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

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UL report office	UL(Changzhou) Quality Technical Service Co., LTD
Applicant name	SHENZHEN ACE BATTERY CO.,LTD.
Applicant address	Room 2905, Hanking Financial Center, No.9968 Shennan Avenue, Nanshan District, Shenzhen, Guangdong Province 518000, P.R.China
Standard	UL 9540A:2025, Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems, 5th Edition, March 12, 2025
Test procedure	Section 8
Non-standard test method	N/A

General disclaimer:

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

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

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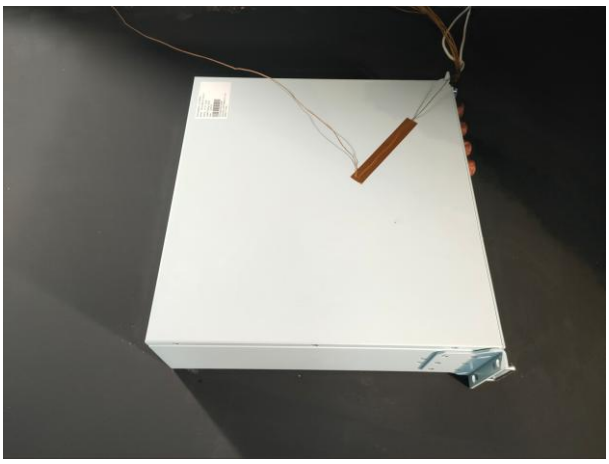
Picture of sample:



Cell information	
Model number	50160116-Fe-100
Rating, Vdc	3.2
Rating, Ah	100
Chemistry of test item	Lithium Iron Phosphate/ Graphite
Format	Prismatic
Overall dimensions, mm	(50.1±0.5) (Thickness) by (160.0±0.5) (Width) by (115.7±0.5) (Height)
Cell weight, g	1985
Original equipment manufacturer (OEM)	SHENZHEN ACE BATTERY CO.,LTD.
Branding manufacturer (if not OEM)	N/A
Standard test item certified to	UL1973
Organization that certified test item	UL Solutions, File No.: MH63650
Summary of cell test results	
Average cell surface temperature at gas venting, °C	182
Average surface temperature at thermal runaway, °C	230
Gas volume, L	46.1
Lower flammability limit (LFL), % volume in air at the ambient temperature	6.95
Lower flammability limit (LFL), % volume in air at the venting temperature	5.85
Burning velocity, (S_u) cm/s	88.06
Maximum pressure, (P_{max}) psig	96.37

Cell gas composition

Gas		Measured %
Carbon Monoxide	CO	6.413
Carbon Dioxide	CO_2	19.265
Hydrogen	H_2	63.238
Methane	CH_4	4.772
Acetylene	C_2H_2	0.184
Ethylene	C_2H_4	2.404
Ethane	C_2H_6	0.937
Propene	C_3H_6	0.413
Propane	C_3H_8	0.176
-	C4 (Total)	0.900
-	C5 (Total)	0.238
-	C6 (Total)	0.161
1-Heptene	C_7H_{14}	0.032
Benzene	C_6H_6	0.054
Toluene	C_7H_8	0.013
Dimethyl Carbonate	$C_3H_6O_3$	0.013
Ethyl Methyl Carbonate	$C_4H_8O_3$	0.786
Total	-	100.000

Module Information	
Module Manufacturer	SHENZHEN ACE BATTERY CO.,LTD.
Model number	RESS-BM-051100-RLX (X: may be 1 to 99, represent the different control panel construction), LiFe4851
Rating, Vdc	51.2
Rating, Ah	100
Module cell configuration, xS/yP	16S/1P
Module dimensions (W x D x H), mm	W(420.0±2.0) × D(482.0±2.0) × H(130.5+1.5/-0)
Module weight, kg	42±2
Standard test item certified to	N/A
Organization that certified test item	N/A

Cell failure test method performed for the module level

☒ External heating using thin film heater(s)

☐ Nail Penetration

☐ Overcharge

☐ External short circuit

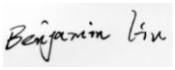
☐ Overdischarge

☐ Others:

Description of method used to fail cells if other than external thin film heater with thermal ramp:
N/A

Description of components employed within the module that serve to suppress thermal runaway propagation (fire protection features):

There was one thermal insulation pad between each two cells in the module, total 3 pcs.

Summary of module level test		
Performance criteria in accordance with Clause 8.5 [X] Vent gas ~~[was]~~ **[** was not **]** nonflammable as determined by the cell level test; [X] There ~~[was]~~ **[** was no **]** spread of flame outside of the module; and [X] The module exterior surface temperature ~~[did]~~ **[** did not **]** exceed the cell venting temperature. [ ] All the performance criteria of the module level test as indicated in 8.5 of UL 9540A, 5th edition have been met, therefore, the unit level test in accordance with Section 9 of UL 9540A was not required to be conducted. [X] All the performance criteria of the module level test as indicated in 8.5 of UL 9540A, 5th edition have not been met, therefore, the unit level test in accordance with Section 9 of UL 9540A is required to be conducted on a complete unit employing this module.		
Testing Laboratory information		
Testing Laboratory and testing location(s)		
Testing Laboratory	Beijing Building Materials Testing Academy	
Testing location/ address	Block 1, B15 Yaxin Road, Doudian Town, Fangshan district, Beijing 102402, CN	
Tested by (name)	Zhang Qi	
Witnessed by (for 3rd Party Lab Test Location) (name, signature)	Oliver Zhao	N/A
Project Handler (name, signature)	Fred Pan (T)/ Sunny Guan	
Reviewer (name, signature)	Benjamin Liu	

List of Attachments (including a total number of pages in each attachment)		
Attachment	**Description**	**Pages**
A	Module Conditioning (Charge/discharge) Profiles	***16** through **18***
B	Module Construction Photos	**19** through **19**
C	Module Instrumentation Photos	***20** through **22***
D	Module and Initiating Cell(s) Temperature Profiles	***23** through **23***
E	Module Testing Photos	***24** through **25***
F	Module Gas Flow Rate, Chemical Heat Release Rate Profile, Smoke Release Rate Profile	***26** through **28***
G	Other models photos (for reference)	***29** through **32***

Test Verdicts	
Clause Requirement Does Not Apply to the Test Item:	N/A (Not Applicable)
Clause Requirement Met**:**	M (Met)
Clause Requirement Not Met:	NM (Not Met)
Clause Requirement Completed:	C (Completed)
Clause Requirement Completed with Modification	Mod (Modified)
Test Dates	
Date of Receipt of Test Item	2025-05-20
Date(s) of Performance of Tests	2025-05-27
General remarks	
"(See Attachment #)" refers to additional information appended to the report. Throughout this report a point is used as the decimal separator.	
Manufacturer's Declaration of samples submitted for test:	
The module can be manufactured at more than one location. The manufacturer provided a written declaration stating that the manufacturing process at all manufacturing locations is identical and product from one manufacturing location is representative of all manufacturing locations listed below.	☐ **Yes** ☒ **Not applicable**
Name and address of factory(ies) supplying samples for test:	SHENZHEN ACE BATTERY CO.,LTD DAPENG BRANCH Room 101, Building B05, BAK Industrial Park, No. 119-2 Kuipeng Road, Kuixin Zone, Kuichong Street, Dapeng District, Shenzhen, Guangdong Province 518119, P.R.China
General product information and other remarks: Battery Module Model RESS-BM-051100-RL1 employs cell Model 50160116-Fe-100, manufactured by SHENZHEN ACE BATTERY CO.,LTD, rated 3.2V 100Ah. All the models with the same cell module construction and the same enclosure construction and dimension, only the control panel construction are different. Only model RESS-BM-051100-RL1 performed the test. Battery Module is manufactured by SHENZHEN ACE BATTERY CO.,LTD DAPENG BRANCH, rated 51.2V, 100Ah.	

UL 9540A, Edition 5			
Clause	**Requirement + Test**	**Remark**	**Verdict**
PERFORMANCE			
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	C
8.1.2	100% SOC and allowed to rest for a minimum of 1h before testing		
8.1.3	The module voltage was measured and recorded before testing.		C
8.1.4	Electronic controls such as BMS not relied upon during testing		C
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 2 The Ambient temperature 28.9 °C and humidity 41.5% at the initiation of the test.	C
8.2.2	Test conducted under a smoke collection hood appropriately sized for the module		C
8.2.3	The weight of the module was recorded before and after testing, kg, unless consumed by fire	See Table 9	C
8.2.4	The number of cells within the module that are forced into thermal runaway can be one or multiple cells and is dependent upon the energy contained within the individual cells and the design of the module. 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	C
8.2.5	A sufficient number of cells were forced into thermal runaway to create a condition of cell to cell thermal runaway propagation within the module	See Attachment C	C
8.2.6	Temperatures were measured on • initiating cells, • nearby non-initiating cells, and • exterior surface of module enclosure closest to initiating cell locations	See Tables 4 and 5	C
8.2.7	The method used to initiate thermal runaway in the cell(s) were in accordance with 7.3	See Summary of Cell Testing at the beginning of this report.	C
8.2.8	The occurrence of thermal runaway was verified	See Test Results from Cell Level Test from the beginning of this report See Attachment D	C
8.2.9	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	C

UL 9540A, Edition 5			
Clause	**Requirement + Test**	**Remark**	**Verdict**
8.2.10	The chemical heat release rate of the module was measured with oxygen consumption calorimetry	See Table 8 See Attachment F	C
8.2.11	The chemical heat relate rate was measured for the duration of the test	See Attachment F	C
8.2.12	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	C
	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.		C
8.2.13	The chemical heat release rate at each of the flows was calculated in accordance with 8.2.11.	See Attachment F	C
8.2.14	The hydrocarbon content of the vent gas was measured using flame ionization detection.	See Table 5	C
	Hydrogen gas shall be measured with an appropriate sensor for the anticipated range of gas as well as for exposure to anticipated contaminants, such as a palladium-nickel thin-film solid state sensor.	See Table 5	C
8.2.15	At the request of the BESS manufacturer, the hydrocarbon content of the vent gas may 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 Table 5	C
	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.		C
8.2.16	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.		C
8.2.17	Smoke release rate was calculated as outlined in 8.2.15	See Table 8 See Attachment F	C
8.4	**Module level test report**		
8.4.1	Module level report includes the following:		
	a. Module manufacturer and model number and whether UL 1973 compliant; b. Number of cells in module; c. Module configuration;	See Test Item Description at start of this report.	C

UL 9540A, Edition 5			
Clause	**Requirement + Test**	**Remark**	**Verdict**
	d. Module construction features;	See Attachment C See Critical Components Table See "Description of components employed within the module that impact propagation (fire protection features)" at the beginning of this report.	C
	e. Module voltage corresponding to the tested SOC;	See Table 2	C
	f. Thermal runaway initiation method used;	See Attachment C	C
	g. Heat release rate versus time data;	See Table 8 See Attachment F	C
	h. Flammable gas generation and composition data;	See Attachment F See Table 7	C
	i. Peak smoke release rate and total smoke release data.	See Table 8 See Attachment F	C
	j. Observation(s) of flying debris or explosive discharge of gases;	See Attachment E and Table 10	C
	k. Observation(s) of sparks, electrical arcs, or other electrical events;	See Attachment E and Table 10	C
	l. Identification/location of cells(s) that exhibited thermal runaway within the module;	See Table 3	C
	m. Locations and visual estimations of flame extension and duration from the module;	See Attachments E See Table 10	C
	n. Module weight loss;	See Table 9	C
	o. Module exterior maximum temperature		C
	p. Video of the test.		C
	q. Cell level test report summary		C
8.5	**Performance – Module level**		
8.5.1	Unit level testing is not required if all the following performance conditions are met during the module level test:		
	a. Cell vent gas is nonflammable as determined by the cell level test		NM
	b. There is no spread of flame outside of module;		M
	c. Module exterior temperature does not exceed the cell venting temperature as measured adjacent to the initiating cell where the greatest thermal exposure is anticipated		NM

Table 1 – Specified conditioning parameters			
Charging		**Discharging**	
Power (CP), kW	20	Power (CP), kW	20
Rated full charge voltage, Vdc	56	End-of-discharge voltage, Vdc	Module reach 33.6V or any cell reach 2.4V ±0.3V
End-of-charge	5	Discharging test ambient, °C	0~60
Charging test ambient, °C	0~60		
See Attachment A for charge/discharge profiles for each cell.			

Table 2 Test Initiation Details	
Charge completion date,	2025-05-27
Charge completion time,	01:11
Test Date,	2025-05-27
Test Start Time,	12:59
Initial Lab Temperature, °C	28.9
Initial Relative Humidity, %RH	41.5
Module OCV at Start of Test, Vdc	54.59
Method used to force cell into thermal runaway, details of failure methods (such as overcharge parameters)	External heating using thin film heaters

Table 3 – Approximate time of thermal runaway propagation through module	
Time to thermal runaway, hh:mm:ss	**Location**
00:55:55	Cell 9 TR
00:58:45	Cell 12 TR

Table 4 – Test overview timeline		
Time, hh:mm:ss	**Event**	**Description**
00:00:00	Test Start	The test was started and the heater was turned on to heat the initiating cell (Cell 9) at a ratio of 4 ~ 7 °C/min.
00:55:35	Venting of initiating Cell 9	Initiating cell (Cell 9) vented at around 148°C measured through TC-9-4 by an indication of sudden dip in cell's temperature curve and the bulge of top enclosure. See Figure (b)
00:55:55	Thermal runaway of initiating Cell 9	Initiating cell (Cell 9) was at around 157°C. The temperature of cell 9 began to increase in an uncontrollable manner, Gas venting observed from all sides with no flame observed. See Figure (c)
00:58:45	Thermal runaway of adjacent Cell 12	Thermal runaway propagated to nearby cell (cell 12). More Gas released. See Figure (d)
02:00:00	Test Termination	Propagation through complete module, no further thermal runaway observed after this time. Data collection stopped. See Figure (e).

Table 5 – Gases measured and measurement methods used in unit level testing			
Measurement Method	**Gases Measured**	**Chemical Formula**	**Gas Type**
Flame Ionization Detection (FID)	Total Hydrocarbons	-	Hydrocarbons
Solid-state Hydrogen Sensor	Hydrogen	H_2	-
Non-dispersive infrared spectroscopy (NDIR)	Carbon Dioxide	CO_2	Carbon Containing
	Carbon Monoxide	CO	Carbon Containing
# - This table was modified to reflect the gases measured during testing.			

Table 6 - Gas generation periods	
Time, hh:mm:ss to hh:mm:ss	**Condition**
00:55:35 to 02:00:00	No-Flaming
N/A	Flaming
External Flaming of Gas	
Condition	**Duration (hh:mm:ss)**
External Flaming of Vent Gases:	N/A

Table 7– Summary of battery gas volumes for deflagration hazard calculations				
Gas Component	Gas Type	During Pre-flaming, L	During Flaming, L	Minimum detectable flow rate, LPM
Total Hydrocarbons (Propane Equivalent)	Hydrocarbons	201.60	No flaming	0.08
Carbon Monoxide	Carbon Containing	12.65	No flaming	0.40
Carbon Dioxide	Carbon Containing	31.48	No flaming	0.49
Hydrogen	Hydrogen	39.53	No flaming	4.47

Table 7A – Summary of battery gas volumes identified during thermal runaway in module test when using FTIR			
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 8 – Chemical heat and smoke release rates			
Chemical Heat Release Rate (HRR)		**Smoke Release Rate (SRR)**	
Peak Chemical HRR, kW	No flame	Maximum SRR, m^2/s	0.85
		Total Smoke Released, m^2	77.12

Table 9 – Module Weight Loss and Temperature	
Module weight Before Test, kg:	42.48
Module weight After Test, kg:	41.95
Weight Loss, kg:	0.53
Maximum measured temperature on module enclosure, °C	123

Table 10 – Other Observations		
	Observed, Yes/No	**Location**
Flying debris	No	N/A
Enclosure rupture	No	N/A
Explosive discharge of gas	No	N/A
Sparks or electrical arcs	No	N/A
Flaming outside of module	No	N/A

Attachment A: Module Conditioning (Charge/discharge) Profiles - (*Pages **16** through **18**)*

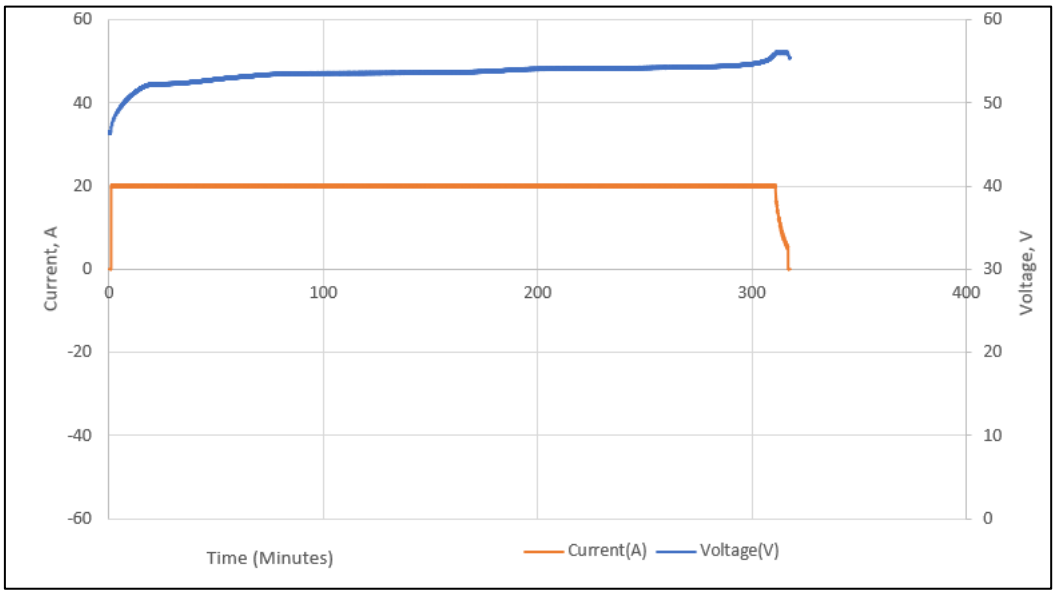


Figure 1 - Charge/Discharge Cycle (1st Charge)

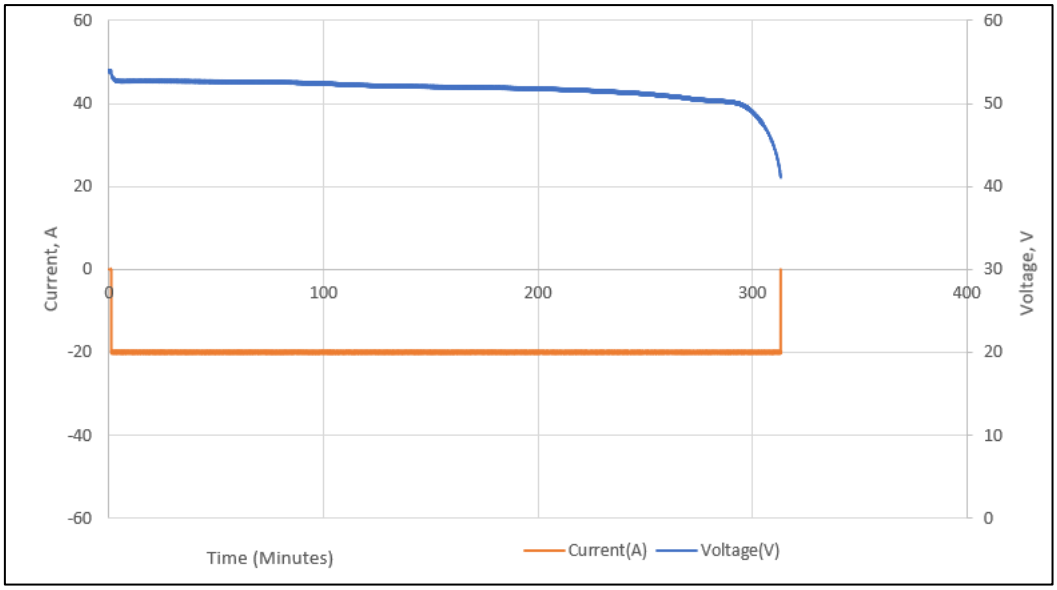


Figure 2 – Charge/Discharge Cycle (1st Discharge)

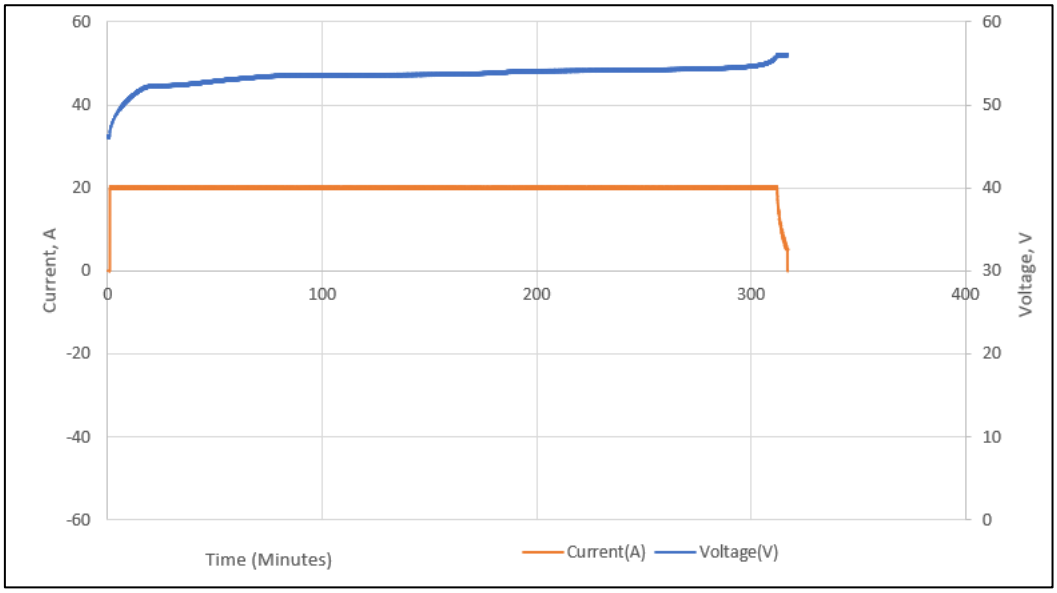


Figure 3 – Charge/Discharge Cycle (2nd Charge)

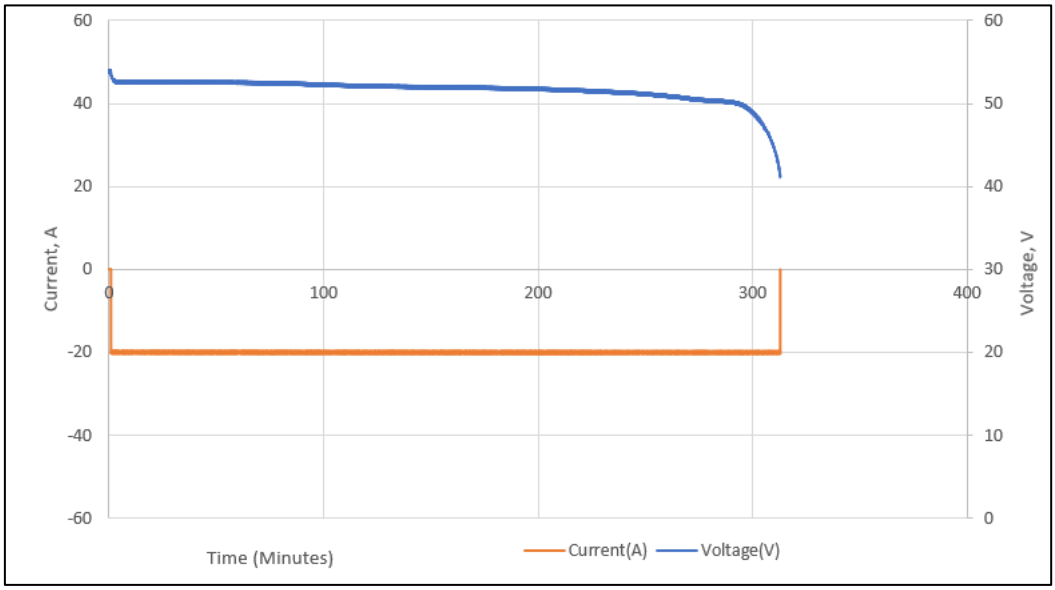


Figure 4 – Charge/Discharge Cycle (2nd Discharge)

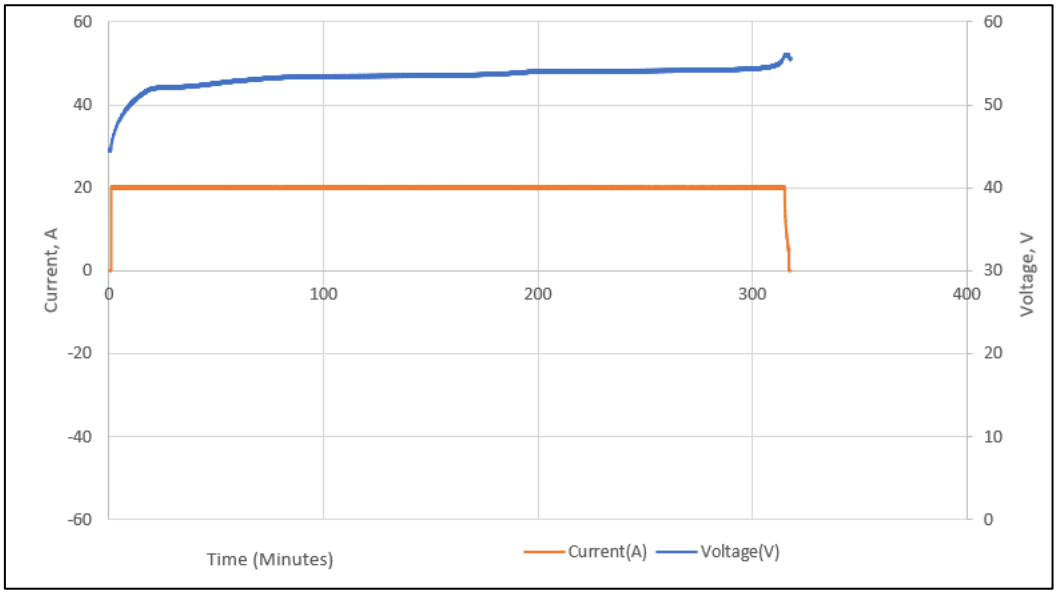


Figure 5 – Charge/Discharge Cycle (3rd Charge)

Attachment B: Module Construction Photos - (Pages ***19*** rough ***19)***

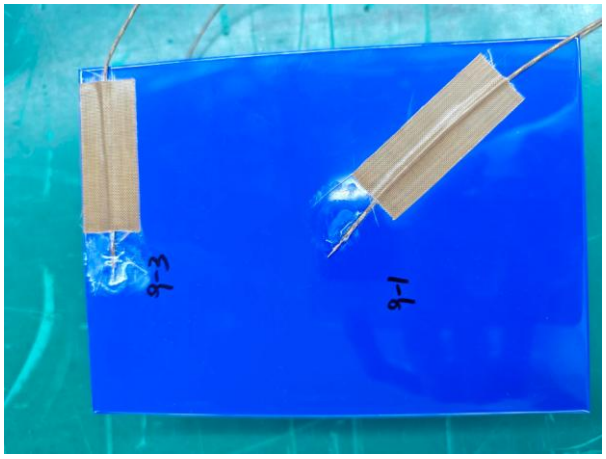


Figure 6 - Photo of cell – large side

Figure 7 - Photo of cell – Top view

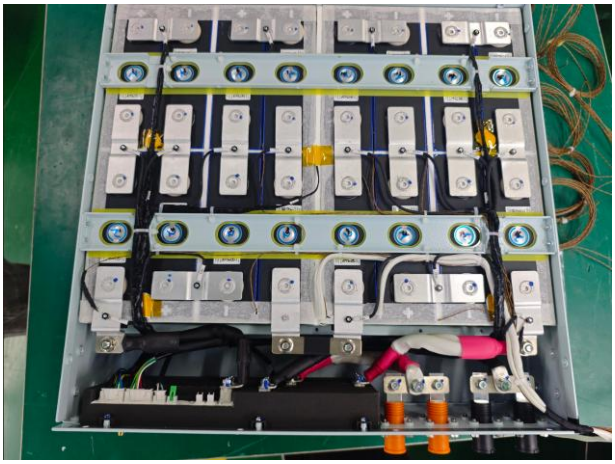


Figure 8 - Photo of module – Internal view

Figure 9 - Photo of module – Front view

Attachment C: Module Instrumentation Photos - (*Pages **20** through **22***)

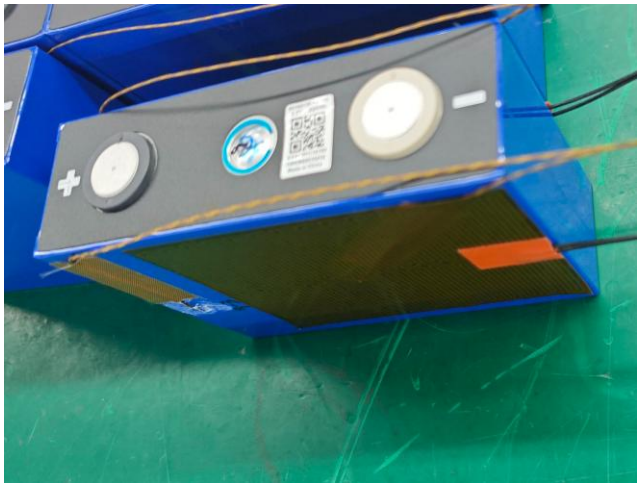


Figure 10 – Cell with heater. 1 piece of 152.4 mm by 203.2 mm for each wide surface, total 2 pieces for cell 9.

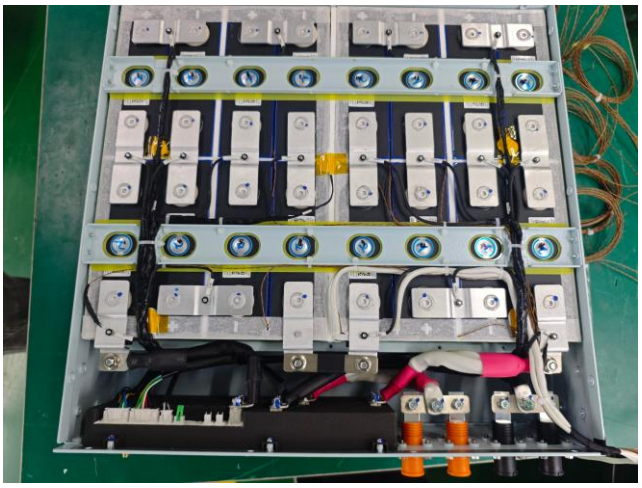
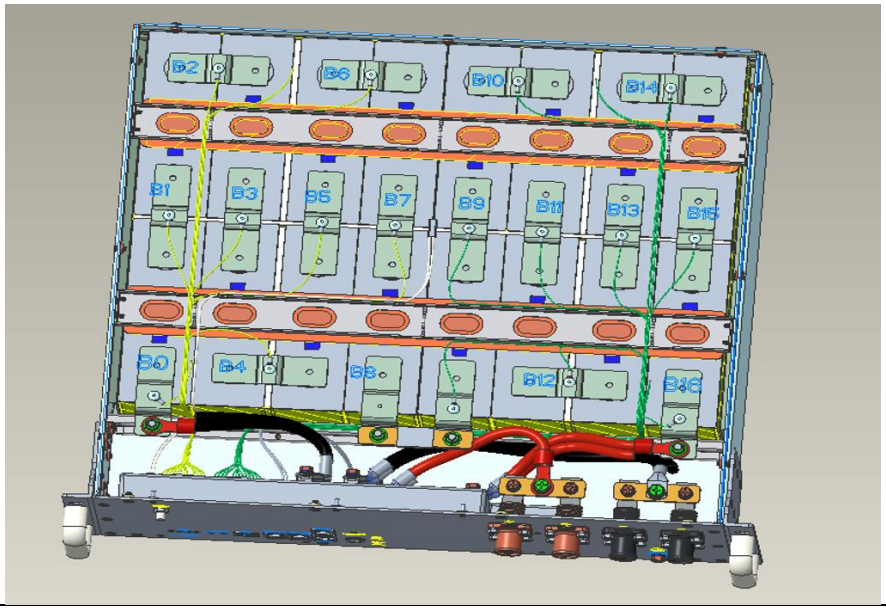


Figure 11 – Module with heater, TCs Sampling wires.

Note:
The thermocouple TC-9-1 was used to control the supply power to the heater to keep the heating rate at 4 ~ 7 °C/min. TC-9-3 and TC-9-4 were used to represent the temperature of initiating cell.
TC-9-1 and TC-9-2, on the wide side surface center of cell 9, between the cell and heater.
TC-9-3 and TC-9-4, on each wide side surface center of cell 9, not covered by heater.
Enclosure, on the external enclosure surface nearby cell 9 position
TC-7, TC-8, TC-10, TC-11, TC-12 and TC-13 were attached on the wide surface center of cells shown in below illustration.



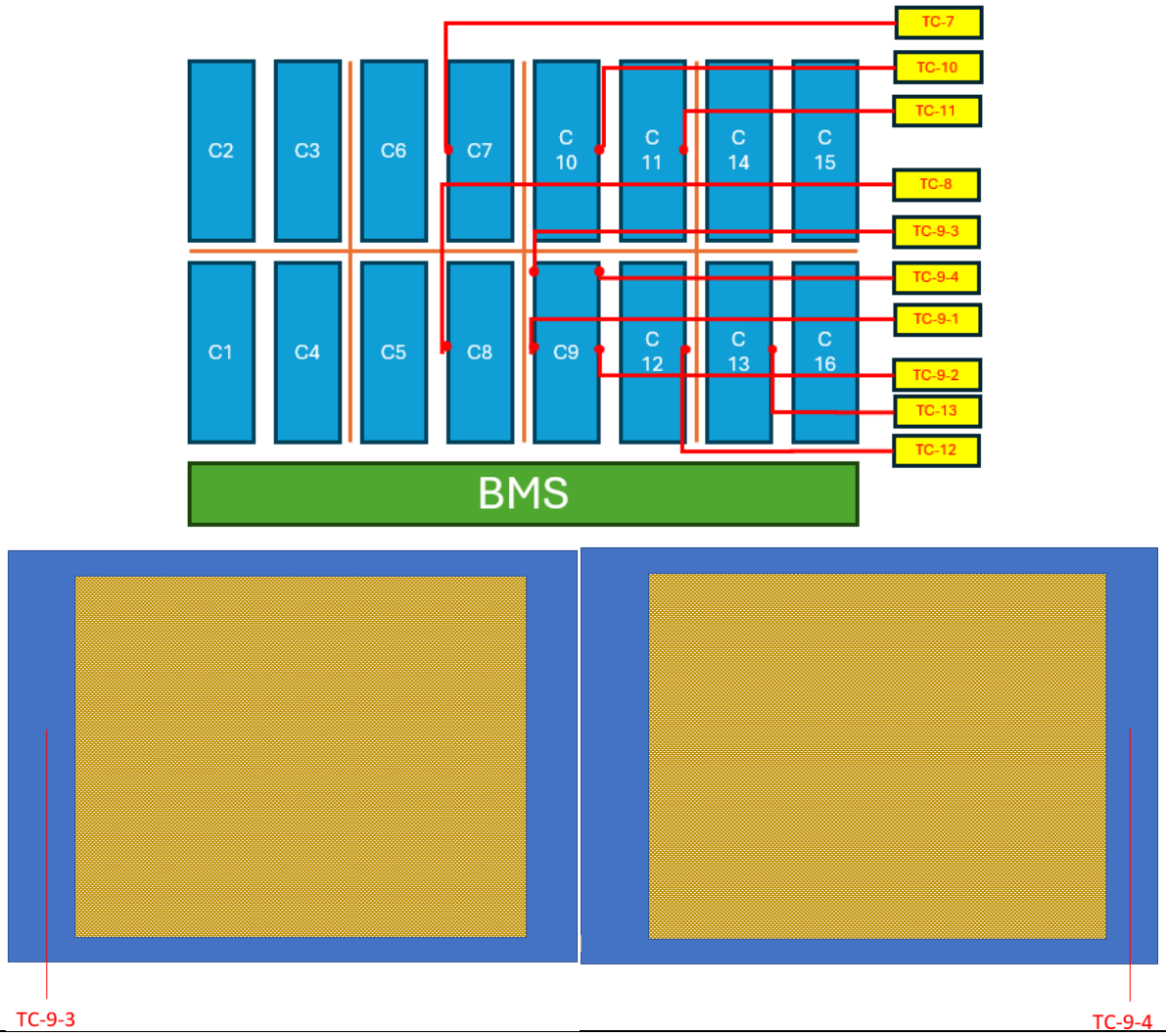


Figure 12 – Locations of TCs

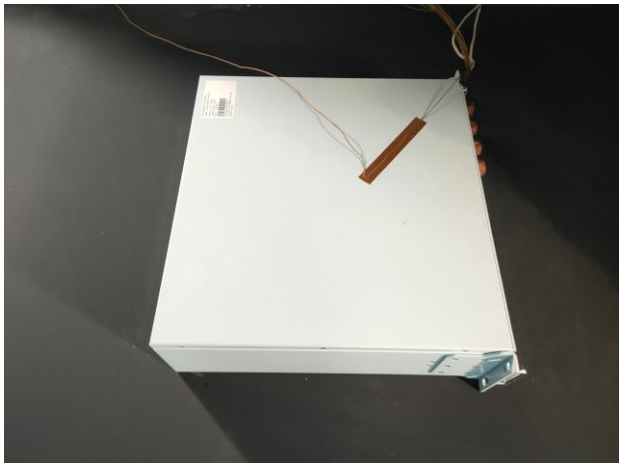


Figure 13 – Module on the test platform – Side view

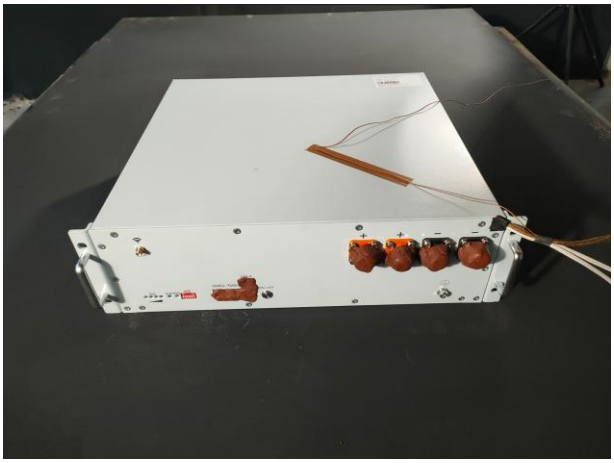


Figure 14 – Module on the test platform – Front view

Figure 15 – Module on the test platform – Rear view

Attachment D: Module and Initiating Cell(s) Temperature Profiles - (*Pages **23** through **23***)

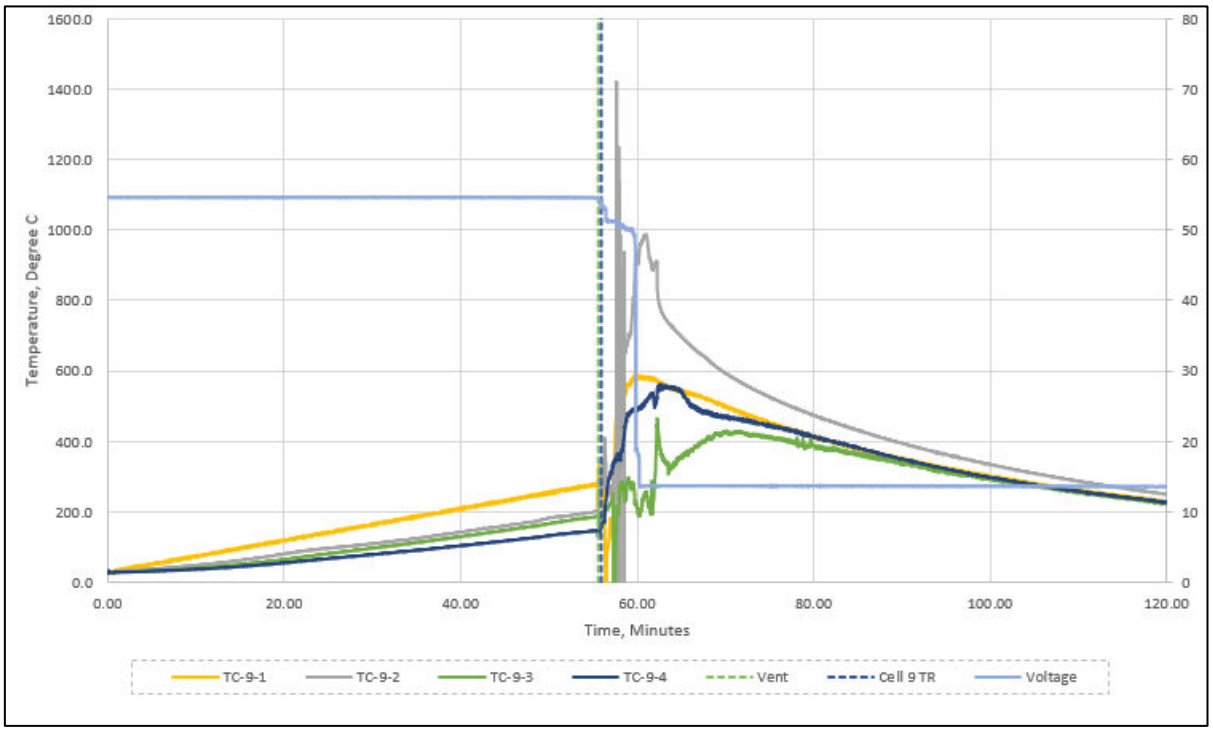


Figure 16 – Initiating cell Temperature Profiles During Testing

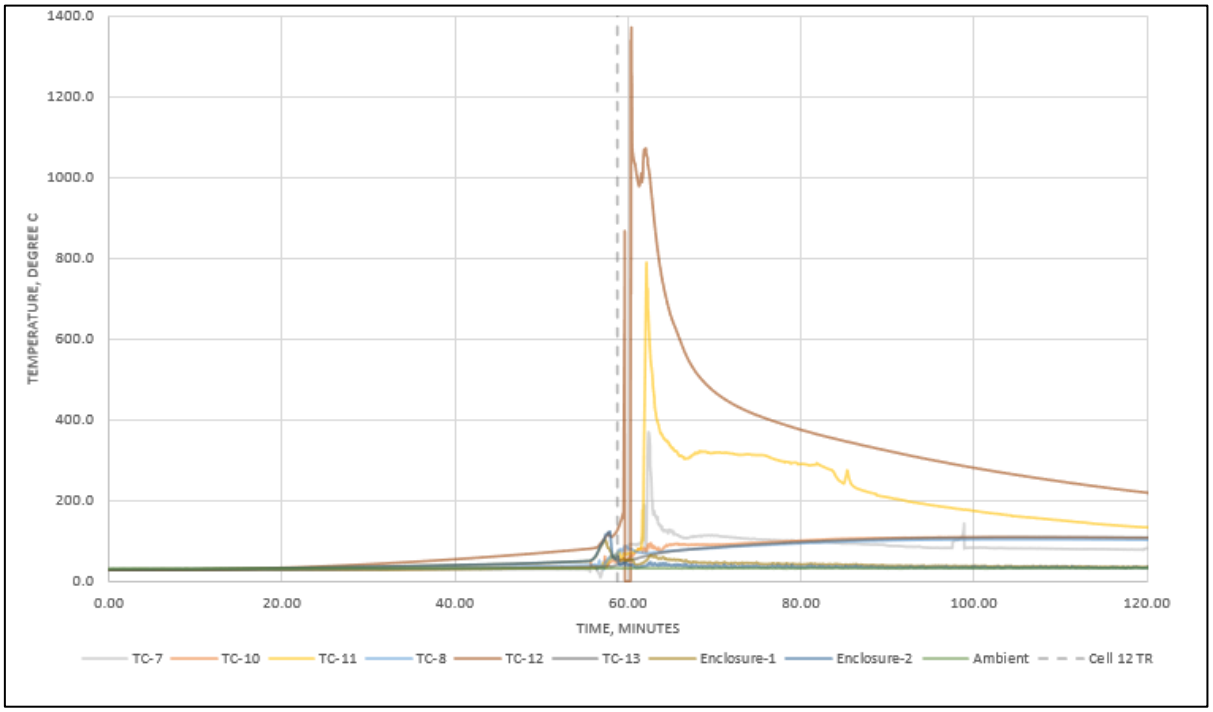
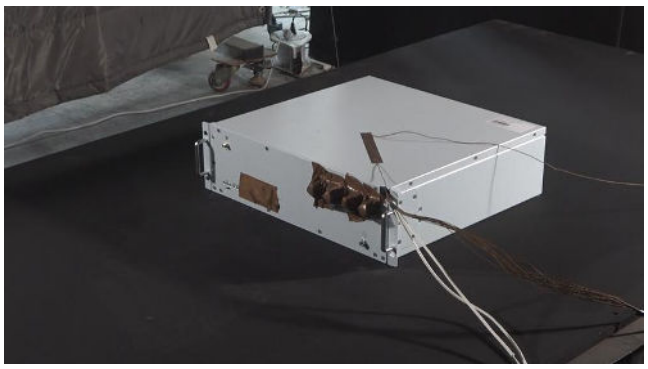
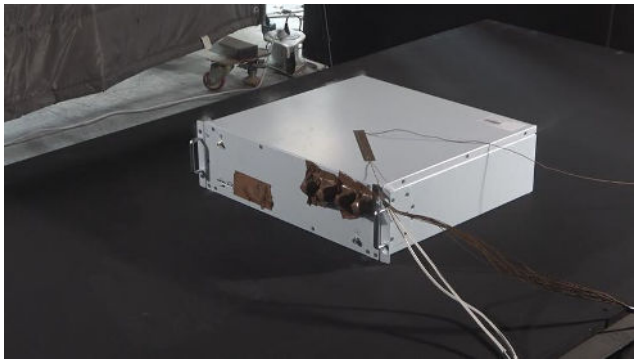
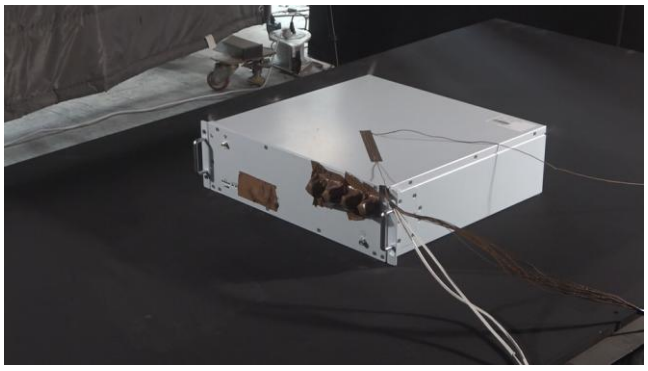
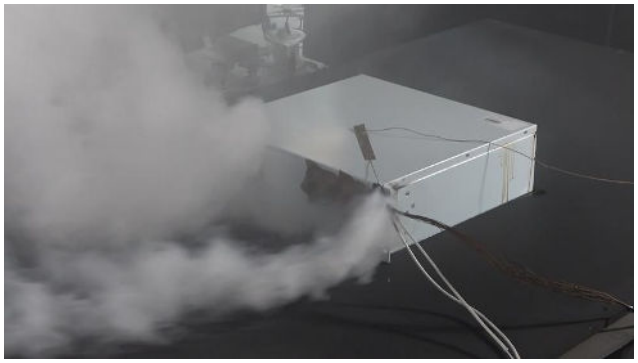
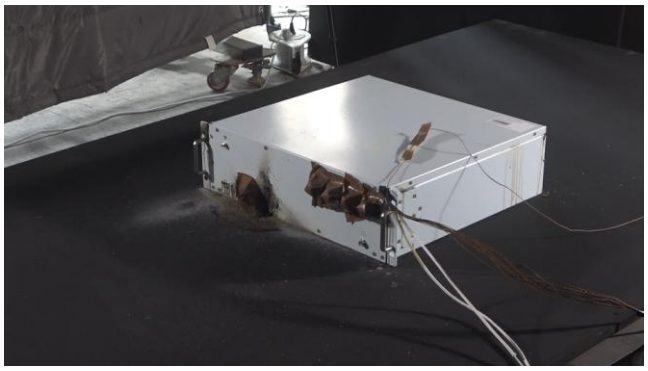
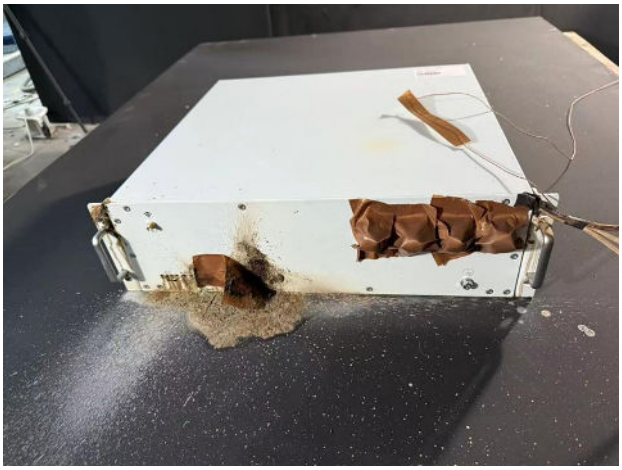


Figure 17 – Temperature Profiles Describing Cell to Cell Propagation

Note: cell 7, cell 11 didn't go into thermal runaway

Attachment E: Module Testing Photos - (*Pages **24** through **25***)

	
(a) Test Start [00:00:00]	(b) Initiating cell Venting [00:55:35]
	
(c) Thermal runaway of initiating cell [00:55:55]	(d) Thermal runaway of adjacent cell 12 [00:58:45]
	--
(e) Test Termination [02:00:00]	--



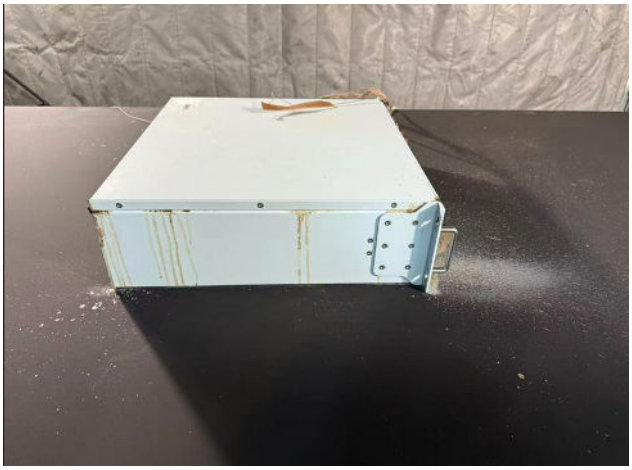


Figure 18 – Module Post Testing Photos

Attachment F: Module Gas Flow Rate, Smoke Release Rate Profile - (*Pages **26** through **28***)

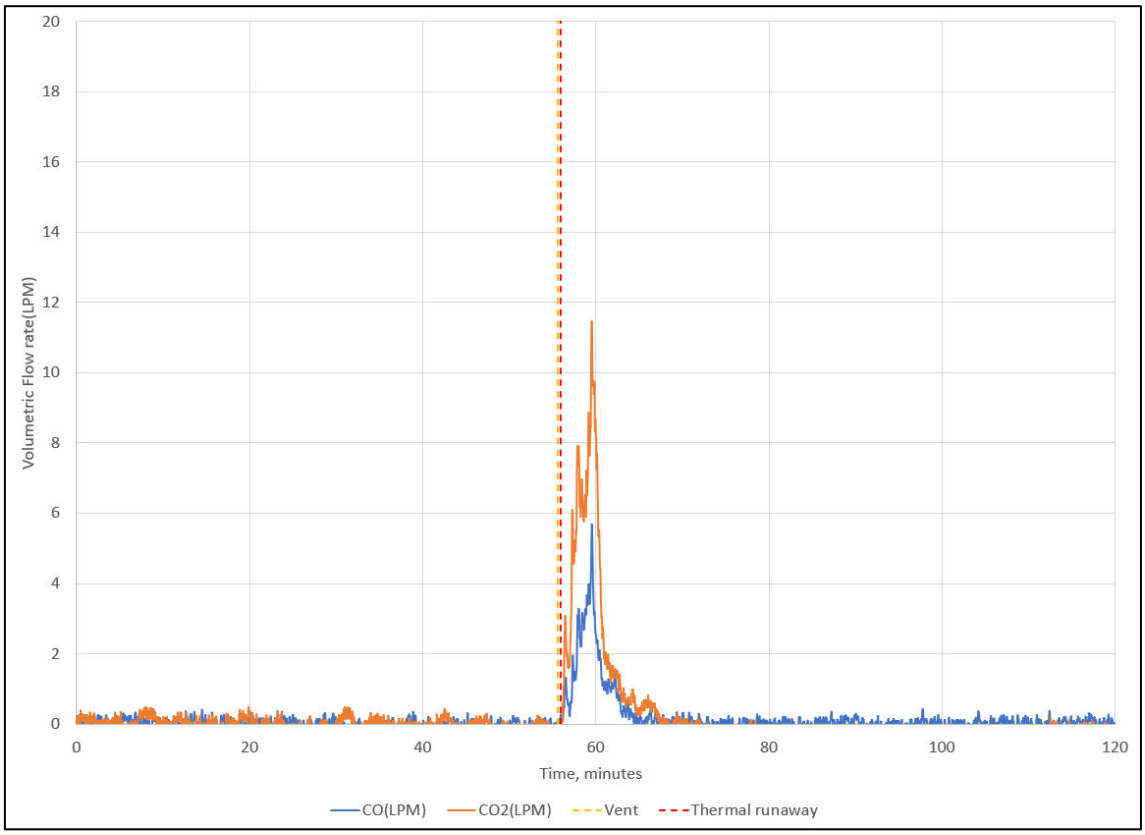


Figure 19 – CO, CO2 Volumetric flow rates

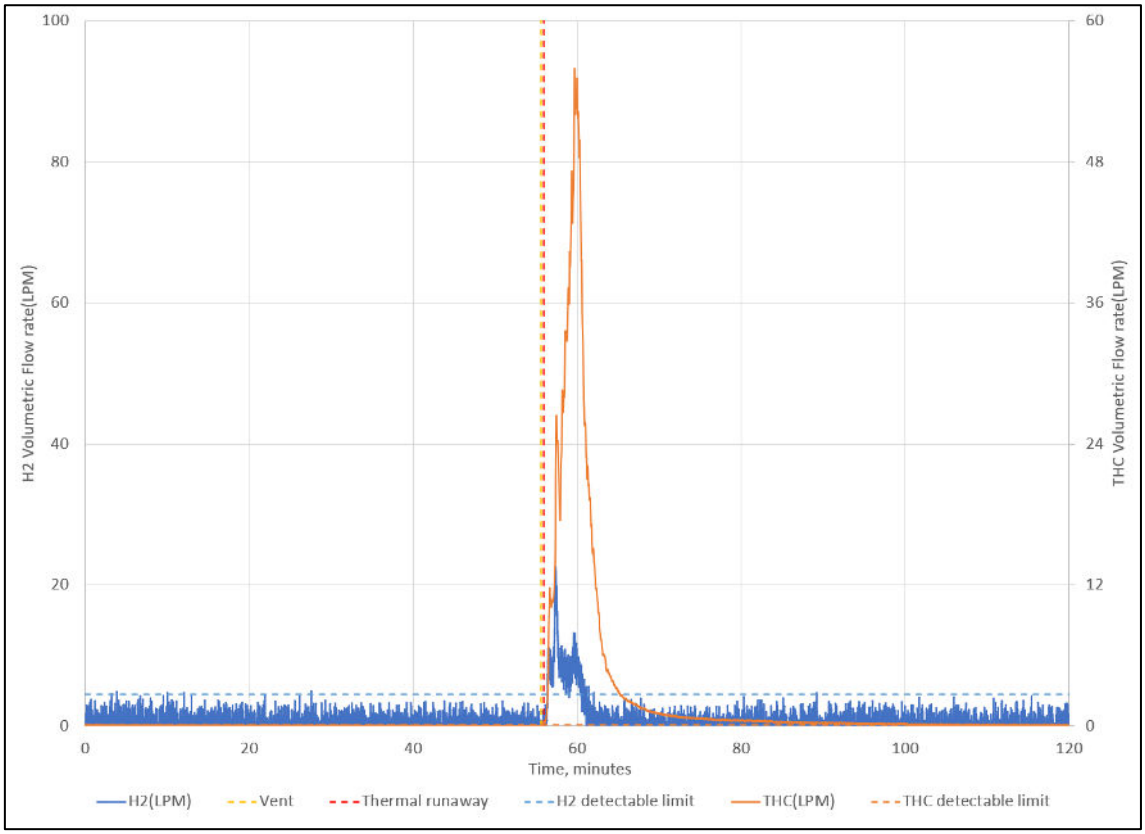


Figure 20 – THC, H2 Volumetric flow rates

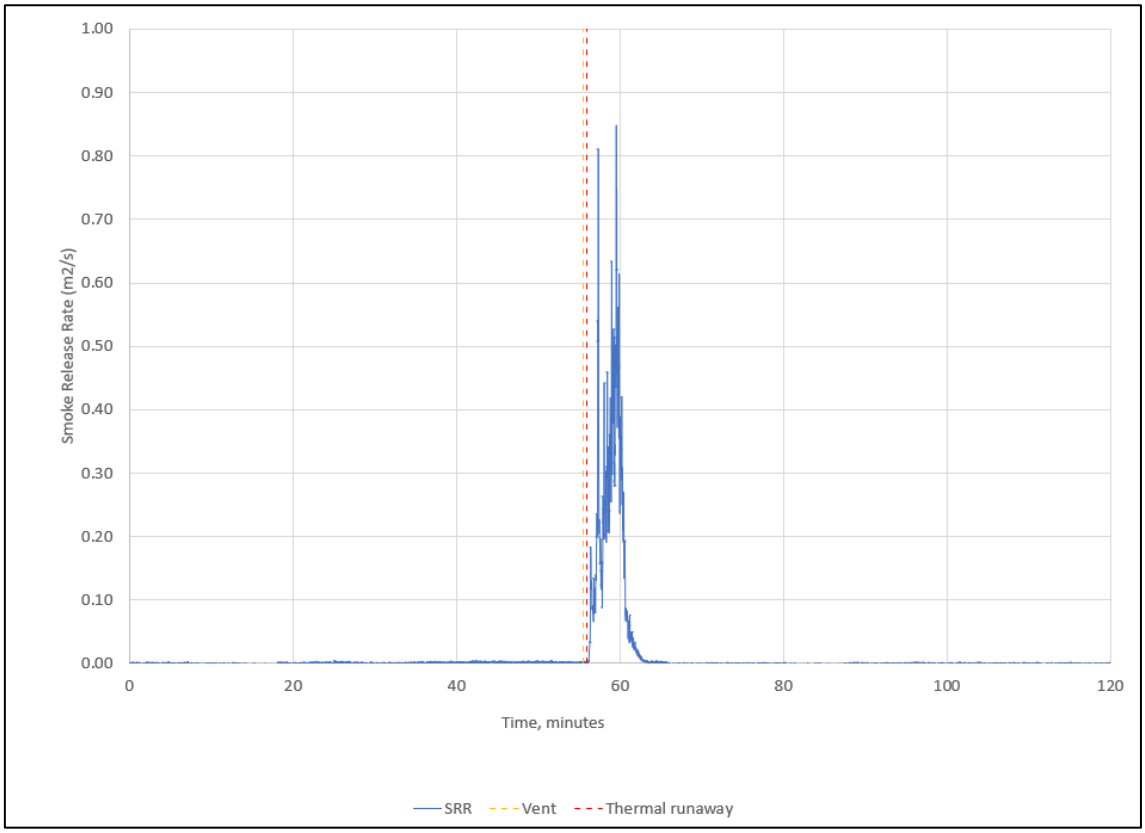


Figure 21– Smoke release rate

Attachment G: Other models photos (for reference) - (*Pages **29** through **32***)

Model RESS-BM-051100-RL2

Model LiFe4851

Model RESS-BM-051100-RL3

Model RESS-BM-051100-RL4

Model RESS-BM-051100-RL5

Model RESS-BM-051100-RL6

Model RESS-BM-051100-RL7

Model RESS-BM-051100-RL8

Model RESS-BM-051100-RL9

Model RESS-BM-051100-RL10

Model RESS-BM-051100-RL11

Model RESS-BM-051100-RL12

Model RESS-BM-051100-RL13

Model RESS-BM-051100-RL14

Model RESS-BM-051100-RL15

Model RESS-BM-051100-RL16

Model RESS-BM-051100-RL17

Model RESS-BM-051100-RL18

Model RESS-BM-051100-RL19

Model RESS-BM-051100-RL20

<End of report>