Cell compression force testing and its effects on thermal runaway response

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Project Team

Presenter	Jason Graika
Date	11/28/2018

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Background

- Lessons learned from recent aerospace lithium-ion battery (LIB) mishaps has created a new industry-wide awareness of catastrophic thermal runaway (TR) risks and hazards
- The NASA Engineering and Safety Center (NESC) has responded by sponsoring independent assessments of the ISS Extravehicular Mobility Unit (EMU) and Main LIB orbital replacement unit (ORU) energy storage systems
- NASA uses GS Yuasa LSE 134-101 cells for the ISS main battery
  - Configuration controlled cell with 1 vent on top
- Previous thermal runaway testing* has shown this particular cell has a propensity to eject cell contents from top of cell

***International Space Station Lithium-Ion Battery Thermal Runaway Propagation Test – 2017 NASA battery workshop** *Timothy North, Boeing; and Penni Dalton, NASA Glenn Research Center*
And **Assessment of International Space Station (ISS) Lithium-ion Battery Thermal Runaway (TR)** 2017 Space Power Wokshop Jason Graika

Background

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- NESC was concerned the ejection of the cell contents from the can causes an under test of the cell during thermal runaway resulting in lower cell temperatures and potentially misrepresenting the risk for cell-to-cell propagation.
- Cells in ISS main battery (and many other large format batteries) are clamped to immobilize cell contents for flight launch loads
- Aerojet Rocketdyne performed analysis* that showed that the preload clamping forces caused a highly stressed area near the top that would fail under flight compression loads during thermal runway

*TPD- 339467 "Answers to NASA questions on Li-Ion Thermal Runaway" August 2017 Hector Ortiz

Cell Information

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Manufacturer and Part Number	GS-Yuasa LSE134-101
Chemistry	Lithium Cobalt Oxide
Performance	
Capacity (nameplate)	134 A-hr
Energy (nameplate)	496 W-hr
Energy Density at BOL	349 Wh/L
Specific Energy at BOL	155 Wh/kg
Temperature Range	
Charge	+10 to +35C
Discharge	-10 to + 35C
Mechanical	
Dimension (WxDxH) excluding terminals	130 x 50 x 271 mm
Weight	3.53 kg

Flight battery configuration

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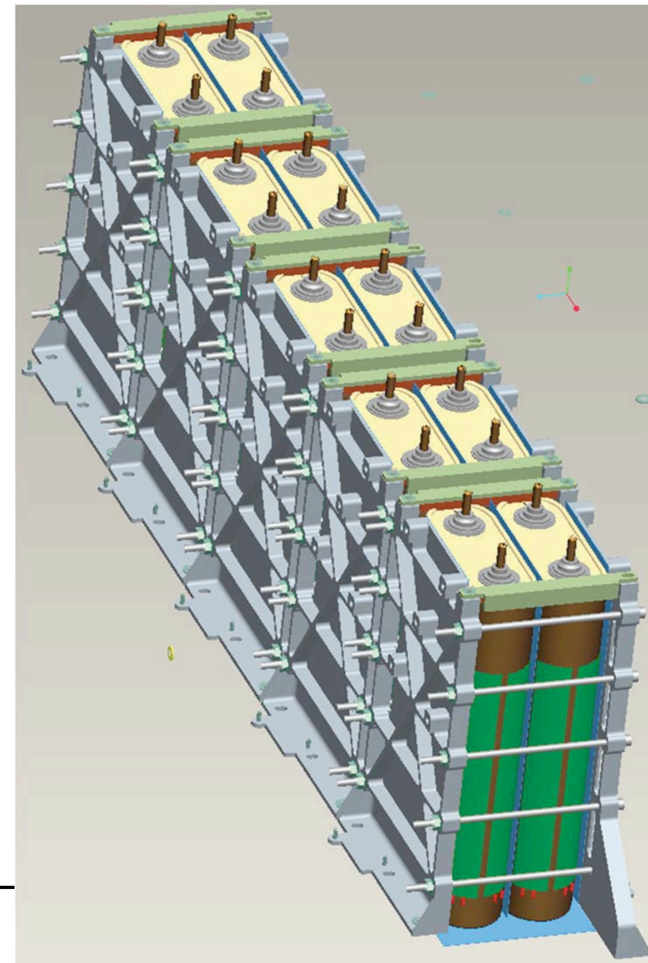
- A flight battery is comprised of 30 cells arranged into 3 separate 10 packs with each 10 pack comprised of 5 pairs of cells in series
- 10 screws are applied to each cell pair
- 1200 lb. of compression force applied to each cell pair



Structural analysis on bolts

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- Analysis was completed to compare flight loading and test setup
  - Ungreased screws were found to create a large degree of uncertainty in the calculations
- 7 in-lb testing was found to be below flight level
- 14 was found to be close to flight load
- 19 in-lbs was found to be high but within the calculation error of flight loading

Test Compression Calculation (4 Bolts)

Bolt Dia = 0.375 $k_{PTFE\ Grease}$ = 0.10 - 0.18

Total Cell Compression	Single Bolt Force	Bolt Torque (in-lbs)			
		Max	Mean	Min	
lb	lb	k = 0.18	k = 0.13	k = 0.10	
2030	507.5	34.3	24.7	19.0	
1900	475	32.1	23.2	17.8	
1800	450	30.4	21.9	16.9	
1700	425	28.7	20.7	15.9	
1560	390	26.3	19.0	14.6	
1490	372.5	25.1	18.2	14.0	
1400	350	23.6	17.1	13.1	
1300	325	21.9	15.8	12.2	
1200	300	20.3	14.6	11.3	**Flight Compression**
1150	287.5	19.4	14.0	10.8	
1125	281.25	19.0	13.7	10.5	
900	225	15.2	11.0	8.4	
827	206.75	14.0	10.1	7.8	
745	186.25	12.6	9.1	7.0	
575	143.75	9.7	7.0	5.4	
500	125	8.4	6.1	4.7	
415	103.75	7.0	5.1	3.9	
300	75	5.1	3.7	2.8	
200	50	3.4	2.4	1.9	

Kauser Imtiaz - ISS Li-Ion Battery Thermal Runaway Test – Bolt Torque Assessment

Test set up

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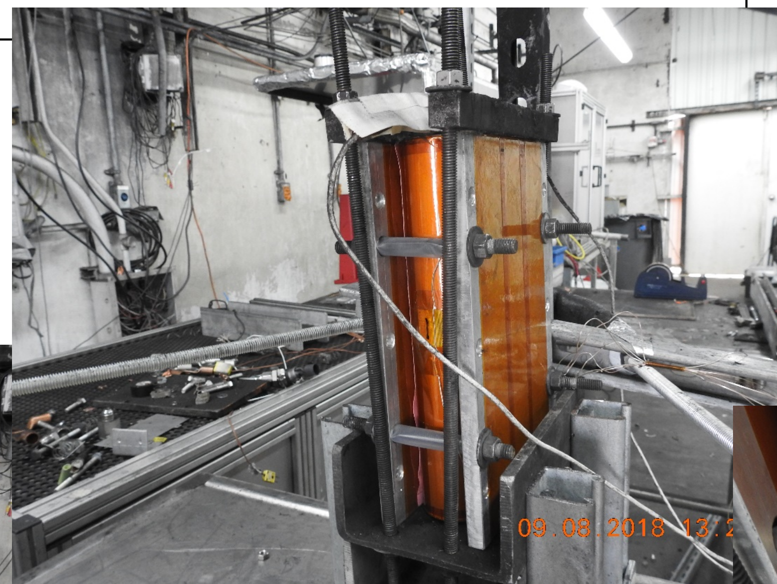

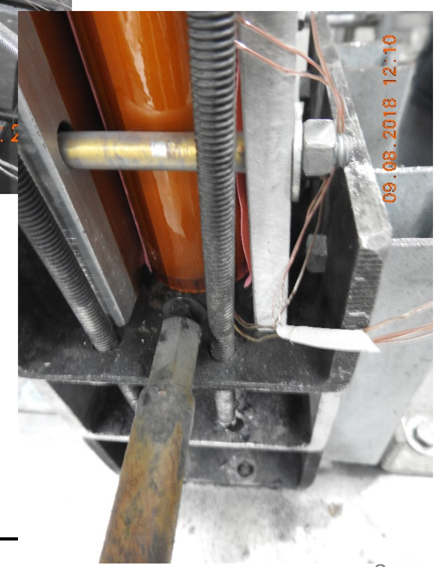

Testing Methodology

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- Cells were clamped following vendor procedure
- Custom drill rig controlled by an operator was used for trigger method
  - Drill bit diameter of .1285” with 4/16” max penetration distance
- Video monitoring, IR video, cell temperature, cell voltage, and cell current were all recorded
- All cells were charged to 3.95V (ISS maximum voltage per cell)
- Tests conducted in open air environment
- Values of 0, 7, 14, and 19 in-lb of torque were applied to screws.

Testing to date

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Test	Trigger method	Clamping forces applied*	Result (eject or not)
Heat to vent 4-13-16	Ni chrome wire heaters	19 in-lb	Full ejection
Drill Penetration 6-6-16	¼" screw steel	19 in-lb	Full ejection
Drill Penetration with enclosure 6-22-16	.1285" 5/16 flute length drill bit cobalt	19 in-lb	Partial ejection (obstructed by lid)
Drill Penetration with enclosure 7-13-16	.1285" 5/16 flute length drill bit cobalt	19 in-lb	Partial ejection (obstructed by lid)
WSTF test 11-3-16	.1285" 4/16 flute length drill bit cobalt	~Flight load	Full ejection
Clamping force test 1 9-7-18	.1285" 4/16 flute length drill bit cobalt	0 in-lb	No ejection
Compression force test 2 9-8-18	.1285" 4/16 flute length drill bit cobalt	14 in-lb	Full ejection
Compression force test 3 9-8-18	.1285" 4/16 flute length drill bit cobalt	7 in-lb	No ejection
Compression force test 4 9-25-18	.1285" 4/16 flute length drill bit cobalt	14 in-lb	Full ejection
Ccompression force test 5 9-25-18	.1285" 4/16 flute length drill bit cobalt	7 in-lb	Full ejection

*Approximate as load cells are not used in these tests

Vent actuation to ejection

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Test	**Time from vent actuation until jelly roll ejection (approximate*)**
Heat to vent 4-13-16	4 seconds
Drill penetration 6-6-16	5.5 seconds
Drill penetration 6-22-16	6.5 seconds
Drill Penetration 7-13-16	8.5 seconds
Clamping forces test 9-8-18 14 in-lbs	12 seconds
Clamping forces test 9-25-18 7 in-lbs	7 seconds
Clamping forces test 9-25-18 14 in-lbs	8 seconds

*Data gathered from watching video and approximating exact times

Video 0 compression force

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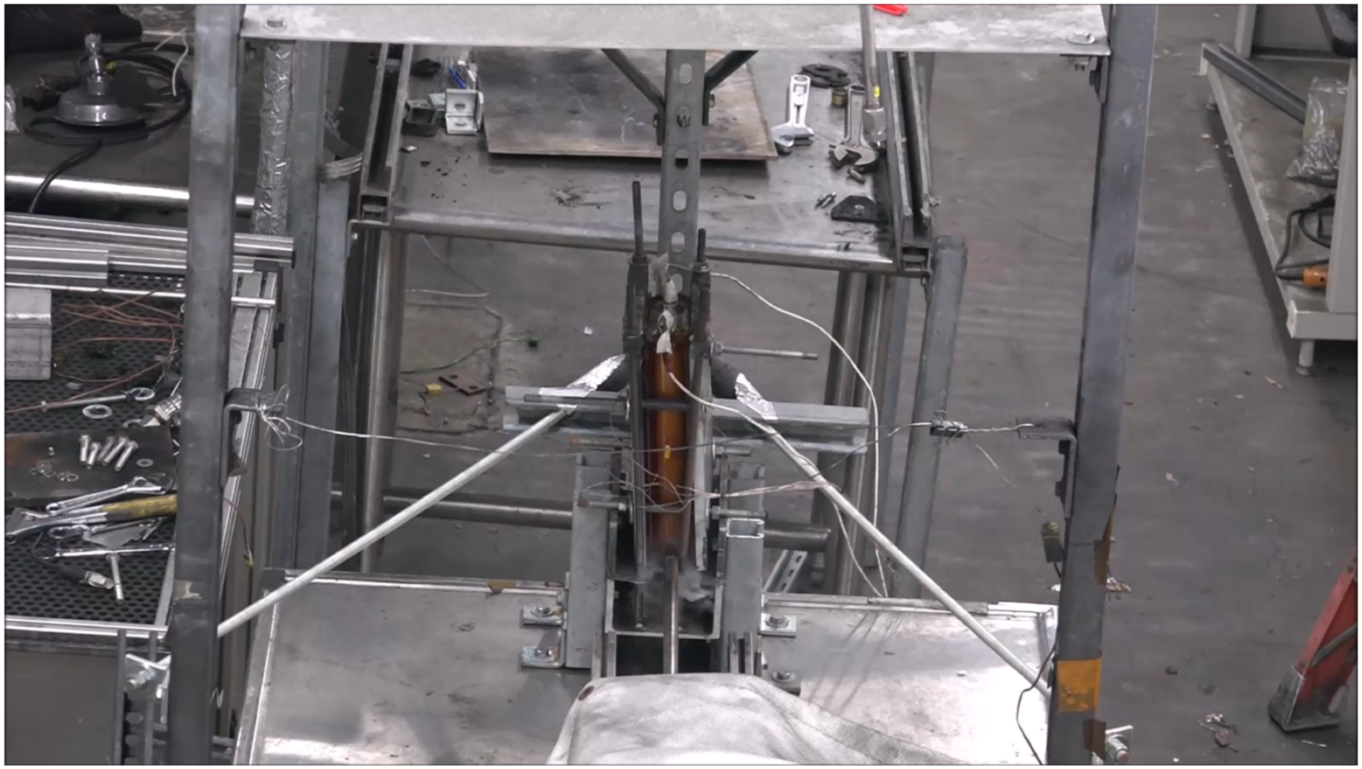

Video 14 in-lb compression force

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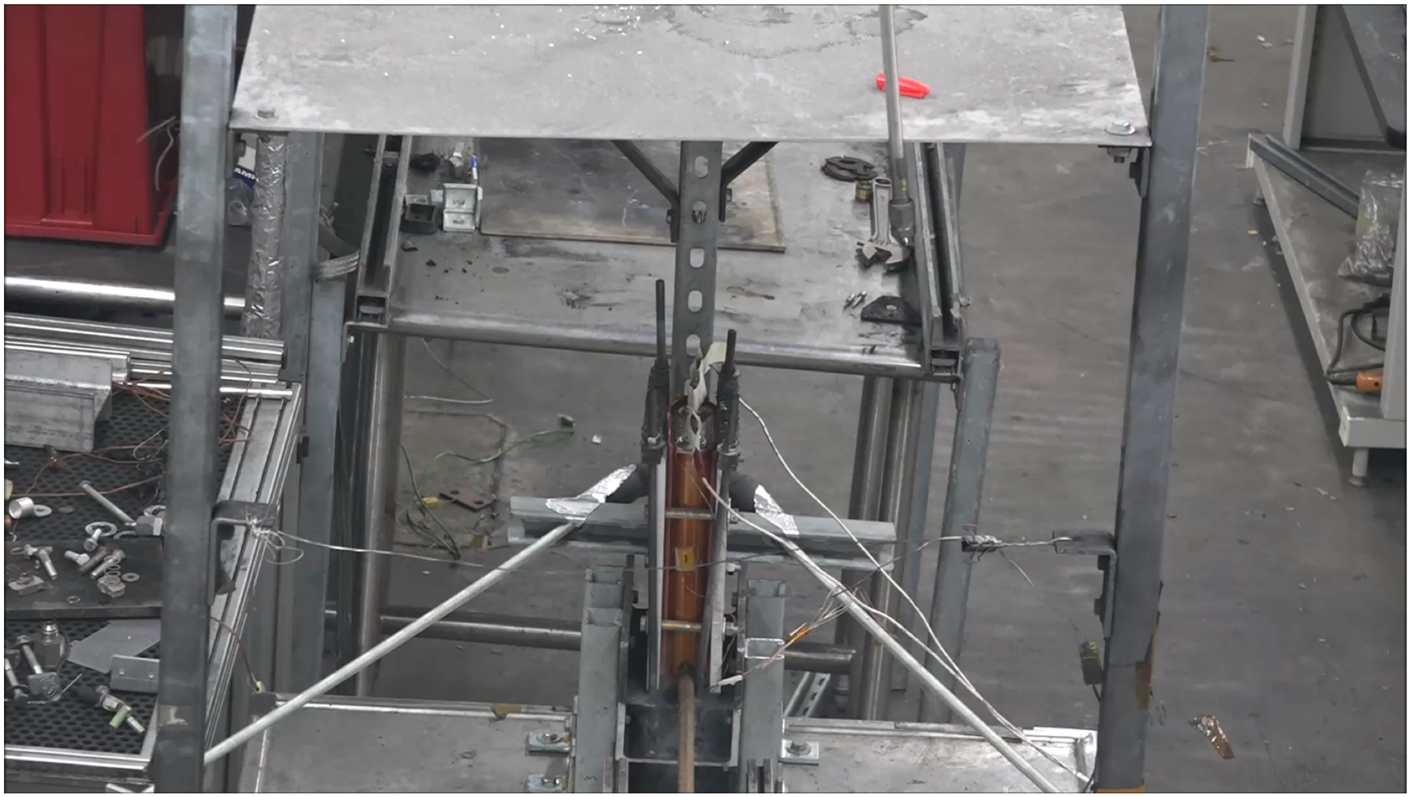

0 in lb test run 1 temp plot

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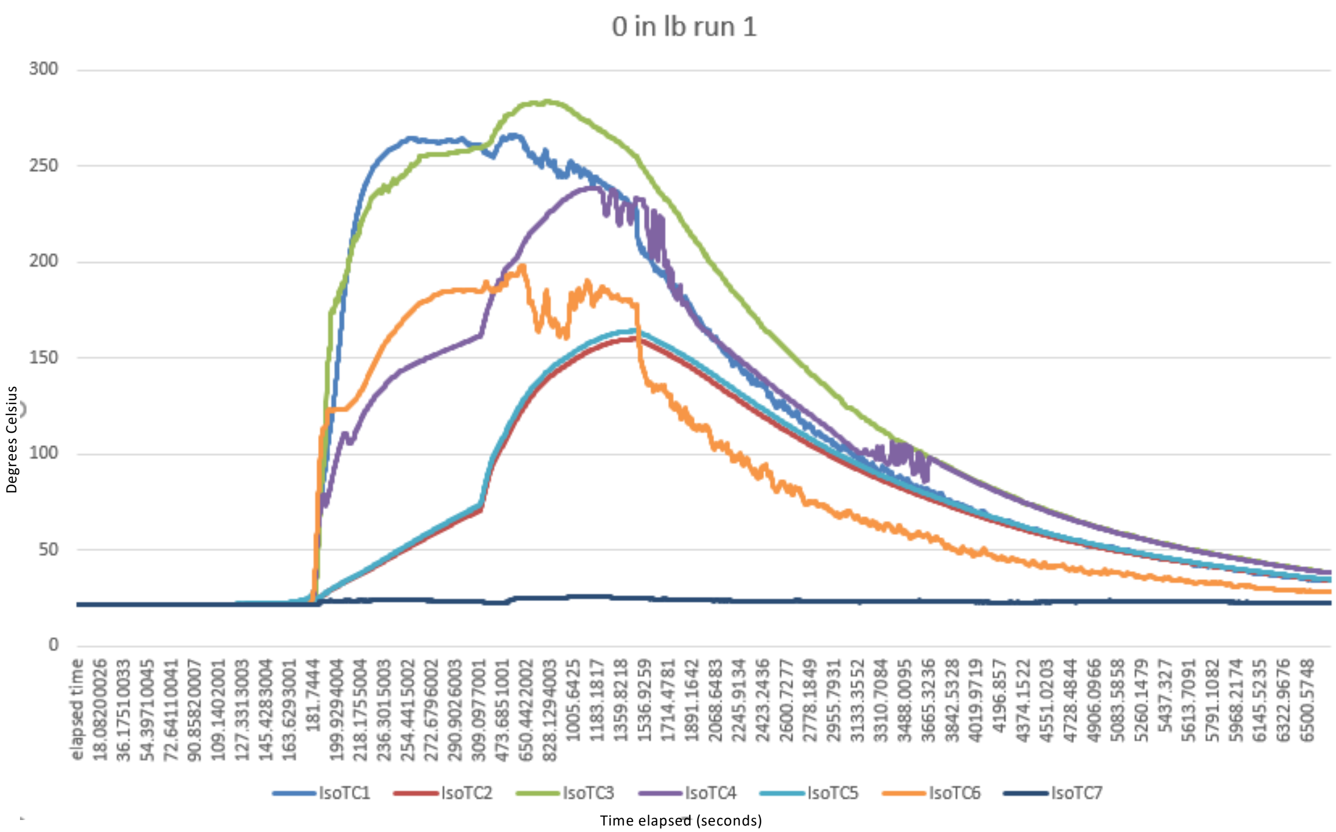
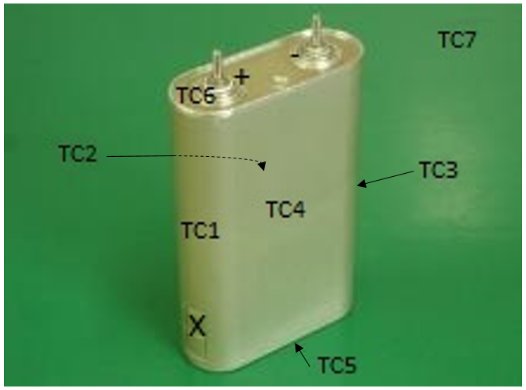


TC map



7 in lb test run 1 temp plot

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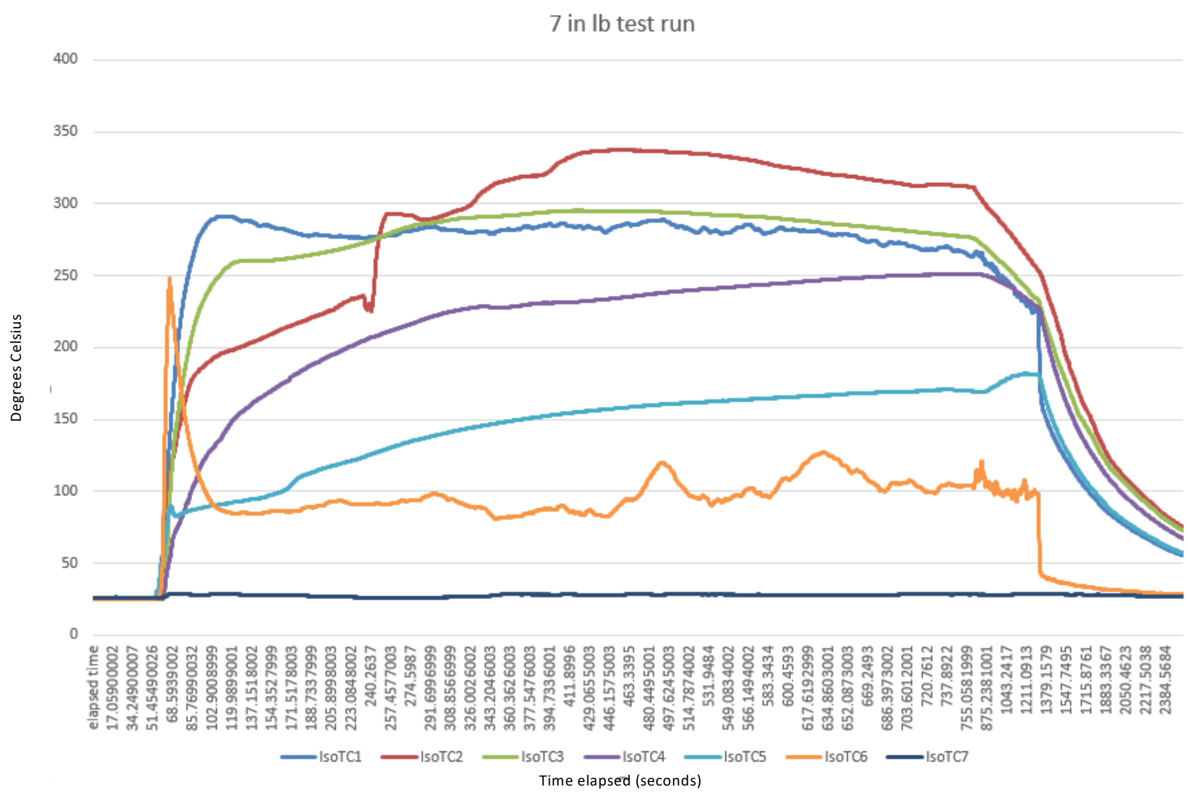
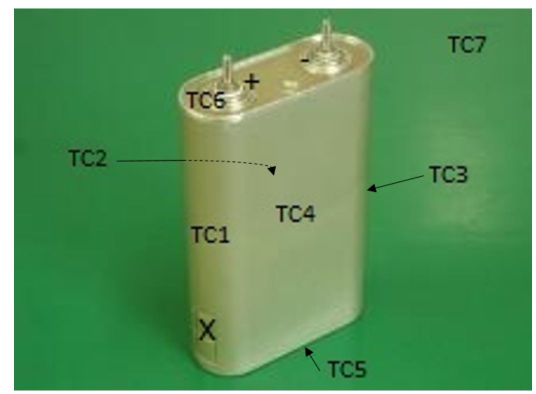


TC map



14 in lb test run 1 temp plot

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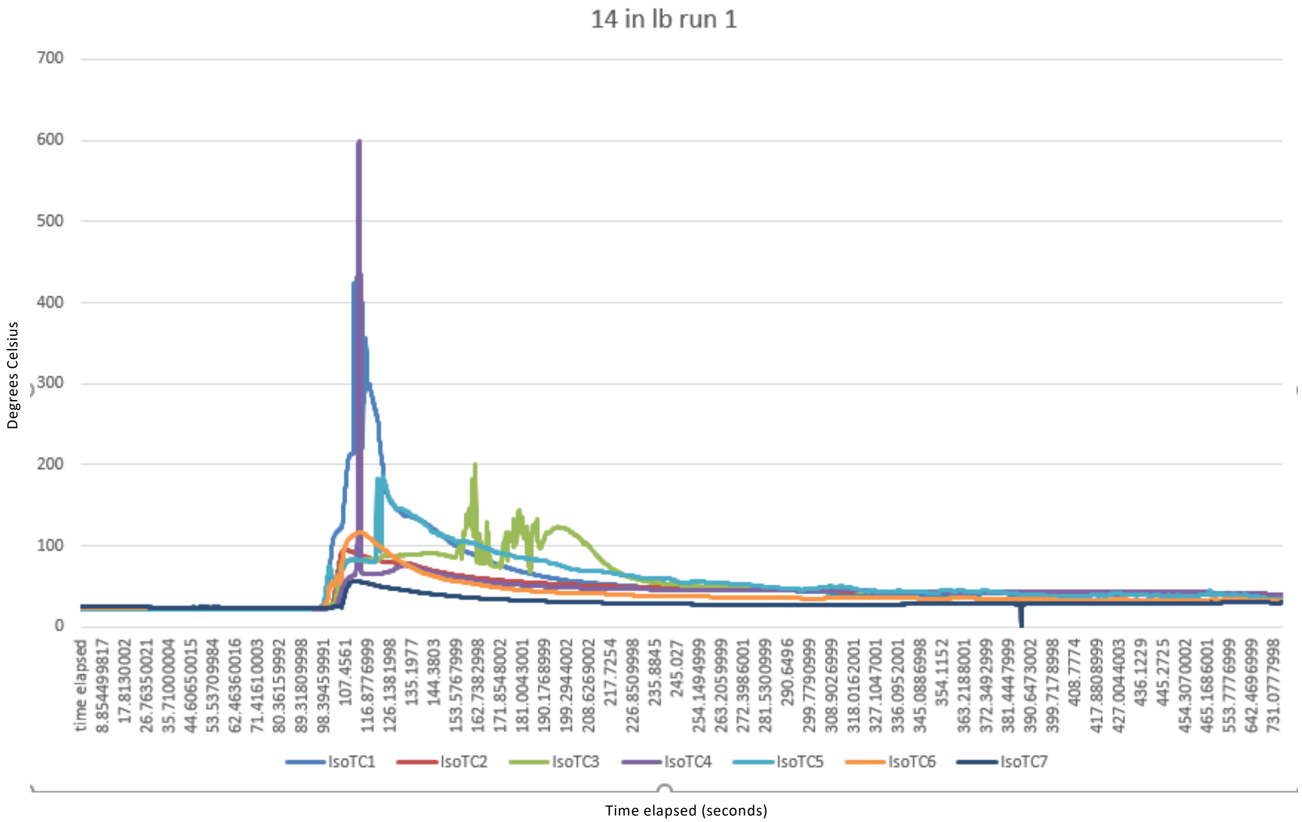
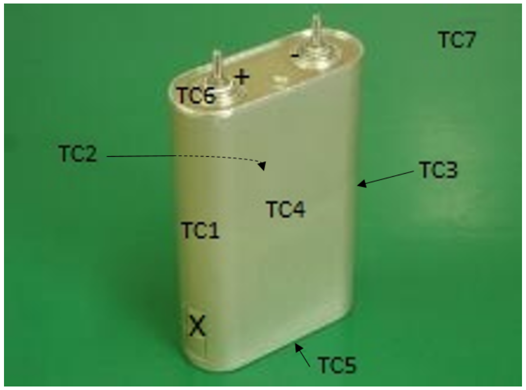


TC map



Compression force Vs max temp TR

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Test	Compression force	Max temp during TR	Cell contents ejected
Heat to vent 4-13-16	19 in-lb	619.17	Yes
Drill Penetration 6-6-16	19 in-lb	542.77	Yes
Drill Penetration with enclosure 6-22-16	19 in-lb	421.76	Yes
Drill Penetration with enclosure 7-13-16	19 in-lb	650.63	Yes
Clamping force test 1 9-7-18	0 in-lb	284.37	No
Clamping force test 2 9-8-18	14 in-lb	430.60	Yes
Clamping force test 3 9-8-18	7 in-lb	337.43	No
Clamping force test 3 9-25-18	14 in-lb	265.77	Yes
Clamping force test 3 9-25-18	7 in-lb	218.45	Yes

Compression force Vs max temp TR

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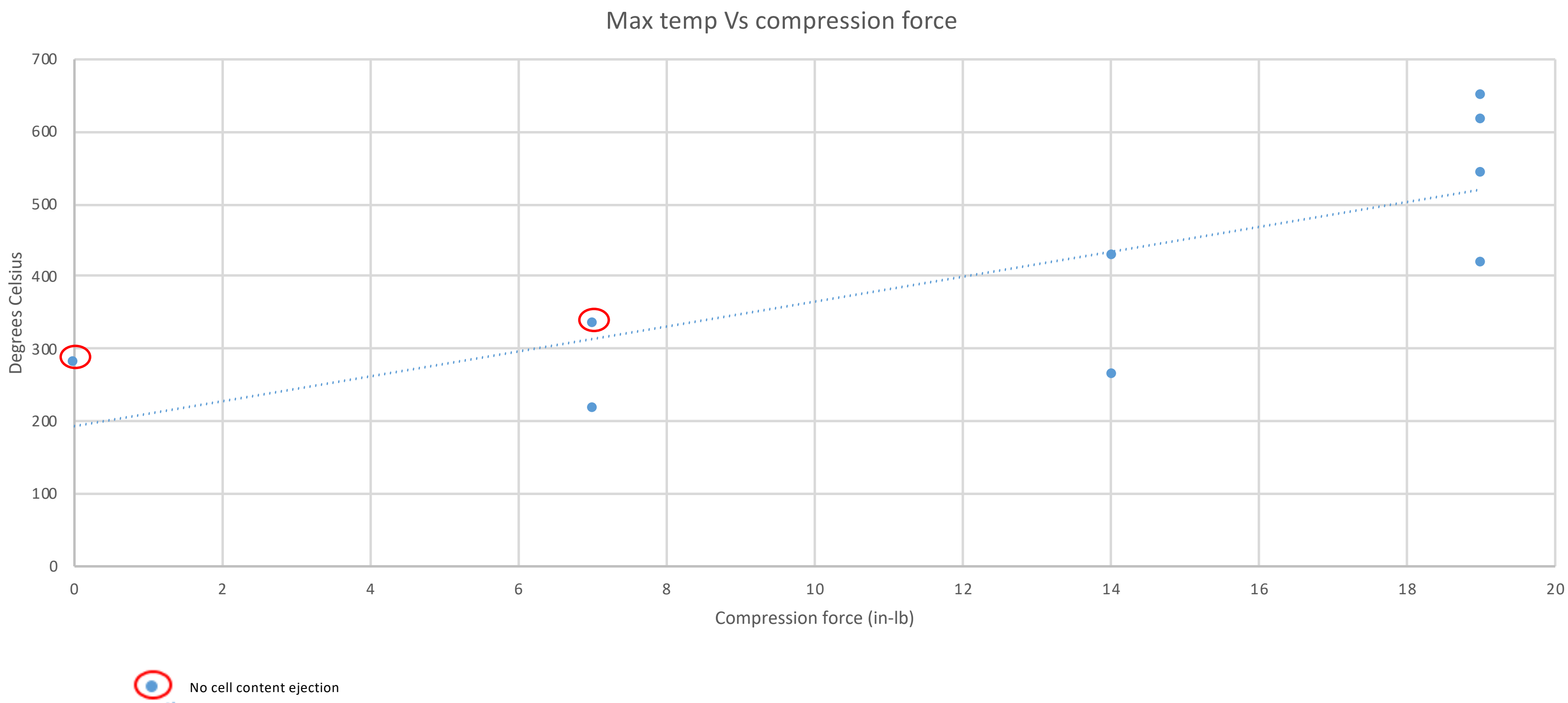
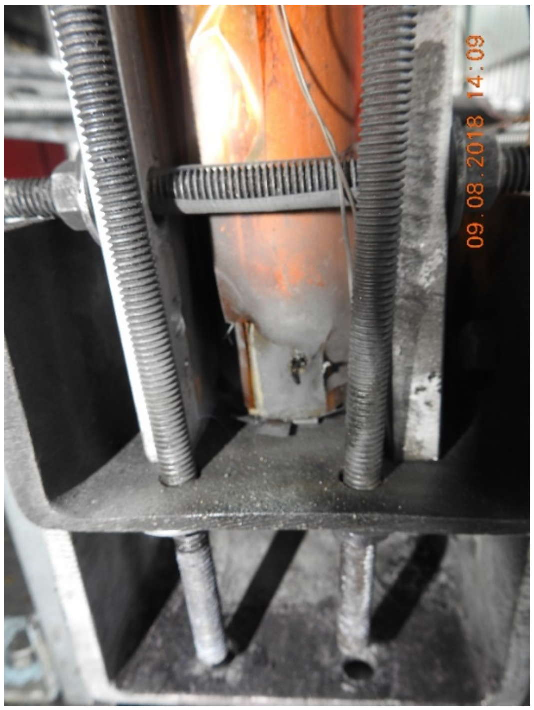


	# Post test	Presenter Jason Graika Date 11/28/2018



Lessons learned

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- Compression force applied to cell does appear to be a factor but not the main factor in how a cell reacts to thermal runway
  - 2 out of 3 runs at lower compression forces (7 or 0 in-lb) did not result in a cell content ejection
  - Cell can appears to swell more in no and lower compression force cases
    - May effect temp measurement as we are measuring skin temp and distance to jelly roll increases with cell can swelling
    - Current discussion on if the cell can is allowed to swell (via low or no clamping force), this could increase the flow path area for internal gasses to escape the cell vents, thereby preventing the very high pressures that are likely causing the cell content ejections.
  - Some correlation between max skin temp measured and compression force applied on the cell

Next steps

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- Recommend further study into area
- May be an opportunity for battery designers to design a battery that behaves more benignly in thermal runaway or is less likely to propagate
- No further testing planned yet but possible further testing includes:
  - Additional compression testing with load cells to better quantify compression forces
  - Possibility of testing different cell types
  - Possibility of testing cells with different vents

Acknowledgments

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