MODULE TEST REPORT
UL 9540A
Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems (AACD)

Project Number.....:	**4789109222.4**
Date of issue.....:	**April 30, 2020**
Date of Revision……:	**July 8, 2020 (UL Project 4789542457)**
Total number of pages.....:	**25**

UL Report Office .....:	**UL LLC**
Applicant's name.....:	**Natron Energy, Inc.**
Address .....:	**3542 Bassett Street** **Santa Clara, 95054** **USA**
Test specification:	4th Edition, Section 7, November 12, 2019
Standard.....:	UL 9540A, Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems
Test procedure .....:	8.1 – 8.4
Non-standard test method .....:	Overcharge Methodology

General disclaimer:

The test results presented in this report relate only to the sample tested.

UL LLC did not select the sample(s), determine whether the sample(s) was representative of production samples, witness the production of the test sample(s), nor were we provided with information relative to the formulation or identification of component materials used in the test sample(s).

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Test item description ……..:	Sodium Ion Battery Module	
Module cell configuration (xS/**y**P**) …...:**	32S/1P	
Number of cells in module.:	32	
Cells in Module:	Natron Energy, Inc.	
●**Manufacturer Name**	V6.0	
●**Part Number**	Sodium Ion	
●**Chemistry**	Pouch	
●**Format**		
Module dimensions (X x **Y** x **Z** (mm)**)……..:**	483 x 600 x 435 mm	
Module weight (kgs)…… :	37lbs (16.78kg)	
Module enclosure material…….. :	Aluminium	
Original Equipment Manufacturer (OEM):	Natron Energy, Inc.	
Branding Manufacturer (if not OEM):	N/A	
Model No..... :	Blue Tray 4000	
Ratings (Vdc, Ah)..... :	50Vdc, 4.6Ah	
Test item certified? ……:	No	
Standard test item certified to ……:	N/A	
Organization that certified test item ……:	N/A	
Intended BESS Manufacturer and Model No.:	N/A	
Standard BESS certified to:	N/A	
Organization that certified BESS:	N/A	
Testing Laboratory and testing location(s):		
Testing Laboratory:	UL LLC	
Testing location/ address ..... :	333 Pfingsten Road Northbrook, IL 60062 USA	
Tested by (name, signature)..... :	Dustin Fox Dan Wade	Dustin Fox Dan Wade
Witnessed by (for 3rd Party Lab Test Location) (name, signature)..... :	n/a	n/a
Project Handler (name, signature)..... :	Nathan Wang	Nathan Wang
Reviewer (name, signature) ……:	Thomas Skowera	Thomas Skowera

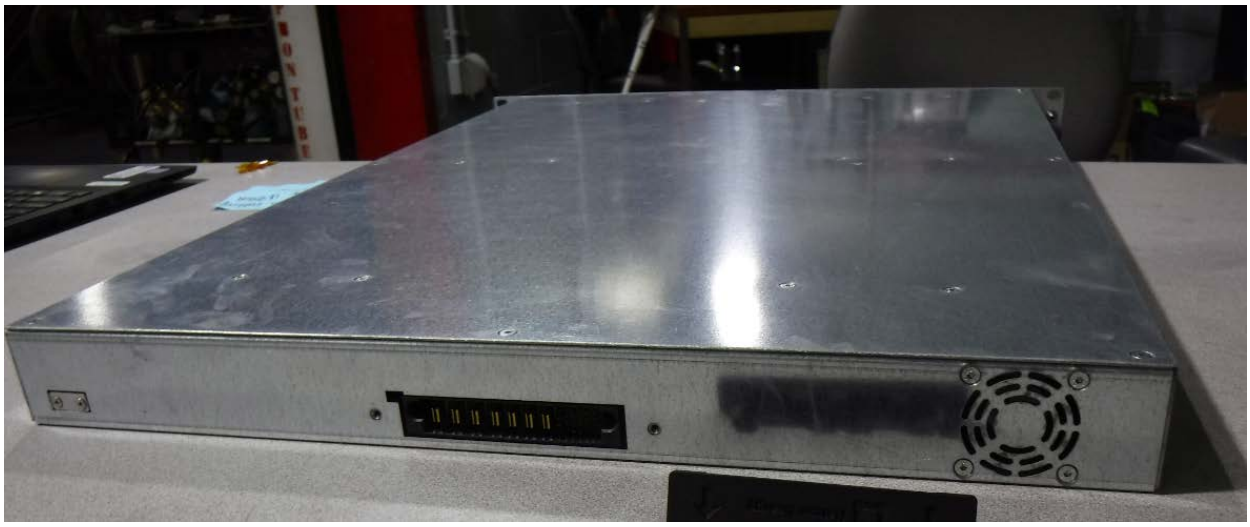
List of Attachments (including a total number of pages in each attachment): **Attachment A:** Module Conditioning (Charge/discharge) Profiles - (*Page **15***) **Attachment B:** Module Construction Photos - (Page **16**) **Attachment C:** Module Instrumentation Photos - (*Pages **17** through **18***) **Attachment D**: Module and Initiating Cell(s) Temperature Profiles During Testing - (*Pages **19** through **20***) **Attachment E**: Module Testing Photos - (*Pages **21** through **23***) **Attachment F**: Module Gas Flow Rate and Heat Release Profiles – (*Pages **24** through **25***)
Summary of cell testing: Cell Level Test Report is filed under UL Project Number: 4789109222 Issued: December 23, 2019, Revised January 14, 2020 **Cell testing consisted of external heating, overcharge, external short circuit, and nail penetration. Thermal runaway was not achieved during any of these cell failure test methods.** **Venting was observed with the use of an external heater and overcharge methods. Overcharge method was used for module level testing.**
Cell failure test method performed (summary of method and test clause): ☐ External heating using thin film with 4°C to 7°C thermal ramp. ☐ Nail Penetration ☒ Overcharge ☐ External short circuit (***X*** Ω *external resistance*) ☐ Others
Description of method used to fail cells if other than external thin film heater with thermal ramp, : The overcharge conditioned used to attempt to put the cell into an abnormal condition to cause venting or thermal runaway. The charge voltage was increased by 1 volt and held for a minimum of one minute before increasing the voltage again. The maximum charge values used were 79.5V, 1A. The fan provided was not operated during the test.

Test Results from Cell Level Test:	**Venting occurred, no thermal runaway observed**
Average cell surface temperature at gas venting, °C:	**81.9ºC**
Average cell surface temperature at thermal runaway, °C:	**N/A**

Description of components employed within the module that serve to supress propagation (fire protection features). **N/A – the module does not employ any components intended to serve to supress propagation.**	
Summary of Module Test Results	
Thermal Runaway Propagation:	**No observation**
External Flaming:	**No observation**
Location of Flame Venting:	**N/A**

<table>
<tr><td>Flying Debris:</td><td>No observation</td></tr>
<tr><td>Re-ignitions:</td><td>No observation</td></tr>
<tr><td colspan="2">Gas Analysis:
☒ Flame ionization detection
☐ Fourier-Transform infrared Spectrometer
☒ Hydrogen Sensor (palladium-nickel, thin-film solid state sensor)
☒ White light source with photo detector (smoke release rate)</td></tr>
<tr><td>Summary of Gas Analysis Data:</td><td></td></tr>
<tr><td>• Gas Composition & Volume for Each Compound (Pre-flaming and After flame):</td><td>
<table>
<tr><th>Gas Compound</th><th>Gas Type</th><th>Pre-Flaming (L)</th><th>Flaming (L)</th></tr>
<tr><td>N/A</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
</table>
</td></tr>
<tr><td>• Smoke Release Rate (m^2/s)</td><td>N/A – no venting or thermal runaway of the initiating cell observed</td></tr>
<tr><td>• Total Smoke Released: (m^2)</td><td>N/A – no venting or thermal runaway of the initiating cell observed</td></tr>
<tr><td>• Peak Chemical Heat Release Rate: (kW):</td><td>N/A – no venting or thermal runaway of the initiating cell observed</td></tr>
<tr><td colspan="2">☐ Performance Criteria Met in accordance with Clause 8.4:
- No thermal runaway observed
- Cell vent gas flammable as determined by the cell level test</td></tr>
</table>

Photos of module:



Test Item Charge/Discharge Specifications:	
• **Charge current, A:**	**Standard: 4A (Maximum: 80A)**
• **Maximum charge voltage, Vdc:**	**58V**
• **Charge temperature range, °C:**	**-20°C to 45°C**
• **End of charge current, A:**	**0.2A**
• **Discharge current, A:**	**Standard: 4A (Maximum: 200A)**
• **End of discharge voltage, Vdc:**	**32V for discharge > 4A** **38V for discharge < 4A**
• **Discharge temperature range, °C:**	**-20°C to 45°C**

Test item particulars.....:	N/A
Possible test case verdicts:	
- test case does not apply to the test object.....:	N/A
- test object does meet the requirement.....:	P (Pass)
- test object does not meet the requirement.....:	F (Fail)
Testing.....:	Natron Blue Tray 4000 module
Date of receipt of test item .....:	2020-01-27
Date of performance of tests .....:	2020-02-04

General remarks: No venting or thermal runaway observed during testing. The cell being overcharged expanded but did not rupture.

"(See Enclosure #)" refers to additional information appended to the report.
"(See appended table)" refers to a table appended to the report.

Throughout this report a point is used as the decimal separator.

Manufacturer's Declaration of samples submitted for test:

The applicant for this report includes samples from more than one factory location and a declaration from the Manufacturer stating that the sample(s) submitted for evaluation is (are) representative of the products from each factory has been provided..... :	☐ **Yes** ☒ **Not applicable**
Name and address of factory.....:	Natron Energy 3542 Bassett St Santa Clara, CA 95054

General product information and other remarks:

The wiring utilized for overcharging of the cell were provided by the customer. Due to the space available to route wiring, only a 24 gauge wire could be used and therefore the current was limited to <2A for the test. The reduced current would result in a longer charge time to achieve a set voltage point.

Revision notes:
July 8, 2020 (UL Project# 4789542457)

- The V6.0 cell capacity rating has been increased from 4.3Ah to 4.6Ah. The increased capacity is a result of the end point cutoff voltage discharge specification being reduced from 1.0V to 0V. This change in end point voltage does not affect the test results as the cell was tested at 100% SOC and the charge voltage rating has not changed. The module ratings were also updated to 4.6Ah as the cells are all in a series configuration.
  No additional testing considered necessary to update the report to reflect the new capacity rating. This revision is to be consistent with the UL1973 certification of the V6.0 cell under UL file number MH63828.

- Page 2, updated nominal capacity of module from 4.3Ah to 4.6Ah

- Page 14, updated nominal capacity of cell from 4.3Ah to 4.6Ah

5.0	CONSTRUCTION		Verdict
5.2	**Module Construction**		—
5.2.1, 5.2.3	Construction information	See Test Item Description at the beginning of this report	—
	General layout of module contents	See Attachment B	—
5.2.2	Module certified to UL 1973	**Module is not certified**	N/A
	Organization that certified module:	**N/A**	—
6.0	**PERFORMANCE**		**Verdict**
6.1	**General**		
8.1	**Samples**		
8.1.1	Samples conditioned through charge discharge cycling a minimum of 2 cycles.	See Attachment A for profiles See Table 1 for specifications See also Table 2	P
8.1.2	100% SOC and stabilize from 1h to 8 h before testing		
8.1.3	Electronic controls such as BMS not relied upon during testing.		P
8.2	**Test Method**		
8.2.1	Ambient indoor laboratory conditions: 25 ±5°C (77 ±9°F) ≤50 ±25% RH at the initiation of the test.	See Table 3 The RH of the test room was lower than 25%RH and did not affect the results of the test.	F
8.2.2	Test conducted under a smoke collection hood appropriately sized for the module		P
8.2.3	The weight of the module was recorded before and after testing, (kg)	See Table 11	P
8,2,4	A sufficient number of cells were forced into thermal runaway to create a condition of cell to cell propagation within the module.	See Attachment C See Tables 4 and 5	N/A
	The location of the cell(s) forced into thermal runaway were selected to present the greatest thermal exposure to adjacent cells	See Attachment C for figures showing location within the module of the cell(s) forced into thermal runaway	N/A
8.2.5	The method used to initiating thermal runaway in the cell(s) were in accordance with 7.2	See Summary of Cell Testing at the beginning of this report.	P
8.2.6	The occurrence of thermal runaway was verified	See Test Results from Cell Level Test from the beginning of this report See Attachments D	N/A
8.2.7	The module was placed on top of a non-combustible horizontal surface with the module orientation representative of its intended final installation.	See Attachment E	P

8.2.8	The chemical heat release rate of the module was measured with oxygen consumption calorimetry	See Table 10 See Attachment F The graph provided indicates the noise from the sensor, there was no thermal event of the cell and therefore no heat release rate measured.	P
8.2.9	The chemical heat relate rate was measured for the duration of the test	See Attachment F	P
8.2.10	The chemical heat release rate was measured using the following equipment: ● Paramagnetic oxygen analyser ● Non-dispersive infrared carbon dioxide and carbon monoxide analyser ● Velocity probe ● Type K thermocouple	See Attachment F	P
	The instrumentation was located in the exhaust duct of the heat release rate calorimeter at a location that minimizes the influences of bends or exhaust devices.		P
8.2.11	The chemical heat release rate at each of the flows was calculated in accordance with 8.2.11.	See Attachment F	P
8.2.12	The hydrocarbon content of the vent gas was measured using flame ionization detection.	See Table 8 and 9	P
	Hydrogen gas shall be measured with a palladium-nickel thin-film solid state sensor.	See Table 9	P
8.2.13	The hydrocarbon content of the vent gas may also be measured using a Fourier-Transform Infrared Spectrometer with a minimum resolution of 1 cm-1 and a path length of at least 2 m (6.6 ft), or equivalent gas analyzer.	See Attachment F	N/A
	Vent gas velocity and temperature measurements respectively were obtained in the exhaust duct of the heat release rate calorimeter using equipment specified in 8.2.10.		P
8.2.14	The light transmission in the exhaust duct of the heat release rate calorimeter was measured using a white light source and photo detector for the duration of the test.		P
8.2.15	Smoke release rate was calculated as outlined in 8.2.15	See Table 10 See Attachment F	P
8.3	**Module level test report**		
	a. Module manufacturer and model number; b. Number of cells in module; c. Module configuration;	See Test Item Description in beginning of this report.	P

	d. Module construction features;	See Attachment C See Critical Components Table See Also "Description of components employed within the module that impact propagation (fire protection features)" at the beginning of this report.	
	e. Module voltage corresponding to the tested SOC;	See Table 3	N/A
	f. Thermal runaway initiation method used;	See Attachment C	P
	g. Heat release rate versus time data;	See Table 10 See Attachment F	N/A
	h. Flammable gas generation and composition data;	See Attachment F See Tables 8 and 9	N/A
	i. Peak smoke release rate and total smoke release data.	See Table 10	N/A
	j. Observation(s) of flying debris or explosive discharge of gases;	See Table 12	N/A
	k. Observation(s) of sparks, electrical arcs, or other electrical events;	See Table 12	N/A
	l. Identification/location of cells(s) that exhibited thermal runaway within the module;	See Tables 4 and 5	N/A
	m. Locations and visual estimations of flame extension and duration from the module;	See Attachments E See Table 7	N/A
	n. Module weight loss;	See Table 11	P
	o. Video of the test.		P
8.4	**Performance – Module level**		
8.4.1	The following performance conditions are met during the module level test: a) Thermal runaway is contained by module design;		P
	b) Cell vent gas is nonflammable as determined by the cell level test	5.24% LFL	F

Table 1 – Specified conditioning parameters			
Charging:		**Discharging:**	
Current (CC), A	80 A	Current (CC), A	200 A
Max Charge Voltage (CV), Vdc	58V	End of discharge voltage, Vdc	38V
End of charge current, A	0.2A	Discharging Test Ambient, °C	-20°C to 45°C
Charging Test Ambient, °C	-20°C to 45°C		
Refer to Attachment A for charge/discharge profiles for the module.			

Table 2 – Charge completion and module test initiation times		
Module No.	**Charge Completion Date and Time**	**Module Test Date and Time**
T64	2020/02/03 13:30	2020/02/04 12:55

Table 3 – Test Initiation Details	
	Module No.: T64
Test Date	2020/02/04
Test Start Time	12:55
Initial Lab Temperature	23°C
Initial Relative Humidity	20.1%R.H [1]
Module OCV at Start of Test, Vdc	N/A Cell OCV at Start of Test 2.89V

[1] The relative humidity of the lab was lower than the standard range of 25%RH to 75%RH. This did not affect the test result.

Table 4 – Approximate time of thermal runaway propagation through module	
Time to thermal runaway	**Location**
N/A – No thermal runaway observed	N/A

Table 5 – Test overview timeline		
Time (HH:MM:SS)	**Event**	**Description**
00:00:00		Data Acquisition Started
00:01:08	Test Start	2.5V, current set to 0.5A
00:02:10		Voltage set to 3.5V
01:05:24		Voltage set to 4.5V
02:30:39 – 02:59:02		Voltage increased by 1 V up to 34.5V, current limit increased to 1A
02:59:47 – 03:02:15		Voltage drops to 3.6V, current drop to 0A
03:02:16		Voltage set to 4.5V, Current limit reduced to 0.5A
03:03:08		Voltage set to 5.5V, Current limit increased to 0.75A
03:08:51		Observe enclosure starting to deform
03:27:35		Voltage set to 6.5V
03:29:34		Current limit increased to 1.0A
03:36:18		Voltage set to 7.5V
03:40:31		Voltage set to 8.5V
03:44:20		Voltage set to 9.5V
03:44:20 – 04:01:42		Voltage remained at 9.5V
04:01:43 – 04:01:56		Voltage ramped to 18.5V
04:01:56 – 04:08:08		Voltage increased to 28.5V
04:08:09 – 04:09:27		Voltage fluctuates between 7.5V – 28.5V
04:09:27		Voltage stabilizes at 28.5V
04:11:32		Voltage set to 29.5V
04:12:40 – 04:46:00		Voltage set to 30.5V
04:46:01 – 05:02:24		Voltage ramped to 50.5V
05:02:25 - 05:03:24		Voltage increased to 79.5V
05:03:24 – 05:18:53		Current drops, cell temperature observed to drop
05:18:53	End of Test	

Table 6 – Gases measured and measurement methods used in module level testing#			
Measurement Method	**Gases Measured**	**Chemical Formula**	**Gas Type**
Flame Ionization Detection (FID)	Acetylene	C_2H_2	Hydrocarbons
	Ethylene	C_2H_4	Hydrocarbons
	Methane	CH_4	Hydrocarbons
	Methanol	CH_3OH	Hydrocarbons
	Propane	C_3H_8	Hydrocarbons
	Formaldehyde	CH_2O	Hydrocarbons (Aldehydes)
	Hydrogen Bromide	HBr	Hydrogen Halides
	Hydrogen Chloride	HCl	Hydrogen Halides
	Hydrogen Fluoride	HF	Hydrogen Halides
	Carbon Dioxide	CO_2	Carbon Containing
	Carbon Monoxide	CO	Carbon Containing
	Ammonia	NH_3	Nitrogen Containing
	Hydrogen Cyanide	HCN	Nitrogen Containing
	Total Hydrocarbons	-	Hydrocarbons
Solid-state Hydrogen Sensor	Hydrogen	H_2	-
# - This table was modified to reflect the gases measured during testing.			

Table 7 - Gas generation periods	
Time	**Condition**
N/A - no flaming	Pre-Flaming
N/A - no flaming	Flaming
External Flaming of Gas	
Condition	**Duration (s)**
External Flaming of Vent Gases:	N/A

Table 8 – Summary of battery gas volumes identified during thermal runaway in unit test			
Gas Component	**Gas Type**	**During Pre-flaming (L)**	**During Flaming (L)**
Carbon Dioxide	Carbon Containing	N/A	N/A
Carbon Monoxide	Carbon Containing	N/A	N/A
Ethylene	Hydrocarbons	N/A	N/A
Methane	Hydrocarbons	N/A	N/A

Table 9– Summary of battery gas volumes for deflagration hazard calculations			
Gas Component	**Gas Type**	**During Pre-flaming (L)**	**During Flaming (L)**
Total Hydrocarbons (Propane Equivalent)	Hydrocarbons	N/A	N/A
Carbon Dioxide	Carbon Containing	N/A	N/A
Carbon Monoxide	Carbon Containing	N/A	N/A
Hydrogen	Hydrogen	N/A	N/A

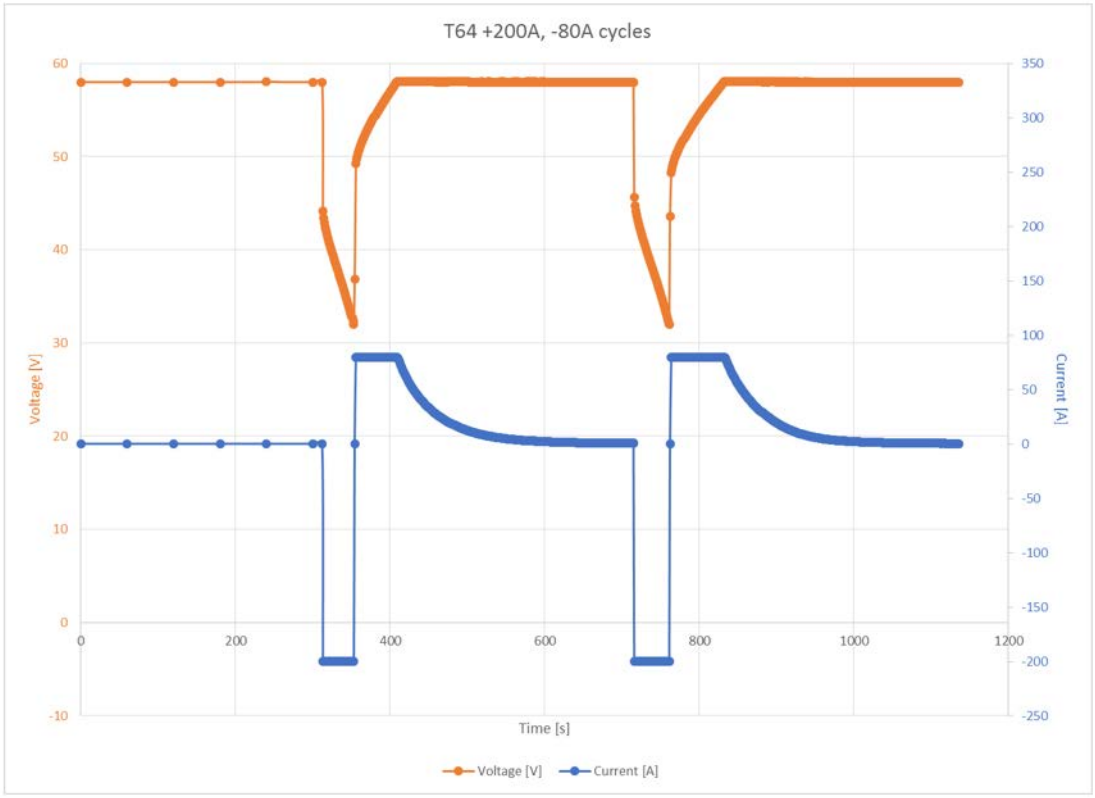
Table 10 – Smoke and heat release rate			
Heat Release Rate (HRR)		**Smoke Release Rate (SRR)**	
Peak Chemical HRR (kW)	N/A	Maximum SRR (m^2/s)	N/A
		Total Smoke Released (m^2)	N/A

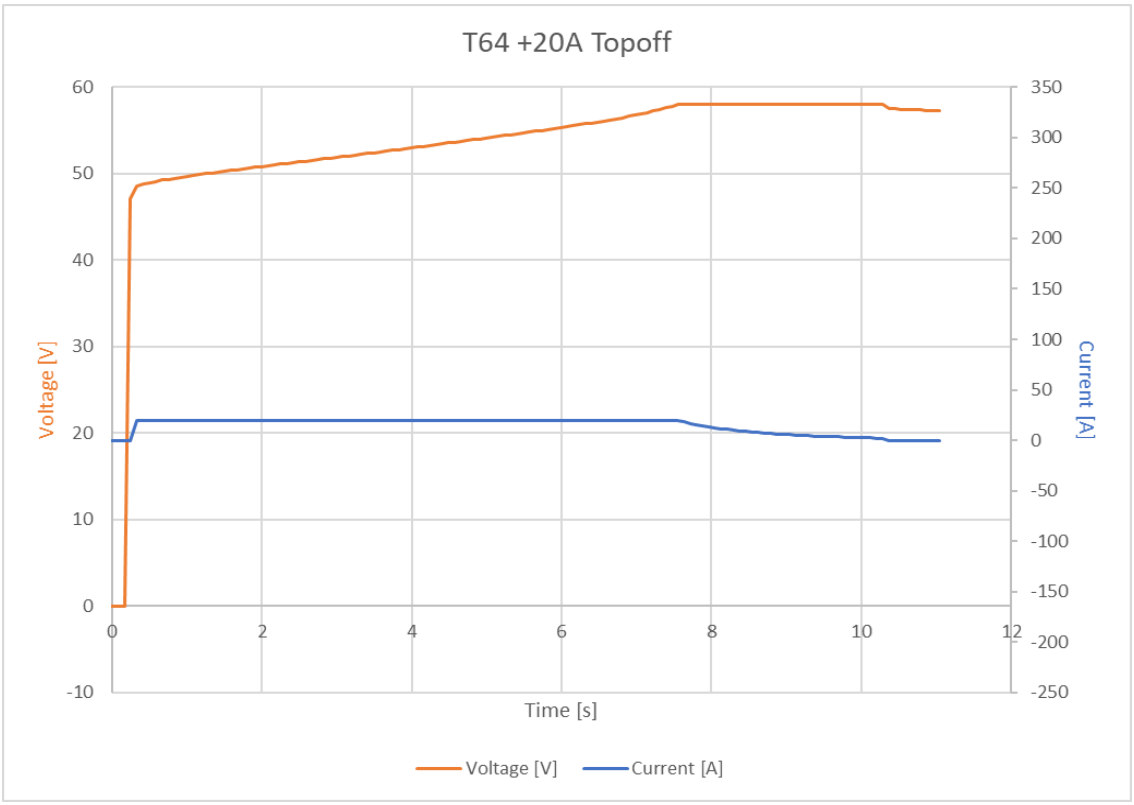
Table 11 – Module Weight During Test, kg	
Before Test:	37lbs (16.78kg)
After Test:	37lbs (16.78kg)
Weight Loss:	0lbs (0kg)

Table 12 – Other Observations during module test		
	Observed, Yes/No	Location
Flying debris	No	N/A
Explosive discharge of gas	No	N/A
Sparks or electrical arcs	No	N/A

	TABLE: Critical components information				
Object / Part No.	**Manufacturer/ trademark**	**Type / model**	**Technical data**	**Standard**	**Mark(s) of conformity[1)]**
Cells	Natron Energy Inc	V6.0	1.56V, 4.6Ah	UL 1973	UL MH63828
Case	N/A	Aluminium	N/A	N/A	N/A
Internal Wiring	Unverified	Unverified	Unverified	Unverified	Unverified
Fire Protection Mechanisms	N/A	N/A	N/A	N/A	N/A
Electrical Protection Mechanisms	Eaton	180LET	Fuse	Unverified	Unverified
Fan	Unverified	Unverified	Unverified	Unverified	Unverified

Attachment A: Module Conditioning (Charge/discharge) Profiles - (*Pages **15** through **15***)





Attachment B: Module Construction Photos - (*Pages **16** through **16***)

Fig. B1 – Cover removed	Fig. B2 – Top insulator removed

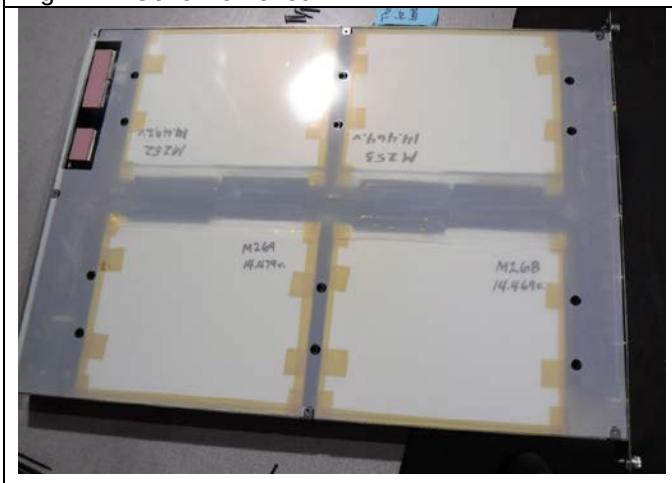
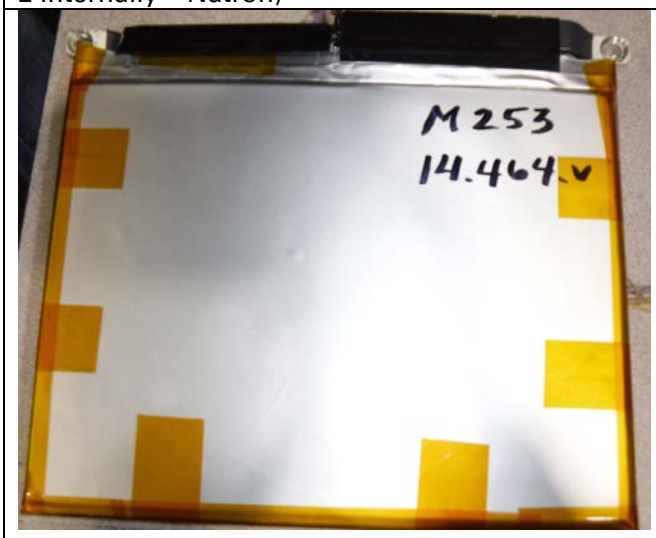



Fig. B3 – 8S/1P cell package (referred to as Module 2 internally – Natron)	
	

Attachment C: : Module Instrumentation Photos - (*Pages **17** through **18***)

Fig. C1 – Top of module (TC center of enclosure)	Fig. C2 –Bottom of module (TC center of enclosure)

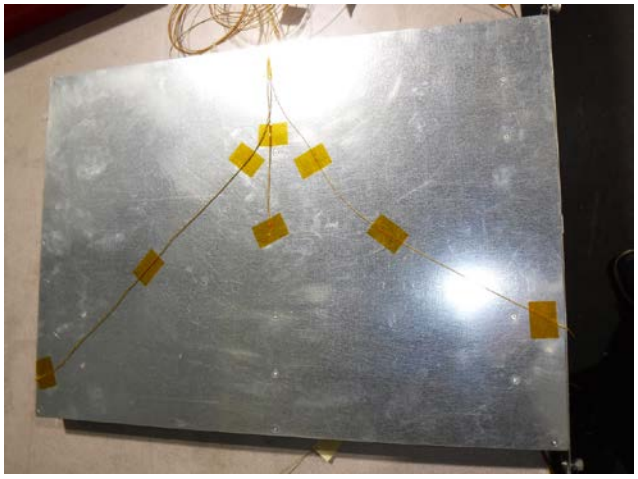
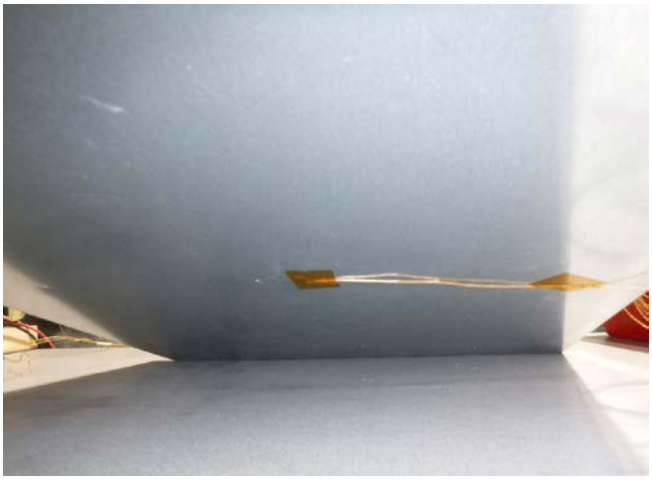

	

Fig. C3 –Front of module (TC in vent opening)	Fig. C4 –Rear of module (TC in fan opening)

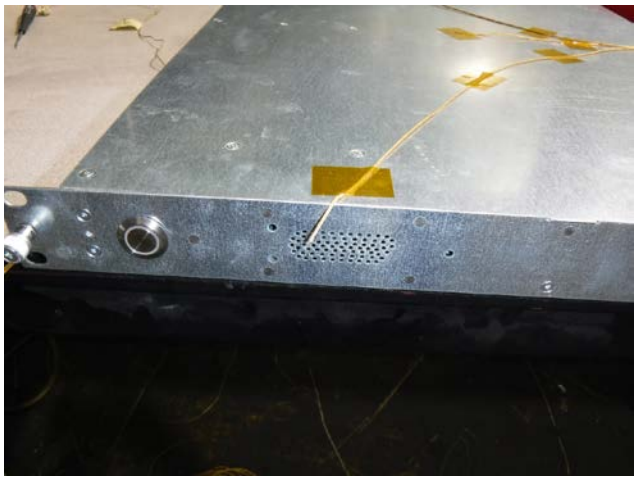
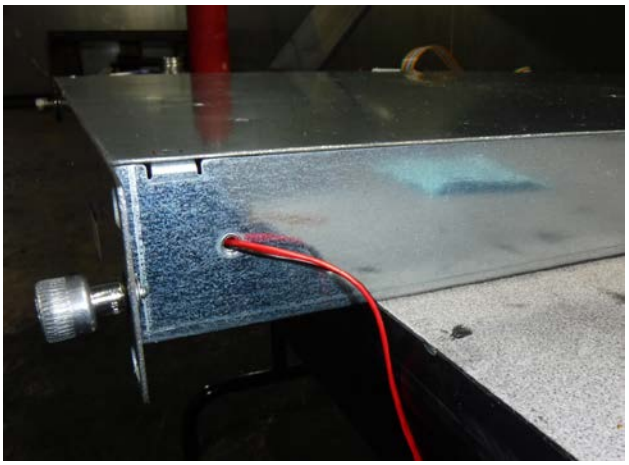



Fig. C5 –Overall Photo (TC exiting enclosure)	Fig. C6 –Side showing location where charging leads exit enclosure
	
Fig. C7 –Overall Photo of cell group with initiating cell	Fig. C8–Mod2Cell5 Top (initiating cell)

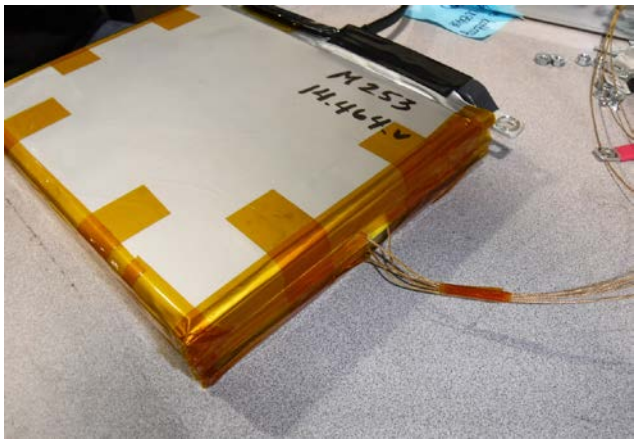


Fig. C9–Mod2Cell5 Bottom (initiating cell)

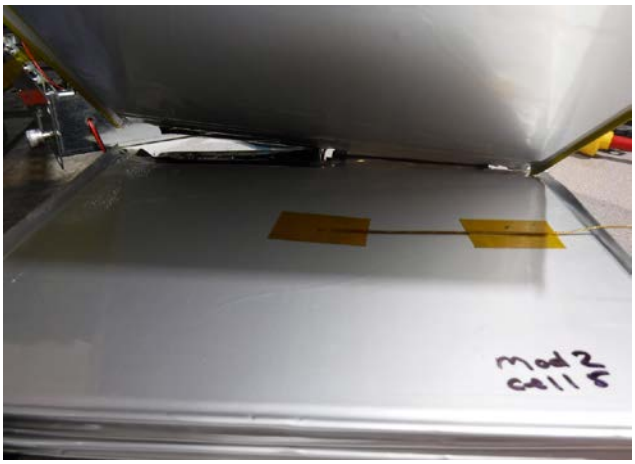


Fig. C10 –Mod2Cell4 (Top) – located above initiating cell

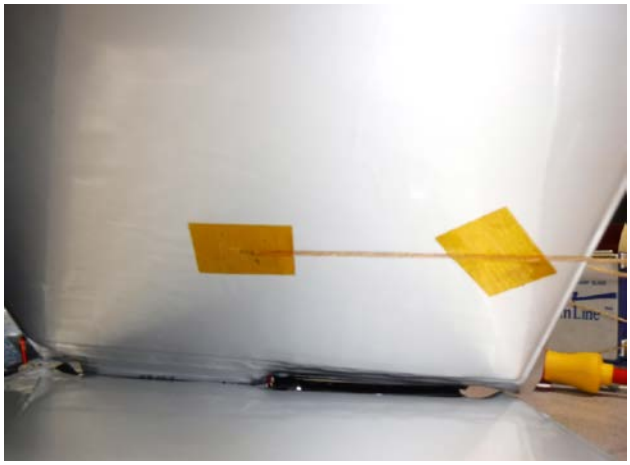


Fig. C11 –Mod2Cell6 Bottom – located below initiating cell

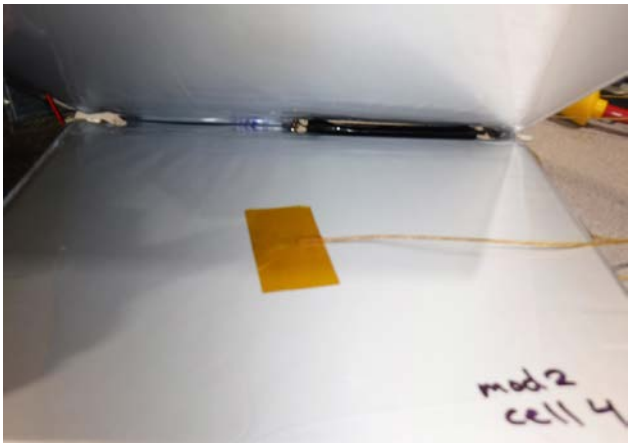
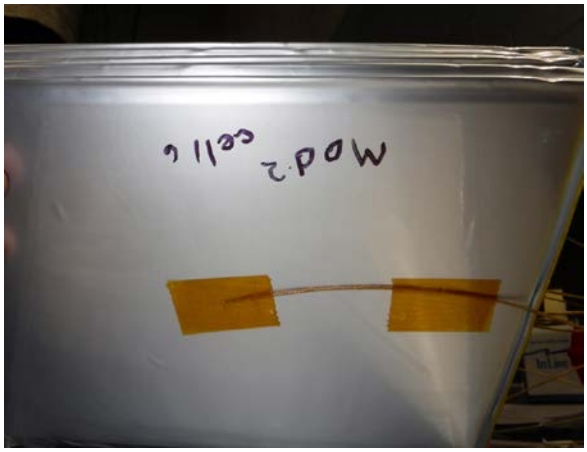


Fig. C12 – Overall internal layout



Attachment D: Module and Initiating Cell Temperature Profiles During Testing - (*Pages **19** through **20***)

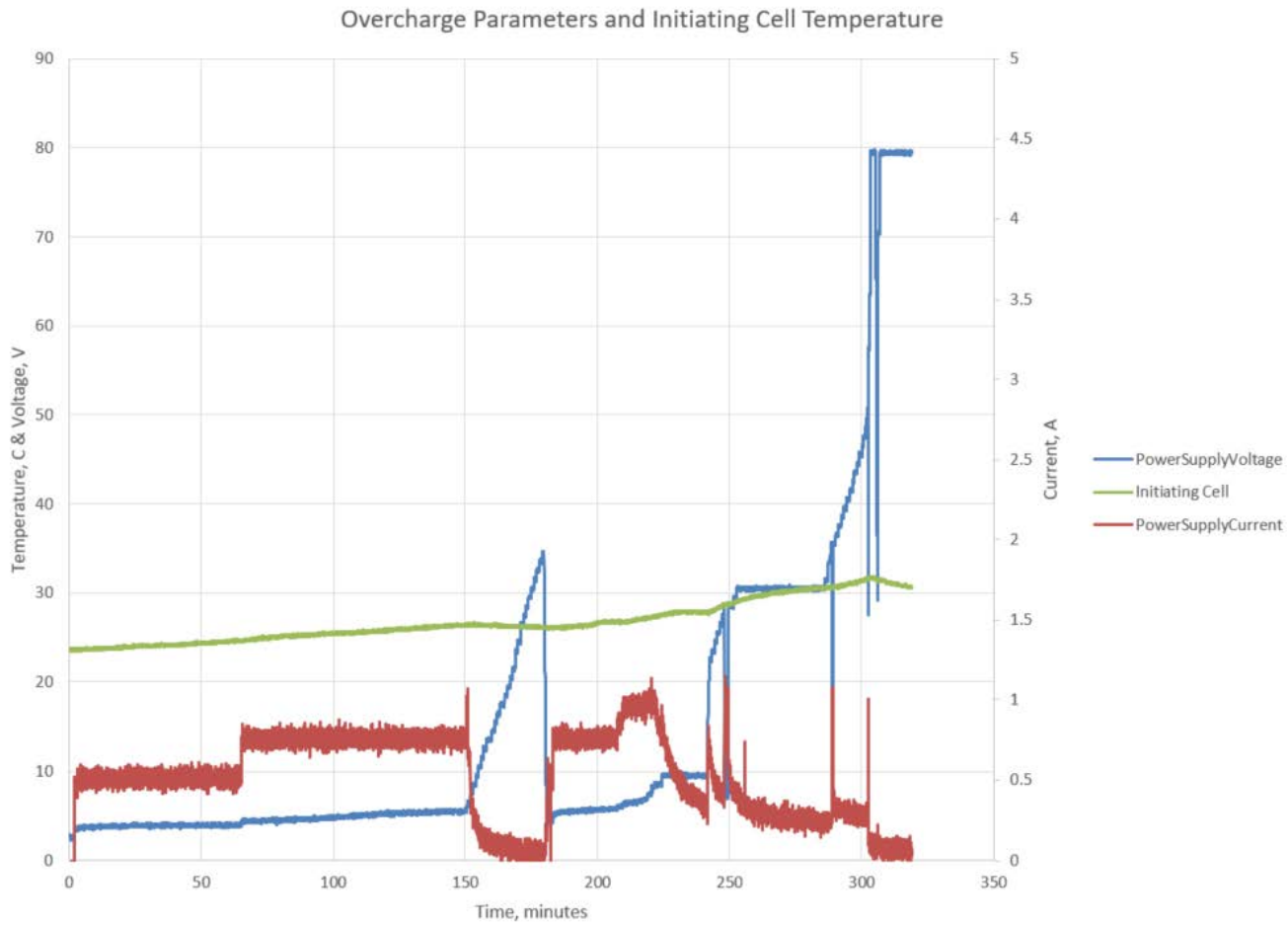


Fig D1 – Charging Voltage & Current, Initating Cell Temperature

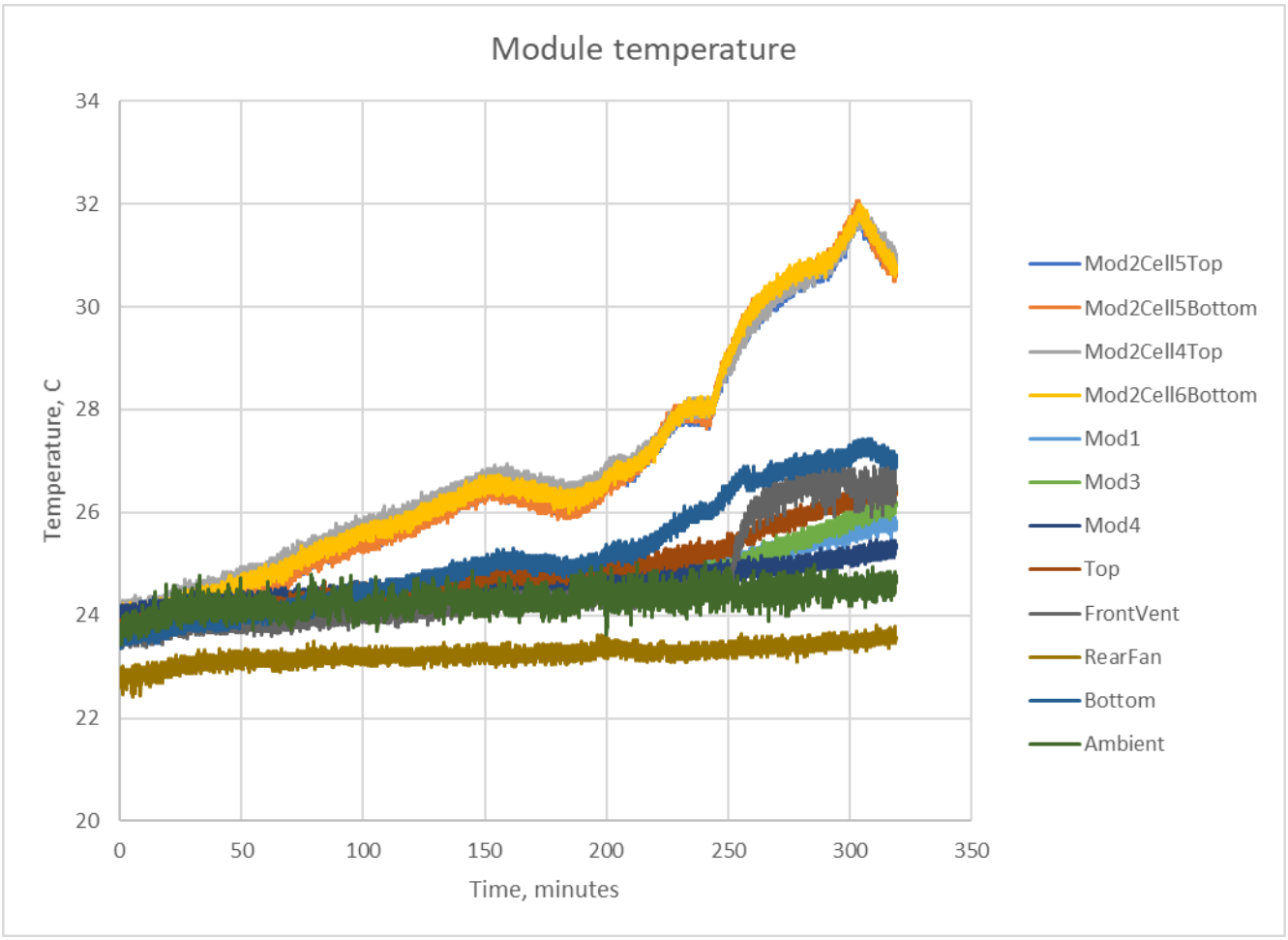


Fig D2 – Temperatures for all parts

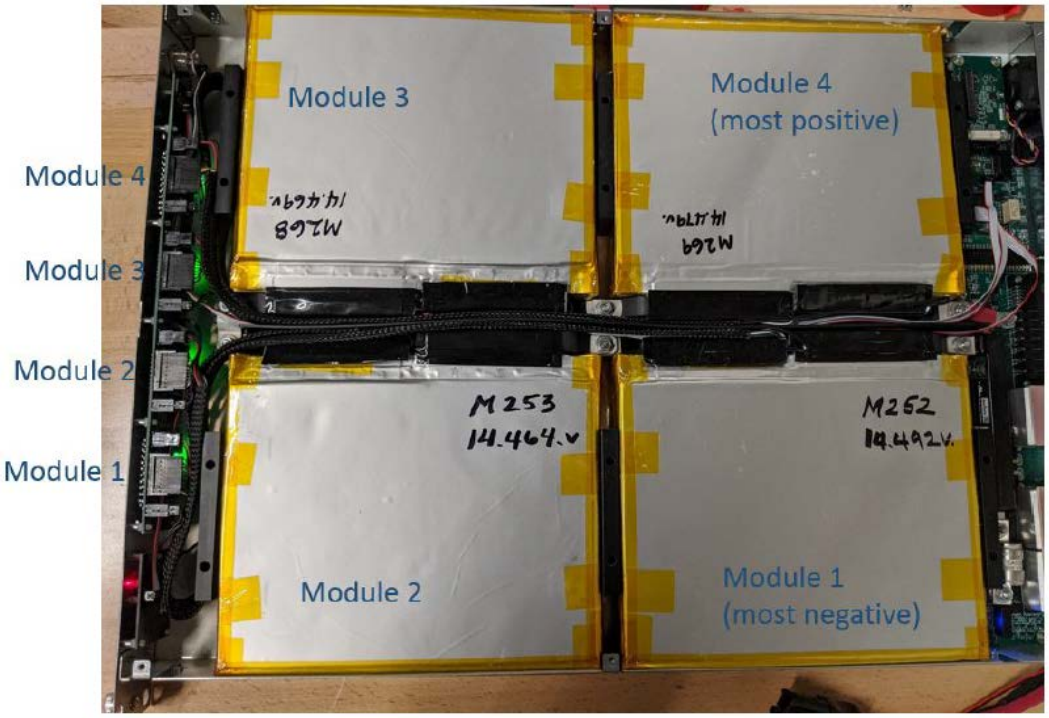


Fig D3 – Guide for naming of interal thermal couples

Attachment E: Module Testing Photos - (*Pages **21** through **23***)

Fig. E1 - Initial Observation of the expansion of the initiating cell causing the enclosure to deform.

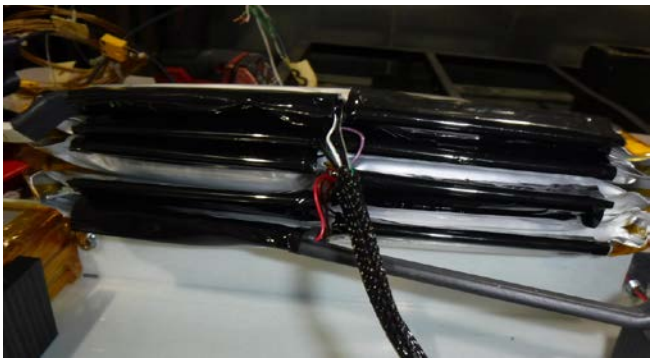
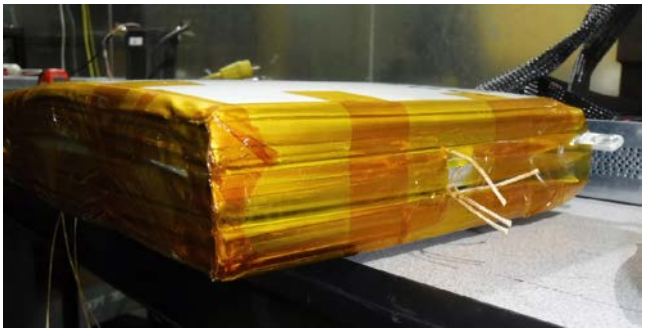
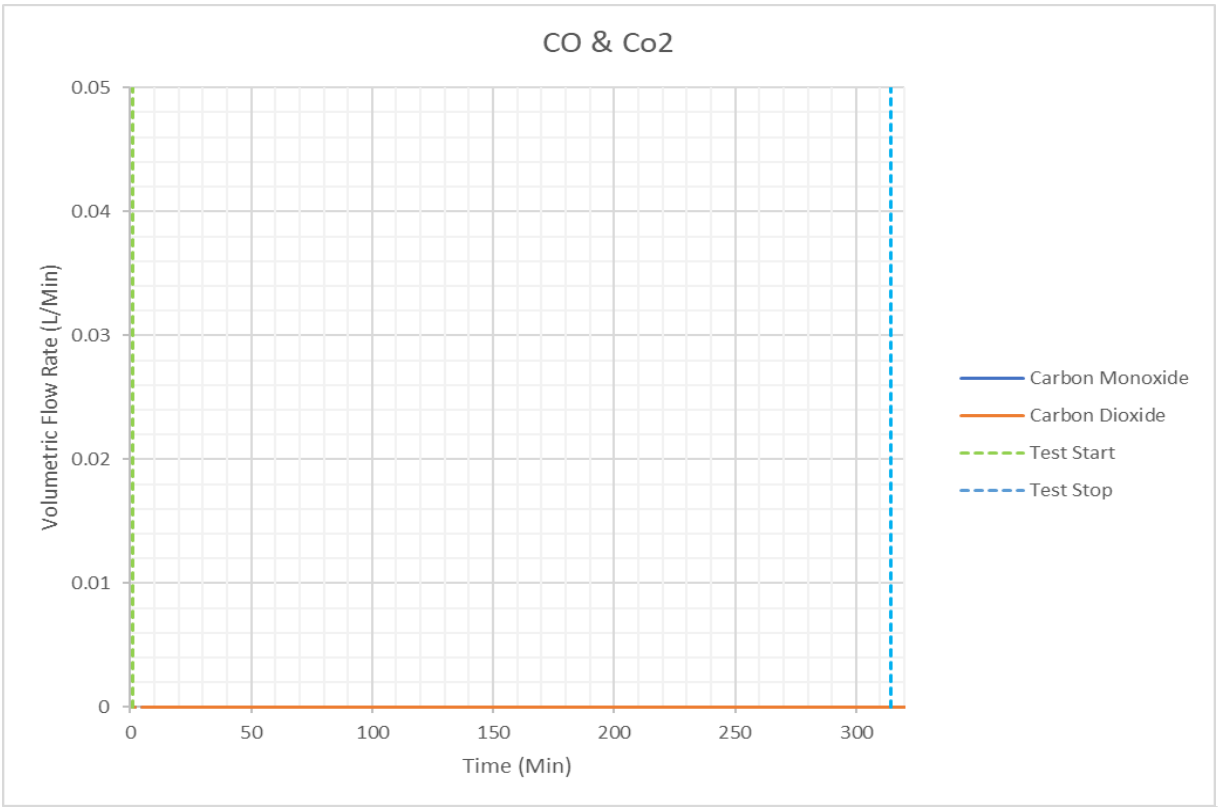
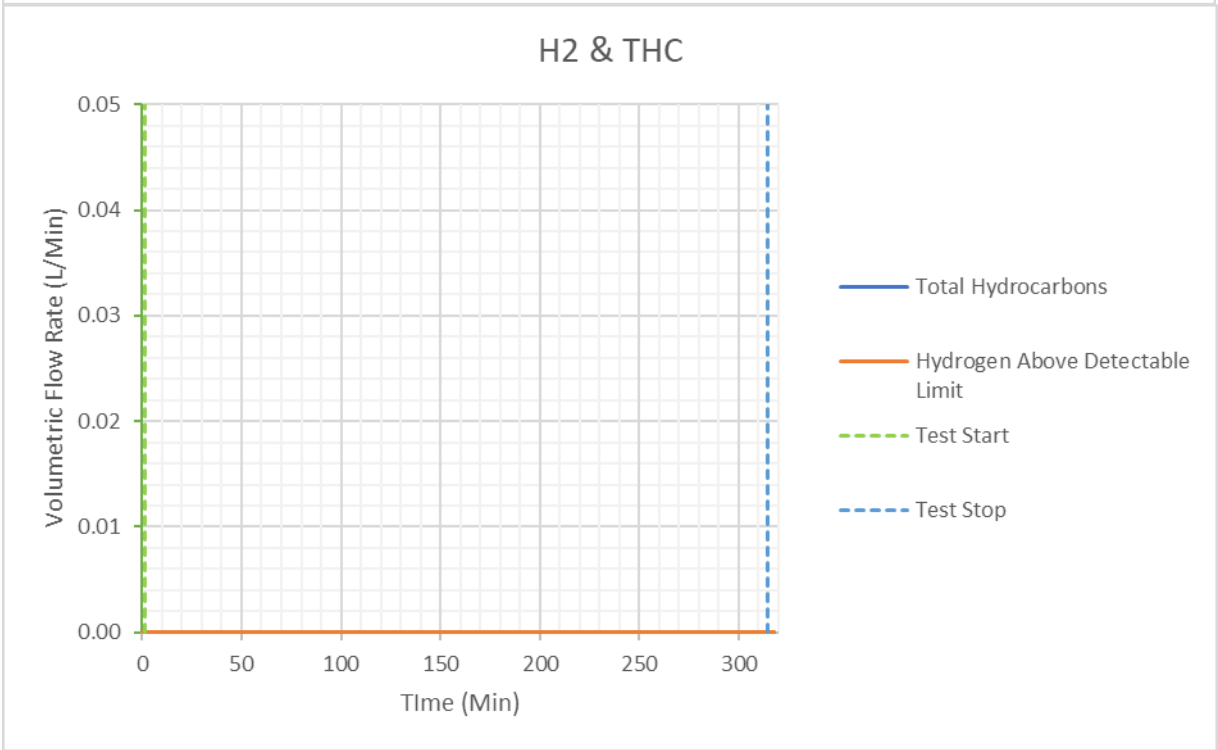
Fig. E2 – Observed expansion of enclosure	Fig. E3 – Measured expansion of 1cm.
	
Fig. E4 – Internal cell group (view from cells facing the right side of module)	Fig. E5 – Internal cell group (view from cells facing the left side of module)
	
Fig. E6 – Internal cell group (view from cells facing the front of module)	Fig. E7 – Internal cell group (view from cells facing the rear of module)
	

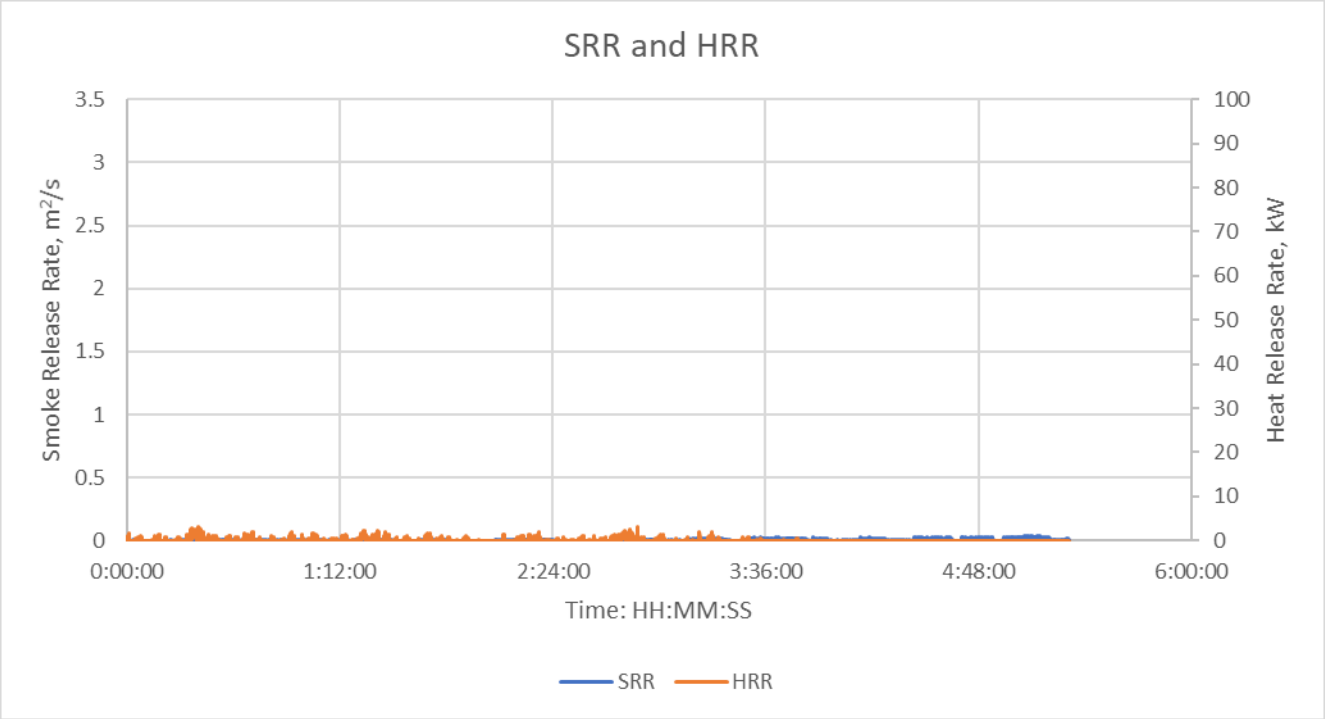
Fig. E8 – Initiating cell & surrounding cells	Fig. E9 – Initiating cell (top side)
	
Fig E10 – Initiating cell (edge)	Fig E11 – Initiating cell (bottom)
	

Reference source not found.

Attachment F: Module Gas Flow Rate and Heat Release Profiles - (*Pages **24** through **25***)






SRR and HRR
Smoke Release Rate, m²/s
Heat Release Rate, kW
3.5
3
2.5
2
1.5
1
0.5
0
100
90
80
70
60
50
40
30
20
10
0
0:00:00
1:12:00
2:24:00
3:36:00
4:48:00
6:00:00
Time: HH:MM:SS
SRR
HRR