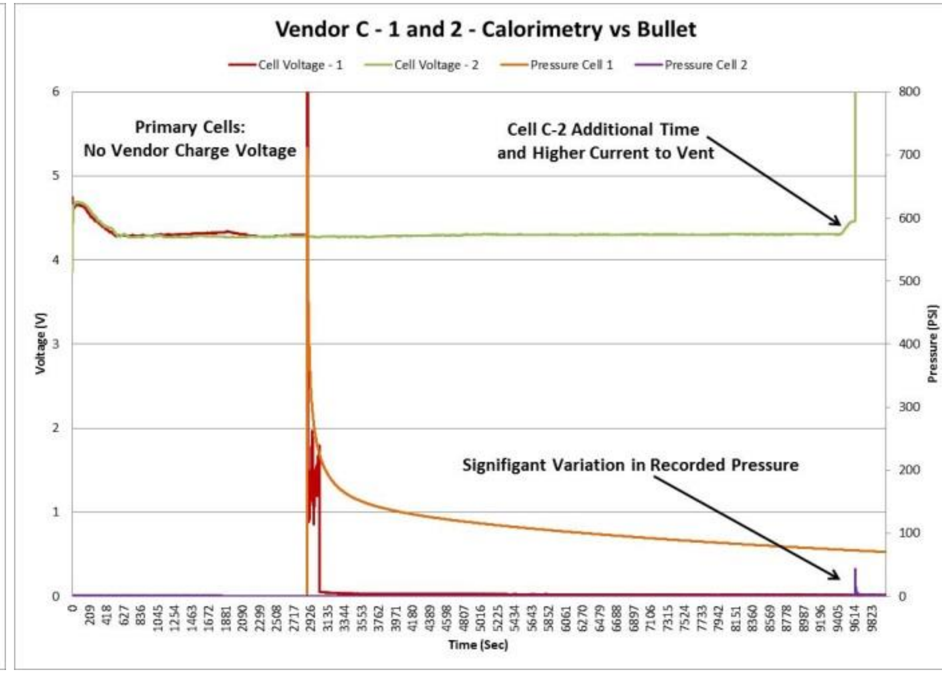
Vendor B – Rechargeable / 26650 (2.5AHr)



	Vendor B - 1 (Lithium Iron Phosphate)	Vendor B - 2 (Lithium Iron Phosphate)
Peak Heat Flow	4.163 W	N/A
Raw Energy Released	21.596 kJ	N/A
Input Energy	34.604 kJ	N/A
Net Energy	-13.008 kJ	N/A

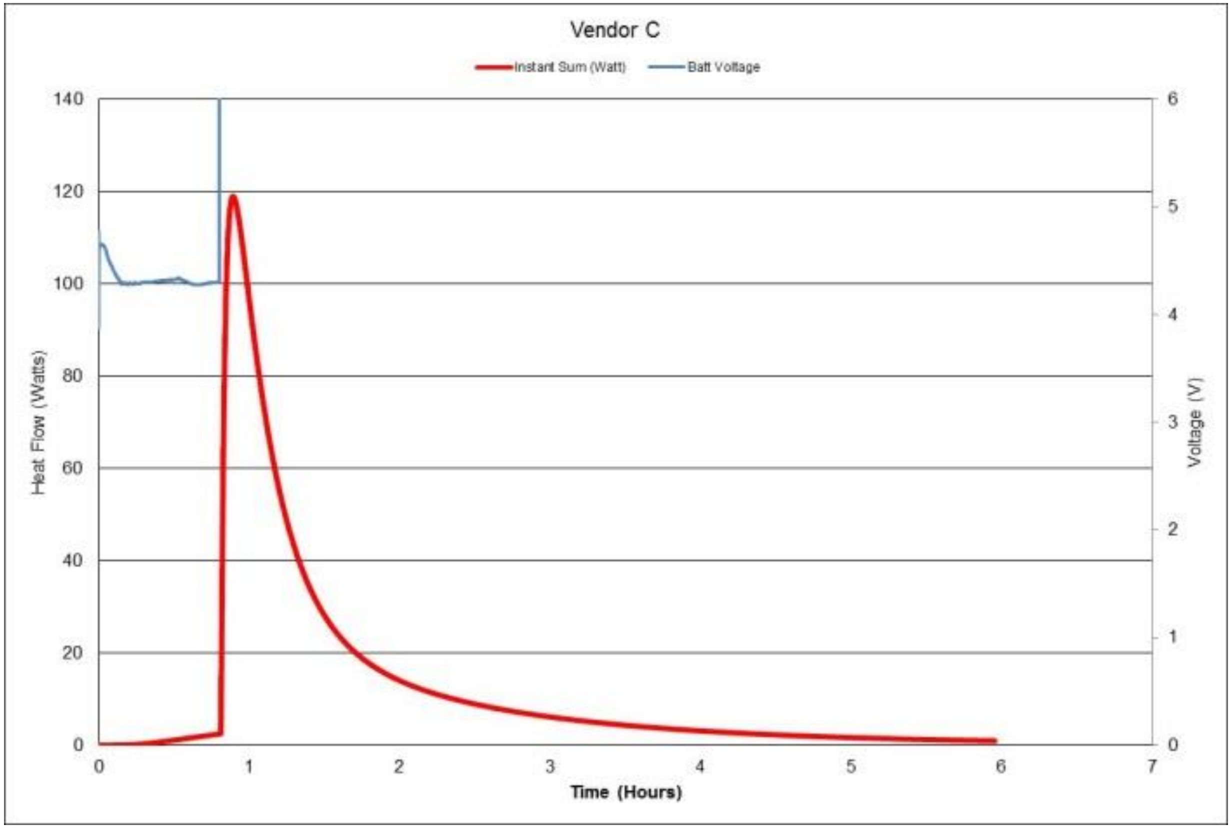
Vendor C – Primary / D Cell (15.0AHr)





- Vendor C Observations (Calorimetry 1 Cell / Bullet 1 Cell)
  - Both cells showed a destructive event and were fully consumed
    - Temperature & pressure sensors (inside the containment vessel) were maxed during testing
  - Bullet test required longer charge duration and an increase in charge current
    - 6°C variation in ambient temperature
  - Testing showed very similar voltage responses to the overcharge
  - Variation in temperature curves could be due to longer charge duration
  - Significant variation in pressure response
    - Variation in enclosure size and failure mechanism may be possible contributor

Vendor C – Primary / D Cell (15.0AHr)



	Vendor C - 1 (Primary Lithium)	Vendor C - 2 (Primary Lithium)
Peak Heat Flow	119.009 W	N/A
Raw Energy Released	265.217kJ	N/A
Input Energy	25.122 kJ	N/A
Net Energy	239.095 kJ	N/A

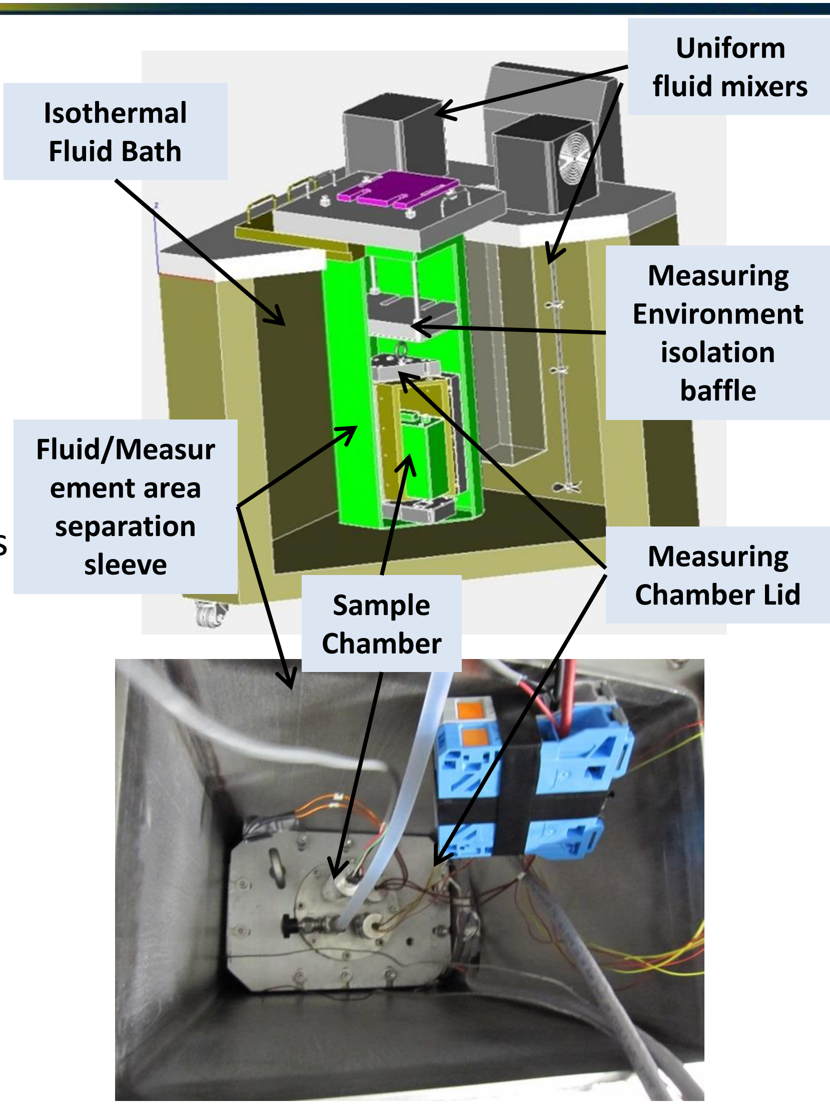
Summary Results

	Vendor A - 1 (Lithium Ion)	Vendor A - 2 (Lithium Ion)	Vendor A - 3 (Lithium Ion)	Vendor B - 1 (Lithium Iron Phosphate)	Vendor B - 2 (Lithium Iron Phosphate)
Capacity / Size	3.2Ahr / 18650	3.2Ahr / 18650	3.2Ahr / 18650	2.5Ahr / 26650	2.5Ahr / 26650
Enclosure	Calorimetry	Calorimetry	Bullet	Calorimetry	Bullet
Max Pressure (psi)	N/A	N/A	35.60	1.12	3.60
Max Cell Temp (°C)	57.94	76.62	499.27	117.18	129.31
Ambient Max Temp (°C)	27.02	31.32	219.93	32.05	48.66
Peak Heat Flow	0.839 W	1.342 W	N/A	4.163 W	N/A
Raw Energy Released	5.087 kJ	7.609 kJ	N/A	21.596 kJ	N/A
Input Energy	39.114 kJ	43.811 kJ	N/A	34.604 kJ	N/A
Net Energy	-34.027 kJ	-36.202 kJ	N/A	-13.008 kJ	N/A

	Vendor C - 1 (Primary Lithium)	Vendor C - 2 (Primary Lithium)
Capacity / Size	15.0Ahr / D Cell	15.0Ahr / D Cell
Enclosure	Calorimetry	Bullet
Max Pressure (psi)	711.61	65.40
Max Cell Temp (°C)	1259.58	1408.18
Ambient Max Temp (°C)	1346.17	117.47
Peak Heat Flow	119.009 W	N/A
Raw Energy Released	265.217kJ	N/A
Input Energy	25.122 kJ	N/A
Net Energy	239.095 kJ	N/A

Summary Conclusion

- Effort suggests that the Calorimetry process
  - Is repeatable
  - Provides very similar data to the standard methods
  - Specific cell failure mode can cause variation in results
- Lessons learned
  - Calorimetry cell enclosure needs to be sized for the appropriate cell size (Amphr)
    - D cell failure event caused minor leak through seals due to incompatibility with the electrolyte
    - Enclosure size must be selected to ensure test safety but provide adequate data resolution
  - Need to ensure sensors, inside the event environment, are ranged for the worst case event to collect accurate data
  - Conduct testing on a larger sample set and implemented lessons learned to further validate the process
  - Cycle test cells in calorimeter to establish consistent SOC prior to forced overcharge



Questions?

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Thank you to the NSWC Crane Team
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William Ridge