UNIT 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's name.....:	**Contemporary Amperex Technology Co Limited**
Address .....:	**No.2 Xingang Road Zhangwan Town, Jiaocheng District, Ningde, FuJian 352100 China**
Test specification:	4th Edition, Section 9, November 12, 2019
Standard.....:	UL 9540A, Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems
Test procedure .....:	9.1 – 9.8
Non-standard test method .....:	N/A

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General disclaimer:

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

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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Cell level information	
Cells in Module:	
•Manufacturer Name	Contemporary Amperex Technology Co Limited
•Part Number	CB310, CB2W0
•Chemistry	Lithium iron phosphate
•Format	Prismatic
Ratings (Vdc, Ah) :	3.2V, 280Ah
Cell certified? :	Yes
Standard the cell was certified to:	UL1973
Organization that certified the cell:	UL (MH62898)
Average cell surface temperature at gas venting, ℃:	168.2
Average cell surface temperature at thermal runaway, ℃:	239.6
Gas Volume:	221.3L
Lower flammability limit (LFL), % volume in air at the ambient temperature:	7.85
Lower flammability limits (LFL), % volume in air at the venting temperature:	6.47
Burning velocity (S_u) cm/s:	64
Maximum pressure (P_{max}) psig:	103

Cell level Gas Composition:

Gas		Measured %
Carbon Monoxide	**CO**	11.086
Carbon Dioxide	**CO_2**	33.290
Hydrogen	**H_2**	35.698
Methane	**CH_4**	10.075
Acetylene	**C_2H_2**	0.164
Ethylene	**C_2H_4**	5.259
Ethane	**C_2H_6**	1.089
Propadiene (Allene)	**C_3H_4**	0.000
Propyne	**C_3H_4**	0.000
Propene	**C_3H_6**	0.571
Propane	**C_3H_8**	0.232
-	**C4 (Total)**	0.382
-	**C5 (Total)**	0.091
-	**C6 (Total)**	0.060
-	**C7 (Total)**	0.005
-	**C8 (Total)**	0.000
Benzene	**C_6H_6**	0.023
Toluene	**C_7H_8**	0.002

Dimethyl Carbonate	**$C_3H_6O_3$**	1.879
Ethyl Methyl Carbonate	**$C_4H_8O_3$**	0.091
Diethyl Carbonate	**$C_5H_{10}O_3$**	0.000
Total	-	**100**

Module level Information

Model No ..... :	M52280-E, M52280-P
Ratings (Vdc, Ah) ..... :	166.4V 280Ah
Module dimensions (X x Y x Z (mm))..... :	810±5mm*1155±5mm*243.4±5mm
Module cell configuration (xS/yP) .....:	52S/1P
Module weight (kgs)..... :	330±5kg
Module enclosure material..... :	Top enclosure is made of plastic bottom enclosure is made of aluminium alloy
Was the module certified? .....:	No
Standard the module was certified to .....:	N/A
Organization that certified test item .....:	N/A
Number of initiating cells failed to achieve propagation.	1
Thermal Runaway Propagation:	Initiating cell went into thermal runaway and propagated to two adjacent cells
External Flaming:	No external flaming occurred.
Location(s) of Flame Venting:	No flaming occurred
Flying Debris:	No flying debris observed.
Re-ignitions:	No further re-ignitions were observed during post test observation.
Test Maximum Smoke Release Rate (m^2/s)	4.9
Test Total Smoke Released: (m^2)	376.7
Test Peak Chemical Heat Release Rate: (kW):	No flaming observed

Module level test Gas Composition & Volume for Each Compound (Pre-flaming and After flame):

Gas Compound	Gas Type	Pre-Flaming (L)	Flaming (L)	Minimum detectable flow rate (LPM)
Total Hydrocarbons (Propane Equivalent)	Hydrocarbons	150	No flaming	0.52
Carbon Monoxide	Carbon Containing	53	No flaming	0.68
Carbon Dioxide	Carbon Containing	143	No flaming	2.98
Hydrogen	Hydrogen	189	No flaming	8.79

Unit level Information	
Model No.:	Ox52280-E, Ox52280-P
Ratings (Vdc, Ah) .....:	1331.2Vdc, 280Ah
BESS dimensions (W x D x H (mm)).....:	1300(W)x1300(D)x2280(H)
BESS module configuration	8S/1P
Number of modules in BESS	8
Module cell configuration (xS/yP) .....:	52S/1P
Number of cells in module.:	52
BESS weight (kgs)..... :	3650
BESS enclosure material..... :	Galvanized steel
BESS Intended Installation: **Non Residential:** outdoor ground mounted, indoor floor mounted, outdoor wall mounted, indoor wall mounted, roof top, open garage **Residential:** Outdoor ground mounted, indoor floor mounted, outdoor wall mounted, indoor wall mounted	Non Residential: outdoor ground mounted, indoor floor mounted
Residential Indoor Use: Smallest volume room installations specified.	N/A
Original Equipment Manufacturer (OEM):	Contemporary Amperex Technology Co., Limited
Branding Manufacturer (if not OEM):	N/A
Was the unit certified? .....:	Yes
Standard the unit was certified to .....:	UL 1973
Organization that certified the unit .....:	TUV SUD (No.U14 004951 0008 Rev.00/No.U14 004951 0008 Rev.01)
Cell failure test method performed (summary of method and test clause): ☒ External heating using thin film with 4 ℃ to 7 ℃ 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, : N/A	
Description of components employed within the BESS unit that serve to suppress propagation (fire protection features) Liquid coolant and aerosol system were employed in the container; however, the pipes for the coolant were empty without the coolant and both coolant system and the aerosol system were not powered during the test at the request of the applicant (CONTEMPORARY AMPEREX TECHNOLOGY CO., LIMITED) Therefore, these systems were neither used nor evaluated in the test; the detailed information on these systems are described in the critical components.	
Deviation from the module level test	

N/A	
Number of initiating cell(s)	1
Thermal Runaway Propagation:	Initiating cell went into thermal runaway and propagated to one adjacent cell.
External Flaming from BESS:	No external flaming occurred
Location(s) of Flame Venting:	No Flaming occurred
Maximum Target BESS Temperature, ℃	30
Maximum Wall Surface Temperature[1], ℃	29
Peak Chemical Heat Release Rate, kW	No flaming observed
Peak Convective Heat Release Rate, kW	No flaming observed
Maximum Smoke Heat Release Rate, m^2/s	0.23
Maximum Heat Flux on Target Modules, kW/m^2	0
Maximum Heat Flux of Egress Path, kW/m^2	0
Flying Debris:	No flying debris observed
Re-ignitions:	No further re-ignitions were observed during post test observation

Gas Analysis:

☒ Flame ionization detection (FID)

☒ Non-Dispersive Infrared Spectrometer (NDIR)

☐ Fourier-Transform infrared Spectrometer

☒ Hydrogen Sensor (palladium-nickel, thin-film solid state sensor)

☒ White light source with photo detector (smoke release rate)

Summary of Unit level test Gas Analysis Data:

Unit level Gas Composition & Volume for Each Compound (Pre-flaming and After flame):

Gas Compound	Gas Type	Pre-Flaming (L)	Flaming (L)	Minimum detectable flow rate (LPM)
Total Hydrocarbons (Propane Equivalent)	Hydrocarbons	284	No flaming	0.65
Carbon Monoxide	Carbon Containing	0.23	No flaming	0.26
Carbon Dioxide	Carbon Containing	7.51	No flaming	0.85
Hydrogen	Hydrogen	121.8	No flaming	6.44

Summary of BESS Unit Test Results

Performance Criteria in accordance with Table 9.1 for Indoor Floor Mounted non-residential unit

[1] Maximum wall surface temperature averaged on 60 seconds.

[X] Flaming outside the initiating BESS unit was not observed; **[X]** Surface temperatures of modules within the target BESS units adjacent to the initiating BESS unit did not exceed the temperature at which thermally initiated cell venting occurs, as determined in 7.3.1.8; **[X]** For BESS units intended for installation in locations with combustible constructions, surface temperature measurements on wall surfaces did not exceed 97 ℃ (175 ℉) of temperature rise above ambient per 9.2.15; **[X]** Explosion hazards were not observed, including deflagration, detonation or accumulation (to within the flammability limits in an amount that can cause a deflagration) of battery vent gases; and **[X]** Heat flux in the center of the accessible means of egress did not exceed 1.3 kW/m^2.
Performance Criteria in accordance with Table 9.1 for Outdoor Ground Mounted non-residential unit **[X]** Separation distances to exposures was farther than the greatest flame extension observed during test. **[X]** Surface temperatures of modules within the target BESS units adjacent to the initiating BESS unit did not exceed the temperature at which thermally initiated cell venting occurs, as determined in 7.3.1.8; **[X]** For BESS units intended for installation in locations with combustible constructions, surface temperature measurements on wall surfaces did not exceed 97 ℃ (175 ℉) of temperature rise above ambient per 9.2.15; **[X]** Explosion hazards were not observed, including deflagration, detonation or accumulation (to within the flammability limits in an amount that can cause a deflagration) of battery vent gases; and **[X]** Heat flux in the center of the accessible means of egress did not exceed 1.3 kW/m^2.
Necessity for an Installation level test
[ ] The performance criteria of the unit level test as indicated in Table 9.1 of UL 9540A 4th edition has not been met, therefore an installation level testing in accordance with UL 9540A will need to be conducted on the representative the installation with this unit installed. **[X]** The performance criteria of the unit level tests as indicated in Table 9.1 of UL 9540A 4th edition has been met, therefore an installation level testing in accordance with UL 9540A need not be conducted.
Testing Laboratory Information
Testing Laboratory and testing location(s):

Testing Laboratory:	Beijing Building Materials Testing Academy	
Testing location/ address ..... :	#17 Raxin Road, Doudian Town, Fangshan district, Beijing 102402, CN	
Tested by (name, signature) ..... :	5.1.2.e 5.1.2.e	
Witnessed by (for 3rd Party Lab Test Location) (name, signature) ..... :	5.1.2.e	BENJAMIN LIU
Project Handler (name, signature)..... :	5.1.2.e	BENJAMIN LIU
Reviewer (name, signature) .....:	5.1.2.e	5.1.2.e

List of Attachments (including a total number of pages in each attachment):
Attachment A: Sample Charging, OCV and SOC Measurement Profiles - (*Pages **28** through **28***)
Attachment B: BESS (including module and any integral fire detection and suppression systems) Construction Photos/Diagrams - (*Pages **29** through **29***)
Attachment C: BESS and Equipment Instrumentation and Test Installation Layout Photos/Diagrams - (*Pages **30** through **31***)
Attachment D: Temperature Profiles and Heat Flux Measurements During Testing (Initiating Cell and Module, Target Modules, Wall Surfaces, etc. - (*Pages **32** through **35***)
Attachment E: BESS Unit Testing and Post Testing Photos - (*Pages **36** through **38***)
Attachment F: BESS Unit Gas Flow Rate and Heat Release and Smoke Release Profiles – (*Pages **39** through **41***)

Photo(s) of BESS unit:



Test Item Charge/Discharge Specifications:	Ox52280-E[2]	Ox52280-P
• Charge power, W:	186.4kW	372.7kW
• Standard Full charge voltage, Vdc:	1497.6V or single cell reach 3.6V	1497.6V or single cell reach 3.6V
• Charge temperature range, ℃:	0~55	0~55
• End of charge current, A:	N/A	N/A
• Discharge power, W:	186.4kW	372.7kW
• End of discharge voltage, Vdc:	1164.8V or single cell reach 2.8V	1164.8V or single cell reach 2.8V
• Discharge temperature range, ℃:	0~55	0~55

[2] Ox52280-E was use for this test.

Test item particulars .....:	
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)
- test object was completed per the requirement...:	C(Complete)
- test object was completed with modification.....:	M(Modification)
Testing.....:	
Date of receipt of test item .....:	2022.06.27
Date (s) of performance of tests.....:	2022.07.04
General remarks:	
"(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 (ies) .....:	Manufacture-1: Contemporary Amperex Technology Co Limited[3] No.2 Xingang Road Zhangwan Town, Jiaocheng District, Ningde, 352100 Ningde, Fujian, PEOPLE'S REPUBLIC OF CHINA Manufacture-2: Guangdong Ruiqing Contemporary Amperex Technology Limited No.1 Contemporary Avenue, Sihui City, Zhaoqing City, Guangdong Province, People's Republic of China Manufacture-3: Sichuan Contemporary Amperex Technology Limited No.1 Chanye Avenue, Lingang Economic Development Zone, Yibin City, Sichuan

[3] Test unit samples were produced in the factory located at No.2 Xingang Road Zhangwan Town, Jiaocheng District, Ningde, 352100 Ningde, Fujian, PEOPLE'S REPUBLIC OF CHINA (Contemporary Amperex Technology Co Limited)

General product information and other remarks:

Battery Module Model M52280-E employs cell Models CB310 manufactured by Contemporary Amperex Technology Co Limited.
Battery Module Model M52280-P employs cell Model CB2W0 manufactured by Contemporary Amperex Technology Co Limited.
The cell Model CB2W0 is identical to model CB310 in construction except for the declared charge and discharge current rating.
The normal charge and normal discharge current rating for Model CB310 are 140A.
The normal charge and normal discharge current rating for Model CB2W0 are 280A.
The Battery Module Model M52280-P is identical to model M52280-E in construction except for the declared charge and discharge current rating.

The unit sample tested in this project was Ox52280-P with module M52280-P. The test module is without mica sheet.

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Clause	Requirement + Test	Result - Remark	Verdict

5.0	**CONSTRUCTION**		**Verdict**
5.3	**Battery energy storage system unit Construction**		—
5.3.1, 5.3.2	Construction information	See Test Item Description at the beginning of this report	—
5.3.2	General layout of BESS unit contents	See Attachment B	—
5.3.3	Details of integral fire suppression system	See Attachment B	
5.3.1	BESS certified to UL 9540	No	
	Organization that certified BESS:	N/A	—
6.0	**PERFORMANCE**		**Verdict**
6.1	**General**		
9.1	**Sample and test configuration**		
9.1.1	The unit level test conducted with BESS units installed as described in the manufacturer's instructions.	See Attachment C for test installations Installation type: outdoor ground mounted, indoor floor mounted.	C
9.1.2	The unit level test required one initiating BESS unit in which an internal fire condition in accordance with the module level test is initiated and target adjacent BESS units representative of an installation.	See Attachment C for test installations	C
	Tests conducted for indoor floor mounted installations are representative of both indoor floor mounted and outdoor ground mounted installations.		C
	Tests conducted indoors with fire propagation hazards and separation distances between initiating and target units representative of the installation.		C
	Testing conducted outdoors for outdoor only installations with following in place: a) Wind screens with wind speed of ≤ 12 mph; b) Temperature range is 10 ℃ to 40 ℃ (50 ℉ to 104 ℉); c) Humidity is < 90% RH; d) Sufficient light to observe the testing; e) There is no precipitation; f) There is control of vegetation and combustibles in the test area; and g) There are protection mechanisms in place to prevent inadvertent access by unauthorized persons in the test area.	The product is not outdoor use only type. The test was conducted indoor.	N/A

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Clause	Requirement + Test	Result - Remark	Verdict
9.1.3	Testing to determine fire characterization was done at the battery system level rather than a complete BESS	Complete ESS was installed inside the unit.	N/A
9.1.4	The initiating BESS contained components representative of a BESS unit in a complete installation.	The BESS included the Power Conversion System	N/A
	Combustible components that interconnect the initiating and target BESS units was included.	Wires were used to connect the units.	C
9.1.5	Target BESS units include the outer cabinet (if part of the design), racking, module enclosures, and components that retain cells components.		C
9.1.6	The initiating BESS was at the maximum operating state of charge (MOSOC),	See Table 2 and Attachment A	C
	After charging and prior to testing, the initiating BESS was at rest for a maximum period of 8 hours at room ambient.	See Table 2	C
9.1.7	The BESS unit included an integral fire suppression system.	The fire suppression system was installed for the test, however, the system was not activated at the request of Contemporary Amperex Technology Co Limited	C
9.1.8	Electronics and software controls such as the battery management system (BMS) are not relied upon for this testing.		C
	Included a fire suppression control in accordance with UL 864 that is external to the BESS.		N/A
9.2	**Test method – Indoor floor mounted BESS units**		
9.2.1	Test room ambient temperature within 10 ℃ (50 ℉) to 32 ℃ (90 ℉).	See Table 2	C
9.2.2	Access door(s) or panels on the initiating BESS unit and adjacent target BESS units were closed, latched and locked duration of the test.		C
9.2.3	The initiating BESS unit was positioned adjacent to two instrumented wall sections.	Attachment C	C
9.2.4	Instrumented wall sections extend not less than 0.49 m (1.6 ft) horizontally beyond the exterior of target BESS units.		C
9.2.5	Instrumented wall sections were at least 0.61-m (2-ft) taller than the BESS unit height, but not less than 3.66 m (12 ft) in height above the bottom surface of the unit.		C

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Clause	Requirement + Test	Result - Remark	Verdict
9.2.6	The surface of the instrumented wall sections were covered with 16-mm (5/8-in) gypsum wall board and painted flat black.	See Attachment C The test was to cover outdoor use as well, however, gypsum was used.	M
9.2.7	The initiating BESS unit was centered underneath an appropriately sized smoke collection hood of an oxygen consumption calorimeter.		C
9.2.8	The light transmission in the calorimeter's exhaust duct was measured using a white light source and photo detector. The smoke release rate was calculated.	See Table 12 See Attachment F	C
9.2.9	The chemical and convective heat release rates were measured for the duration of the test.	See Table 12 See Attachment F	C
9.2.10	The heat release rate measurement system was calibrated using an atomized heptane diffusion burner. The calibration was performed using flows of 3.8, 7.6, 11.4 and 15.2 L/min (1, 2, 3 and 4 gpm) of heptane.		C
9.2.11	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		C
9.2.12	The chemical heat release rate at each of the flows was calculated.		C
9.2.13	The physical spacing between BESS units (both initiating and target) and adjacent walls was representative of the intended installation.	See Attachment C	C
9.2.14	Separation distances were specified by the manufacturer for distance between: a) The BESS units and the instrumented wall sections; and b) Adjacent BESS units.	See Attachment C	C
9.2.15	Wall surface temperature measurements were collected	See Table 6 See Attachment D	C
	The intended installation is composed completely of non-combustible construction		C

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Clause	Requirement + Test	Result - Remark	Verdict
9.2.16	Wall surface temperatures were measured in vertical array(s) at 152-mm (6-in) intervals for the full height of the instrumented wall sections using No. 24-gauge or smaller, Type-K exposed junction thermocouples.		C
	The thermocouples for measuring the temperature on wall surfaces were horizontally positioned in the wall locations to receive greatest thermal exposure from the initiating BESS unit.		C
9.2.17	Thermocouples were secured to gypsum surfaces and the thermocouple tip was depressed into the gypsum so as to be flush with the gypsum surface at the point of measurement .		C
9.2.18	Heat flux was measured with at least two water-cooled Schmidt-Boelter gauges at the surface of each instrumented wall: a) Both are collinear with the vertical thermocouple array; b) One is positioned to receive the greatest heat from the initiating module; and c) One is positioned to receive the greatest heat flux during potential propagation within the initiating BESS unit.		C
9.2.19	Heat flux was measured with 2 water-cooled Schmidt-Boelter gauges at the surface of each adjacent target BESS units facing initiating BESS unit: a) One is positioned at the elevation estimated to receive the greatest heat flux from the initiating module; and b) One is positioned at the elevation estimated to receive the greatest surface heat flux due to initiating BESS.	There is only one heat flux in the target unit-1, position at the mid height of the initiating module; there are two heat fluxes for other target units.	M
9.2.20	Heat flux was measured with the sensing element of at least one water-cooled Schmidt-Boelter gauge positioned in the center of the accessible means of egress.	The distance between the unit and gauge is 0.1m. The height of the gauge is 0.85m.	C
9.2.21	No. 24-gauge or smaller, Type-K exposed junction thermocouples were installed to measure the temperature of the surface proximate to the cells and between the cells and exposed face of the initiating module.	See Attachment C	C
	Each non-initiating module enclosure within the initiating BESS unit was instrumented with at least one No. 24-gauge or smaller Type-K thermocouple(s) within non-initiating modules.	See Attachment C	C

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Clause	Requirement + Test	Result - Remark	Verdict
	Additional thermocouples were placed to account for convoluted geometries.		N/A
9.2.22	For residential use, the DUT was covered with a single layer of cheese cloth ignition indicator. The cheesecloth was untreated cotton cloth running 26 – 28 m2/kg with a count of 28 – 32 threads in either direction within a 6.45 cm^2 (1 in^2) area.	Non residential use.	N/A
9.2.23	An internal fire condition in accordance with the module level test was created within a single module in the initiating BESS unit: a) The position selected to present the greatest thermal exposure to adjacent modules; and b) The setup was the same as that used to initiate and propagate thermal runaway within the module level test.	See Attachment C	C
9.2.24	The composition, velocity and temperature of the initiating BESS unit vent gases was measured within the calorimeter's exhaust duct. Composition, velocity and temperature instrumentation shall be collocated with heat release rate calorimetry instrumentation.		C
	Hydrogen gas shall be measured with a palladium-nickel thin-film solid state sensor.		C
	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.	FTIR analysis was not used in accordance with the Certification Requirement Decision: Corrections to gas measurement methods to make FTIR as an option for measuring hydrocarbon contents of gas emissions and to include Hydrogen measurements during the Unit Level Test.	N/A
9.2.25	The hydrocarbon content of the vent gas was measured using flame ionization detection.	See Tables 8, 9, 10 and 11	
9.3	**Test method – Outdoor ground mounted units**		
9.3.1	Outdoor ground mounted non-residential use BESS for installation: test method described in Section 9.2 was used.		C

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict
	Outdoor use only installations: the smoke release rate, the convective and chemical heat release rate and content, velocity and temperature of the released vent gases were not be measured.	The parameters were measured for indoor use evaluation.	N/A
9.3.2	Outdoor ground mounted residential use BESS: The test method described in Section 9.2 except as noted in 9.3.3 and 9.3.4.	These parameters were measured for indoor use evaluation.	N/A
	Heat flux measurements for the accessible means of egress were measured in accordance with 9.2.20.		C
	Outdoor use only installations: the smoke release rate, the convective and chemical heat release rate and content, velocity and temperature of the released vent gases were not be measured.		N/A
9.3.3	Test samples were installed as shown in Figure 9.2 in proximity to an instrumented wall section that is 3.66-m (12-ft) tall with a 0.3-m (1-ft) wide horizontal soffit (under surface of the eave shown in Figure 9.2).		N/A
	The sample was mounted on a support substrate and spaced from the wall in accordance with the minimum separation distances. The wall and soffit were constructed with 19.05-mm (3/4-in) plywood installed on wood studs and painted flat black.	The test was to cover outdoor use as well, however, gypsum was used.	M
	The instrumented wall extended not less than 0.49-m (1.6-ft) horizontally beyond the exterior of the target BESS units.		C
	If the manufacturer requires installation against non-flammable material, the test setup may include manufacturer recommended backing material between the unit and plywood wall.	16-mm gypsum wall board was used. The test was to cover outdoor use as well, however, gypsum was used.	M
	The No. 24-gauge or smaller, Type-K exposed junction thermocouple array on the walls extended to the surface of the soffit.		C
9.3.4	Target BESS were installed on each side of the initiating BESS in accordance with installation specifications. The physical spacing between BESS units (both initiating and target) were the minimum separation distances specified.		C
9.7	**Unit level test report**		

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict
9.7.1	Installation type tested:	Non Residential: outdoor ground mounted, indoor floor mounted.	C
9.7.2	Testing is intended to represent more than one installation type.	See Test Item Description in beginning of this report.	C
9.7.3	a. Unit manufacturer name and model number (and whether UL 9540 compliant);		C
	b. Number of modules in the initiating BESS unit		C
	c. BESS 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.	C
	d. Fire protection features/ detection/ suppression systems within unit	Fire protection features: Aerosol Fire detection: heat detector and smoke detector However, the fire suppression system was installed but not activated at the request of Contemporary Amperex Technology Co Limited	C
	e. Module voltages corresponding to the tested SOC;	See Table	C
	f. Thermal runaway initiation method used;	See Attachment C	C
	g. Location of the initiating module within the BESS unit;	See Attachment C	C
	h. Diagram and dimensions of the test setup including mounting location of the initiating and target BESS units, and the locations of walls, ceilings, and soffits;	See Attachment C	C
	i. Observation of any flaming outside the initiating BESS enclosure and the maximum flame extension;	See Table	C
	j. Chemical and convective heat release rate versus time data;	See Table 11 See Attachment G	C
	k. Separation distances from the initiating BESS unit to target walls	See Attachment C	C

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Clause	Requirement + Test	Result - Remark	Verdict
	l. Separation distances from the initiating BESS unit to target BESS units	See Attachment C	C
	m. The maximum wall surface and target BESS temperatures achieved during the test and the location of the measuring thermocouple;	Tables 5 and 6	C
	n. The maximum ceillng or soffit surface temperatures achieved during the indoor or outdoor wall mounted test and the location of the measuring thermocouple;	Table 6	N/A
	o) The maximum incident heat flux on target wall surfaces and target BESS units;	Table 7	C
	p) The maximum incident heat flux on target ceiling or soffit surfaces achieved during the indoor or outdoor wall mounted test;	Table 7	N/A
	q. Flammable gas generation and composition data;	See Attachment F See Tables 7, 8, 9, and 10	C
	r. Peak smoke release rate and total smoke release data.	See Table 12 See Attachments F	C
	s. Indication of the activation of integral fire protection systems and if activated the time into the test at which activation occurred;	Table 13	C
	t. Observation(s) of flying debris or explosive discharge of gases;	See Table 15	C
	u. Observation of re-ignition(s) from thermal runaway events	See Table 16	C
	v. Observation(s) of sparks, electrical arcs, or other electrical events;	See Table 15	C
	w. Observations of the damage to: 1) The initiating BESS unit; 2) Target BESS units; 3) Adjacent walls, ceilings, or soffits;	See Table 16	C
	x. Video of the test.		C
9.8	**Performance at Unit level testing**		
9.8.1	Installation level testing in Section 10 was not required if the following performance conditions outlined in Table 9.1 are met during the unit level test.		P
Non-Residential Installations – Indoor floor mounted:			
	a) Flaming outside the initiating BESS unit is not observed;	No flaming observed	P
	b) Surface temperatures of modules within target BESS units do not exceed the cell venting temperature;	Max surface temperature 29 ℃ didn't exceed the cell venting temperature 168 ℃	P

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict
	c) For BESS units intended for installation in locations with combustible constructions, surface temperature measurements on wall surfaces do not exceed 97 ℃ (175 ℉) rise above ambient;	Max wall surface temperature 29 ℃ didn't exceed 97 ℃ rise above ambient	P
	d) Explosion hazards are not observed, including deflagration, detonation or accumulation (to within the flammability llmits in an amount that can cause a deflagration) of battery vent gases;	No explosion observed	P
	e) Heat flux in the center of the accessible means of egress did not exceed 1.3 kW/m^2.	Measured heat flux 0 kW/m^2 didn't exceed 1.3 kW/m^2	P
Non-Residential Installations – Outdoor ground mounted:			
	a) If flaming outside of the unit is observed, separation distances to exposures were determined by greatest flame extension observed during test.	No flaming observed	P
	b) Surface temperatures of modules within target BESS units do not exceed the cell venting temperature;	Max surface temperature 29 ℃ didn't exceed the cell venting temperature 168 ℃	P
	c) For BESS units intended for installation in locations near combustible construction, surface temperature measurements on wall surfaces do not exceed 97 ℃ (175 ℉) rise above ambient;	Max wall surface temperatures 29 ℃ didn't exceed 97 ℃ rise above ambient	P
	d) Explosion hazards are not observed, including deflagration, detonation or accumulation (to within the flammability limits in an amount that can cause a deflagration) of battery vent gases;	No explosion observed	P
	e) Heat flux in the center of the accessible means of egress did not exceed 1.3 kW/m^2.	Measured heat flux 0 kW/m^2 didn't exceed 1.3 kW/m^2	P

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

Table 1 – Specified Unit charging and discharging parameters			
Charging:		**Discharging:**	
Current (CC), A	140	Current (CC), A	140
Standard Full Charge Voltage, Vdc	3.6V per cell	End of discharge voltage, Vdc	2.8V per cell
End of charge current, A	N/A*	Discharging Test Ambient, ℃	0~55
Refer to Attachment A for charge/discharge profiles. *Charging is to continue till the voltage of a single cell reaches 3.6V			

Table 2 - Test Initiation Details	
Test Date	2022.07.04
Test Start Time (HH:MM:SS)	10:52:59
Initial Lab Temperature, ℃	29
Initial Relative Humidity % RH	82
Module OCV at Start of Test, Vdc	173.2

Table 3 – Approximate time of thermal runaway propagation through module			
Locations (Cell #)	**Event**	**Time**	**Temperature of the cell**
Cell 20	Vent	00:39:16	159
Cell 20	Thermal runaway	00:41:42	177
Cell 19	Thermal runaway	00:43:12	102

Table 4 – Test overview timeline		
Time (HH:MM:SS)	**Event**	**Description**
00:00:00	Test Start	The test started and the heater was turned on to heat the initiating cell (Cell 20) at a ratio of 4 ~ 7 ℃/min. See Figure(a)
00:39:16	Vent of initiating cell	Initiating cell (Cell 20) vented at around 159 ℃ measured through T2-1 by an indication of sudden dip in cell's temperature curve. See Figure(b)
00:41:42	Initiating cell Thermal runaway	Initiating cell (Cell 20) was at around 177 ℃ measured through T2-1. The temperature of cell 20 began to increase in an uncontrollable manner. See Figure (c)
00:43:12	2nd cell Thermal runaway	Temperature of the cell increased in an uncontrollable Thermal runaway propagated to nearby cell (cell 19) See Figure (d)
02:00:00	Test end	Data acquisition was stopped. The units were left in the test overnight and with the temperature data collected and the sample was See Figure (g)

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Clause	Requirement + Test	Result - Remark	Verdict

Table 5 - Maximum Temperatures in Target Units					
Cell vent temperature from cell test data, ℃		168			
Target Unit 1		**Target Unit 2**		**Target Unit 3**	
Module Location No.	Temperature (℃)	Module Location No.	Temperature (℃)	Module Location No.	Temperature (℃)
Module-1	29	Module-1	29	Module-1	28
Module-2	28	Module-2	28	Module-2	28
Module-3	28	Module-3	27	Module-3	28
Module-4	29	Module-4	29	Module-4	29
Module-5	28	Module-5	28	Module-5	28
Module-6	28	Module-6	29	Module-6	28
Module-7	28	Module-7	29	Module-7	28
Module-8	29	Module-8	29	Module-8	28

Table 6 - Maximum Temperatures on Instrumented Wall					
Ambient Temperature: 29 ℃					
UL 9540A performance criteria, Ambient + 97 ℃: 126 ℃					
Height, mm	Maximum Temperature (℃)	Height, mm	Maximum Temperature (℃)	Height	Maximum Temperature (℃)
15.2	28	136.8	28	258.4	29
30.4	28	152	28	273.6	29
45.6	28	167.2	28	288.8	29
60.8	29	182.4	28	304	29
76	28	197.6	28	319.2	29
91.2	29	212.8	28	334.4	29
106.4	28	228	28	349.6	29
121.6	29	243.2	29	364.8	29
Note: Temperatures are measured constantly and then averaged every 60-seconds					

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

Table 7 – Heat Flux Measurements			
Summary of maximum heat flux in target units		Summary of maximum heat flux measured on instrumented wall	
Maximum Heat Flux, kW/m^2			
Target Module No.: 3 in the targe unit-1	0	Heat Flux Gauge No.	kW/m^2
Target Module No.: 3 in the targe unit-2	0	Front wall 85-mm high, 5#	0
Target Module No.: 4 in the targe unit-2	0	Front wall 110-mm high, 6#	0
Target Module No.: 3 in the targe unit-3	0	Side wall 85-mm high, 10#	0
Target Module No.: 4 in the targe unit-2	0	Side wall 110-mm high, 11#	0
Egress path measurement:			0

Table 8 – 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
~~[ ] Fourier-Transform Infrared Spectrometer (FTIR)~~	~~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~~
	~~Ammonia~~	~~NH_3~~	~~Nitrogen Containing~~
	~~Hydrogen Cyanide~~	~~HCN~~	~~Nitrogen Containing~~
# - This table was modified to reflect the gases measured during testing.			

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

Table 9 - Gas generation periods	
Time	**Condition**
From the venting point 00:39:16 to the end of test 02:00:00	Pre-Flaming
	~~Flaming~~
External Flaming of Gas	
Condition	**Duration (hh:mm:ss)**
External Flaming of Vent Gases:	N/A

Table 10 – 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	284	No flaming	0.65
Carbon Dioxide	Carbon Containing	0.23	No flaming	0.26
Carbon Monoxide	Carbon Containing	7.51	No flaming	0.85
Hydrogen	Hydrogen	121.8	No flaming	6.44

Table 11 – Smoke and heat release rate			
Heat Release Rate (HRR)		**Smoke Release Rate (SRR)**	
Peak Chemical HRR (kW)	No flaming observed	Maximum SRR (m^2/s)	0.23
Peak Convective HRR, (kW)	No flaming observed	Total Smoke Released (m^2)	69.12

Table 13 - Module OCV voltage measurement comparison before and after testing			
Module Location In Rack	OCV Prior to Test (V)	OCV Post Test (V)	Difference (V)
1	173.2	173.1	0.1
2	173.2	173.2	0
3	173.2	155.1	18.1
4	173.2	173.1	0.1
5	173.2	173.1	0.1
6	173.2	173.2	0
7	173.2	173.2	0
8	173.2	173.2	0

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

Table 14 – Other Observations during Unit test			
	Observed, Yes/No	Comments/Location	
Flaming outside of Unit	N/A	Length of flame:	N/A
Flying debris	N/A	-	
Explosive discharge of gas	N/A	-	
Sparks or electrical arcs	N/A	-	

Table 15 - Post Test Observations	
Thermal runaway behaviour	No further thermal runaway after the test was completed.
Re-ignitions	No re-ignition occurred
Explosions	No explosion occurred
Other Observations	N/A

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Clause	Requirement + Test	Result - Remark	Verdict

	TABLE: Critical components information				
Object / Part No.	**Manufacturer/ trademark**	**Type / model**	**Technical data**	**Standard**	**Mark(s) of conformity**
Cell	CONTEMPORARY AMPEREX TECHNOLOGY CO LIMITED	CB2W0, CB310	3.2Vd.c., 280Ah	UL 1973	MH 62898
Module	CONTEMPORARY AMPEREX TECHNOLOGY CO LIMITED	M52280-E, M52280-P	166.4V 280Ah	-	-
Unit Enclosure	CONTEMPORARY AMPEREX TECHNOLOGY CO LIMITED		Material: Galvanized sheet Thickness: ≥1mm 2280mm(H)*1300mm(W)*1300mm(D)	-	-
Liquid chiller	AIR INTERNATIONAL SHANGHAI CO., LTD	BTMS-80-ES	170 - 275 Va.c., 50/60Hz, 266mm*1040mm*1202mm, 2.2MPa, Maximum input power: 5kW, Maximum input current: 30 Aa.c. 8kW, -40 to 60 ℃, IP56 (control box)	UL 471	UL SA45615
Liquid chiller (Alternative)	Kelvin New Energy Technology Co., Ltd.	BTMS-80-ES	170-275 Va.c., 50/60Hz, 272mm*1039mm*1203mm, 2.2MPa, Maximum input power: 4.5kW, Maximum input current: 27Aa.c. 8kW, -40 to 60 ℃, IP56 (control box)	UL 471	UL SA45847
Gas Detector	NEXCERIS	241029	3-16Vd.c, Ø 28.6 x 25.4 [mm]	IEC 61010, EN60326-1	Intertek, 5016770
Heat Detector (Alternate)	APOLLO FIRE DETECTORS LTD	55000-142	Supply voltage: 9-33 Vd.c., 0 ℃ to 60 ℃, Detection of temperature: 76.7 ℃	UL 521	UL S5053
Smoke Detector (Alternate)	APOLLO FIRE DETECTORS LTD	55000-326	Supply voltage: 9-33 Vd.c., 0 ℃ to 60 ℃	UL 268	UL S5022
Detector base (Alternate)	APOLLO FIRE DETECTORS LTD	45681-256	Supply voltage: 9-33 Vd.c., 0 ℃ to 68 ℃	UL 268	UL S5022
Heat Detector (Alternate)	APOLLO FIRE DETECTORS LTD	4106-1004	Supply voltage: 9-33 Vd.c., -20 ℃ to 90 ℃, Detection of temperature: 65 ℃	AS 7240.5	SAI GLOBAL: SMK40168

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

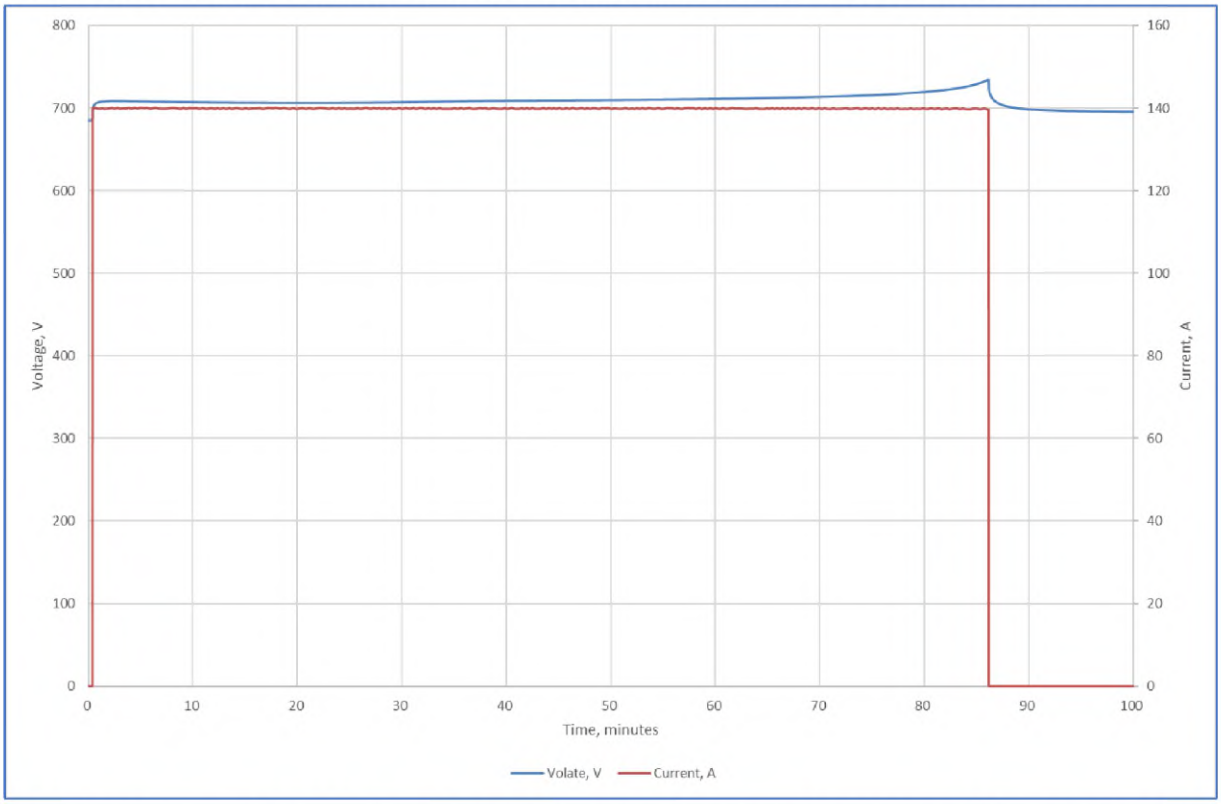
Smoke Detector (Alternate)	APOLLO FIRE DETECTORS LTD	4106-1001	Supply voltage: 9-33 Vd.c., -20 ℃ to 60 ℃	AS 7240.7	SAI GLOBAL: SMK40168
Detector base (Alternate)	APOLLO FIRE DETECTORS LTD	4106-1011	Supply voltage: 9-33 Vd.c., 0 ℃ to 68 ℃	AS 7240	SAI GLOBAL: SMK40168
Heat Detector	APOLLO FIRE DETECTORS LTD	55000-121	Supply voltage: 9-33 Vd.c., -20 ℃ to 90 ℃, Detection of temperature: 65 ℃	EN54-5	LPCB: 010p/05
Smoke Detector	APOLLO FIRE DETECTORS LTD	55000-316	Supply voltage: 9-33 Vd.c., -20 ℃ to 60 ℃	EN54-7	LPCB: 010q/11
Detector base	APOLLO FIRE DETECTORS LTD	45681-246	Supply voltage: 9-33 Vd.c., 0 ℃ to 68 ℃	EN54	LPCB: 010
Heat Detector (Alternate)	POTTER ELECTRIC SIGNAL CO LLC	PAD100-HD	Supply voltage: 24 Vd.c., 0 ℃ to 66 ℃	UL521	UL S24776
Smoke Detector (Alternate)	POTTER ELECTRIC SIGNAL CO LLC	PAD100-PD	Supply voltage: 24 Vd.c., 0 ℃ to 49 ℃	UL268	UL S24776
Detector base (Alternate)	POTTER ELECTRIC SIGNAL CO LLC	PAD100-4DB	Supply voltage: 24 Vd.c., 0 ℃ to 49 ℃	UL268	UL S24776
Aerosol	FIREAWAY INC	Stat-X condensed aerosol generator, Model 100 E	Activated Alumina: CAS 1333-84-2 (Aluminum Oxide non-fibrous): 100g, -40 ℃ to 54 ℃, Supply voltage: 24 Vd.c.	UL/ULC 2775	UL EX15004
Aerosol (Alternative)	FIREAWAY INC	Stat-X condensed aerosol generator, Model 100 T	Activated Alumina: CAS 1333-84-2 (Aluminum Oxide non-fibrous): 100g, -40 ℃ to 54 ℃, Trigger temperature:70 ℃	AS/NZS 4487	CSIRO: afp-2284

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

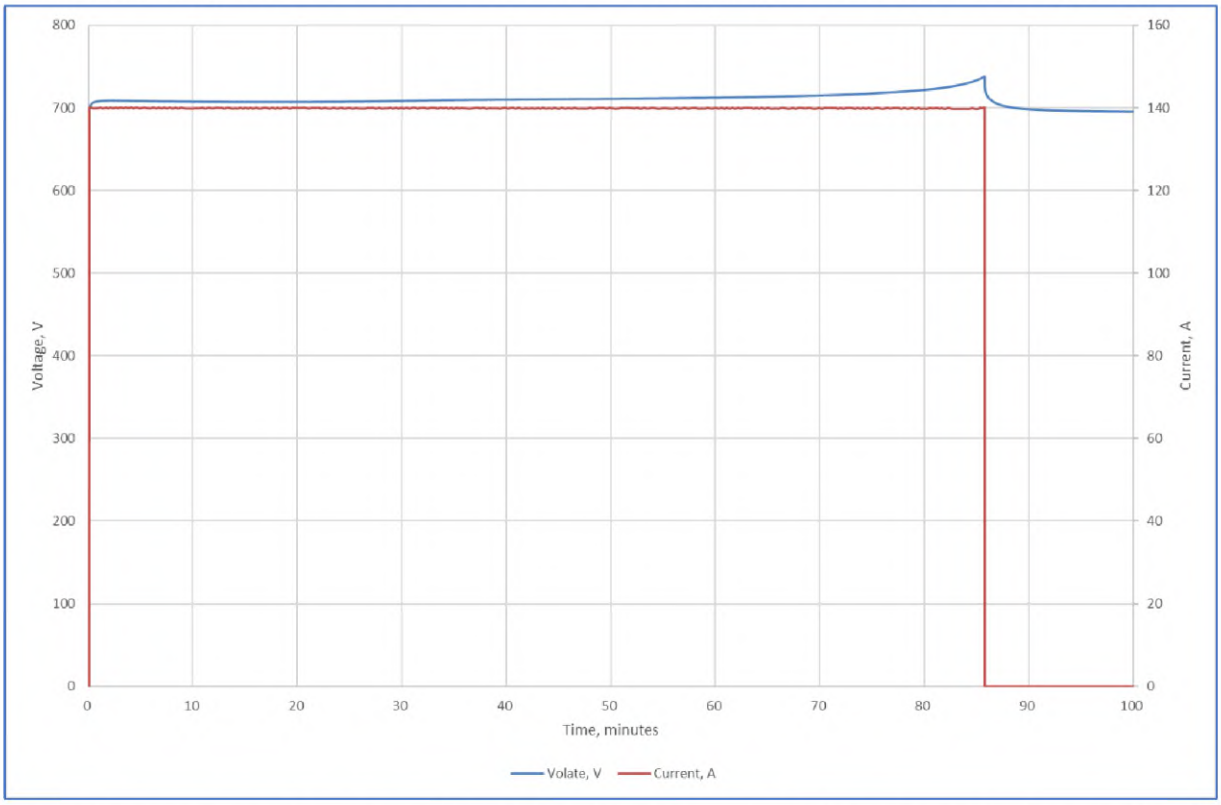
Aerosol (Alternative)	FIREAWAY INC	Stat-X condensed aerosol generator, Model 250MT	Activated Alumina: CAS 1333-84-2 (Aluminum Oxide non-fibrous): 197g, -40 ℃ to 54 ℃, Trigger temperature:70 ℃	SI 1998 No.1609 Reg 8(1), SI 1998 No.2271 Reg (6), SI 2001 No.0009 Reg 7(1), SI 2002 No. 2201 Reg 5(1) MGN 280	MCA, File reference: MS 47/11/1042
The material of cover for waterproof strip	CENTURY CREATION INTERNATIONAL	EPDM	Thickness:1.0mm Temperature: 60 ℃	UL 1973, IEC/EN 62477-1 Environment test	Tested with appliance VBD01J00452200004C
The material of cover for waterproof strip (Alternative	ASIA LANNERET SCIENCE & TECHNOLOGY CO LTD	EPDM-2015	Thickness:1.0mm Max.service temperature: 70 ℃	UL 157	UL MH60816
Internal connecting wires for HV	DONGGUAN NISTAR TRANSMITTING TECHNOLOGY CO INC	UL3932	2000 Vd.c., 125 ℃, 95mm2	UL 758	UL E214184
Lead wire for high voltage sampling circuit	DONGGUAN NISTAR TRANSMITTING TECHNOLOGY CO INC	UL3932	2000 Vd.c., 125 ℃, 1mm2	UL 758	UL E214184
Power cable for auxiliary power supply	DONG GUAN NISTAR TRANSMITTING TECHNOLO G Y CO., INC.	UL3666	2.5/4 mm2 XLPE 105 ℃ 600 Va.c.	UL 758/UL1581	UL E214184

Note: the alternate component in this report is only for reference only. UL didn't test the product with alternate component and no follow-up service evaluation is being performed for UL9540A products.

Attachment A: Sample Charging, OCV and SOC Measurement Profiles - (*Pages **28** through **27***)



From the bottom up, module 1 to module 4 of the initiating unit, series connected, charge to 100% SOC



From the bottom up, module 5 to module 8 of the initiating unit, series connected, charge to 100%SOC

Attachment B: BESS (including module and any integral fire detection and suppression systems) Construction Photos/Diagrams - (*Pages **28** through **29***)



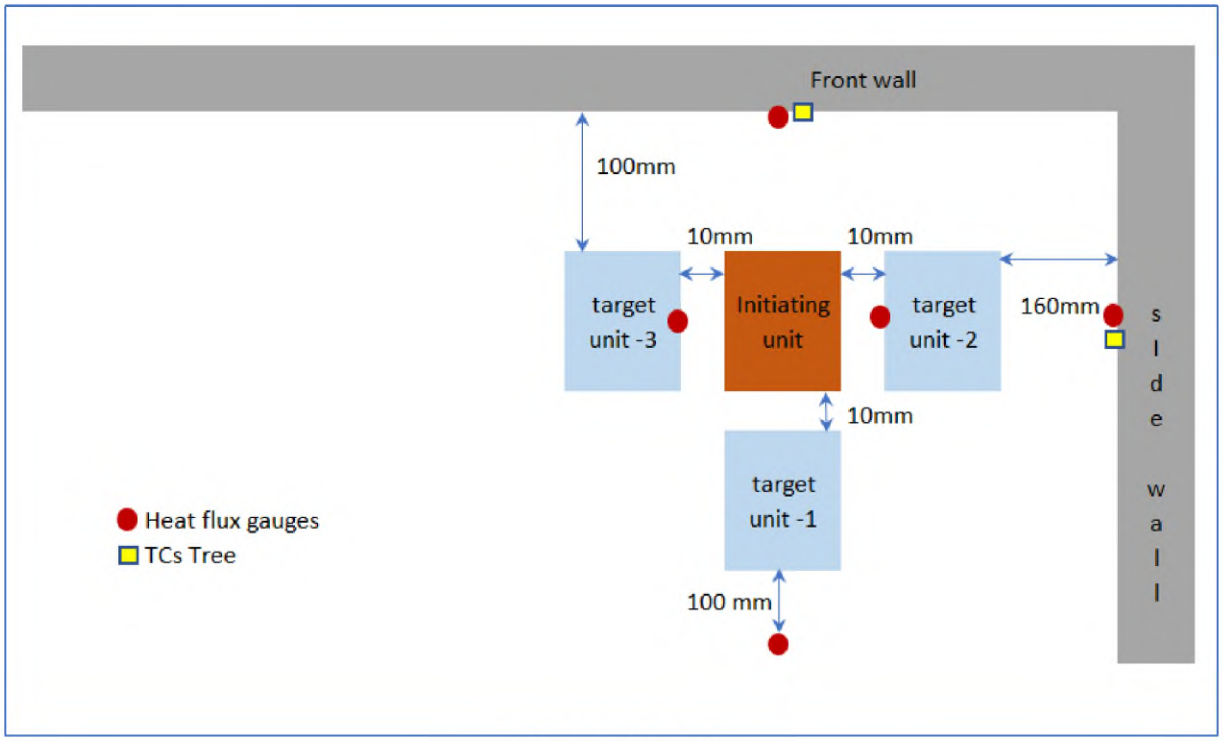




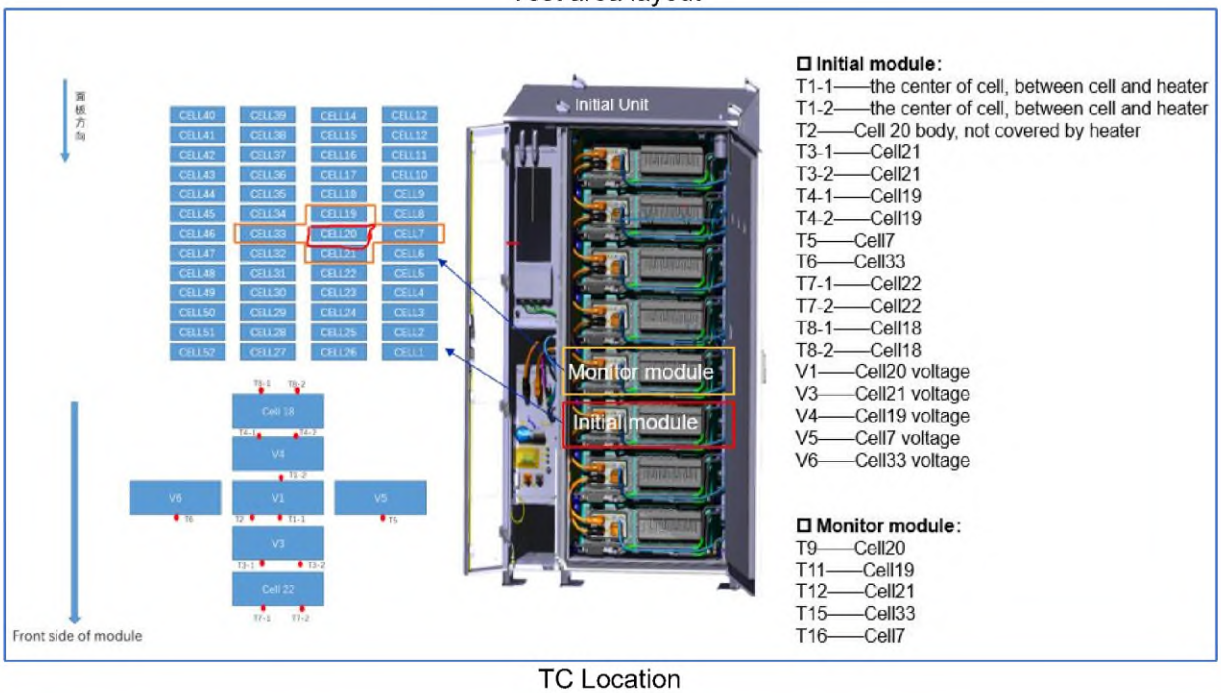


BESS Construction Photos

Attachment C: BESS and Equipment Instrumentation and Test Installation Layout Photos/Diagrams - (*Pages **30** through **31***)

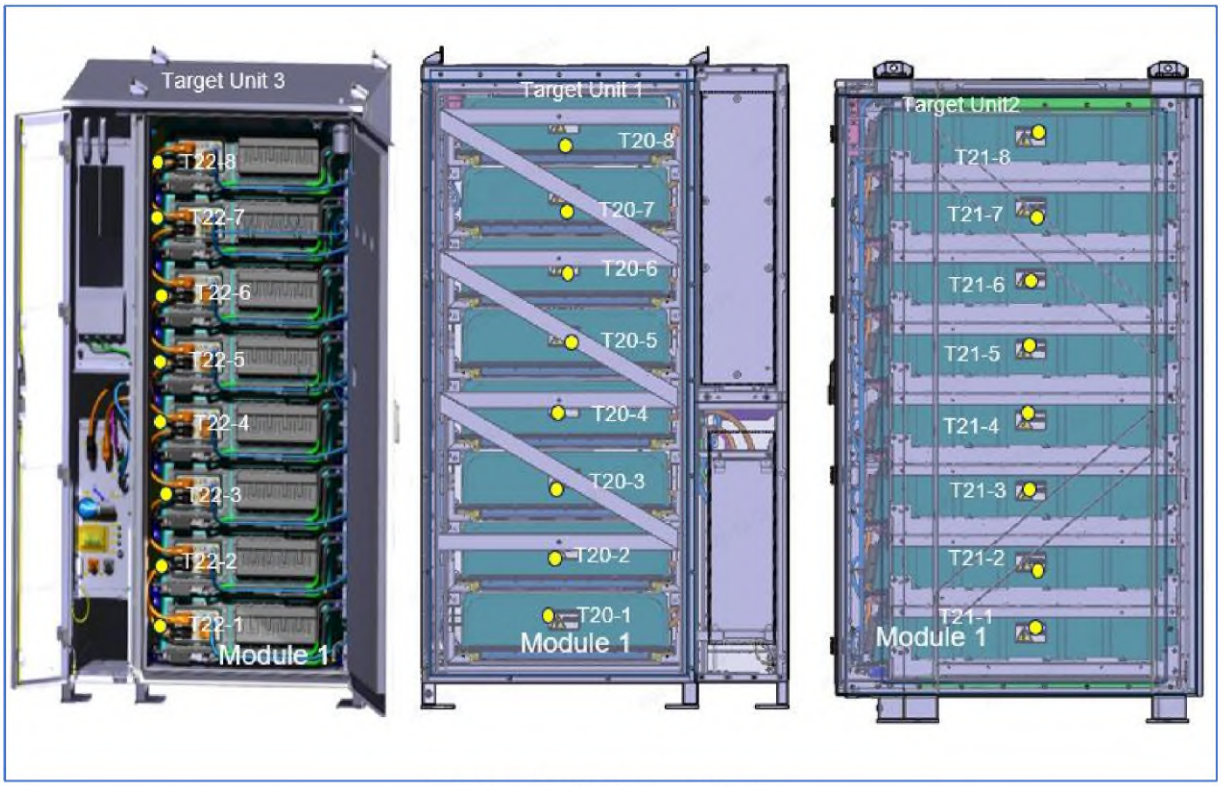


Test area layout[4]



TC Location

[4] The egress gauge location was selected by client. The lower gauge of the front wall also can be on behalf of the egress path heat flux.

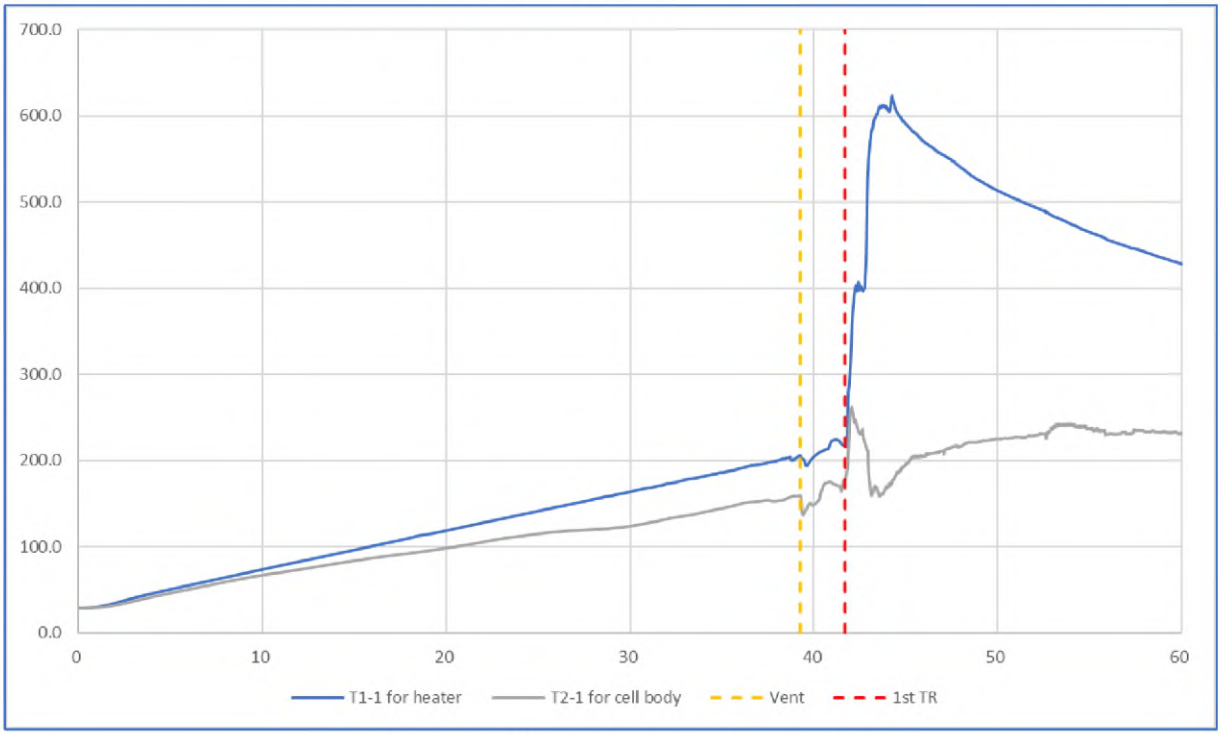


TC location in the target units

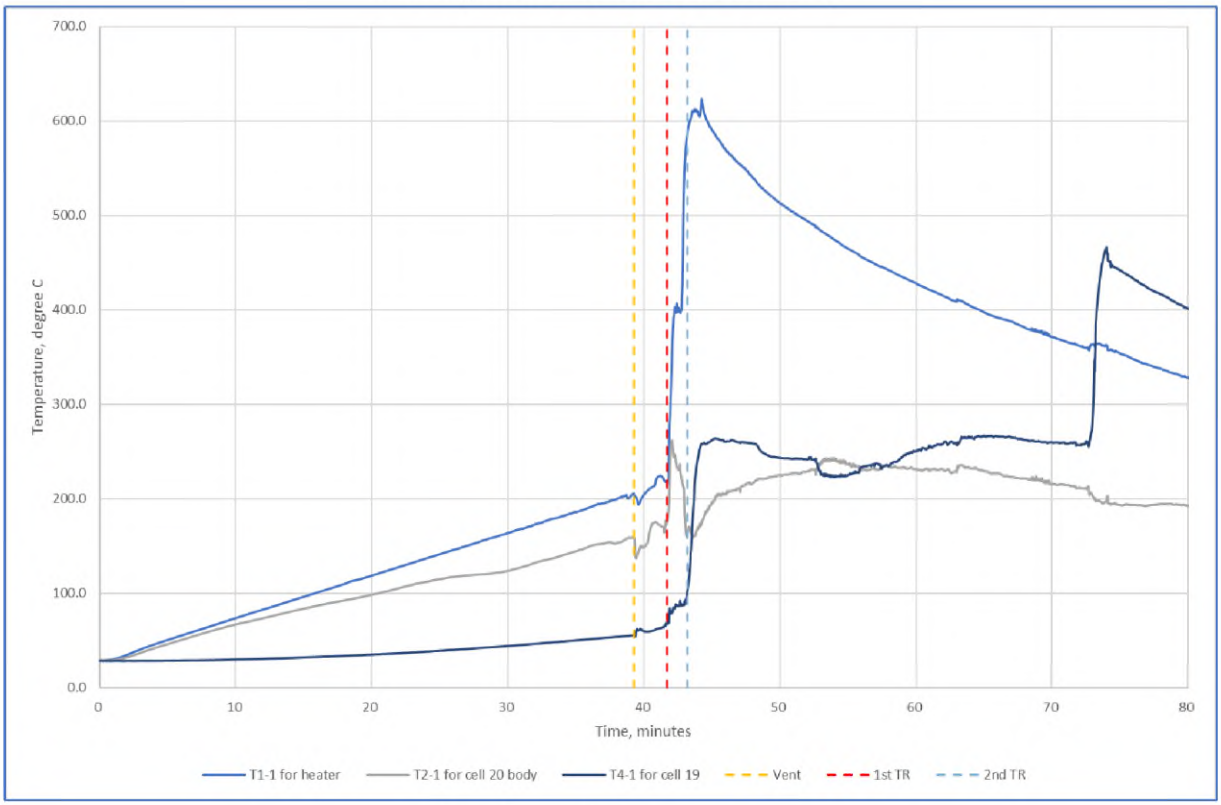


Test area photo

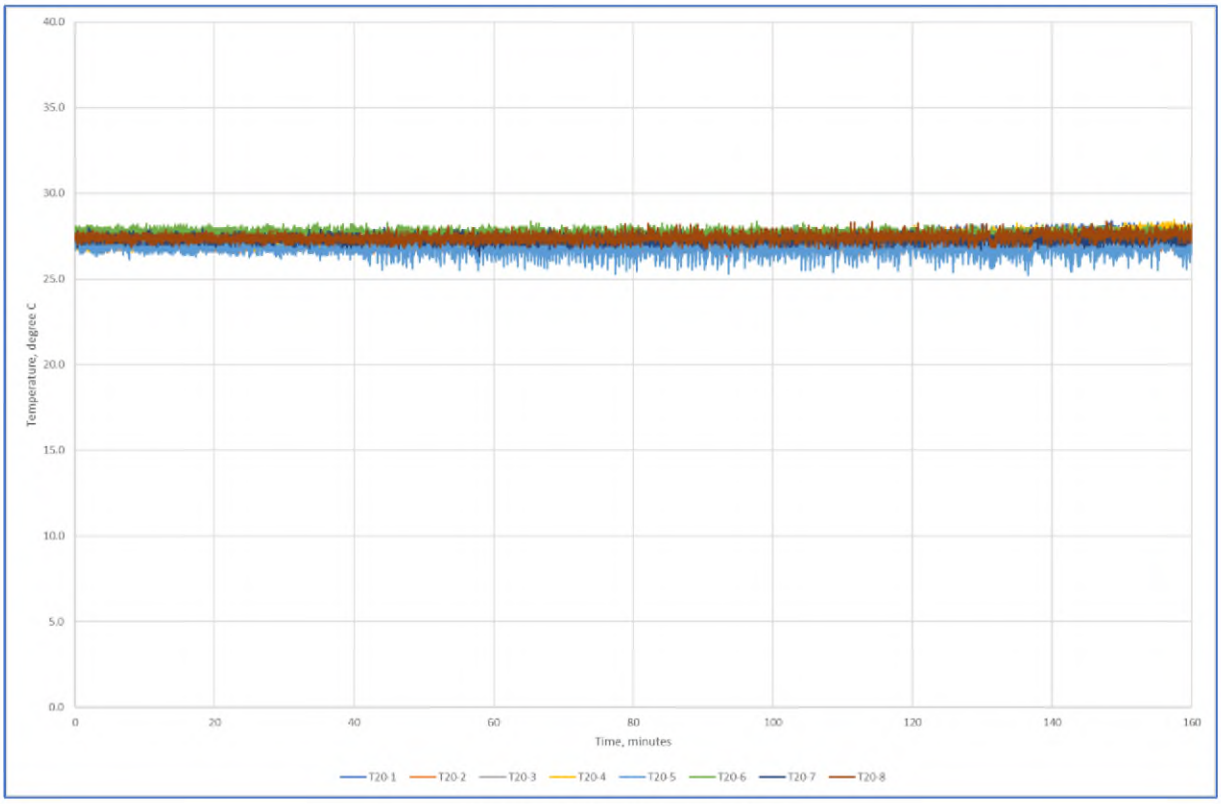
Attachment D: Temperature Profiles and Heat Flux Measurements During Testing (Initiating Cell and Module, Target Modules, Wall Surfaces, etc. - (*Pages **32** through **35***)



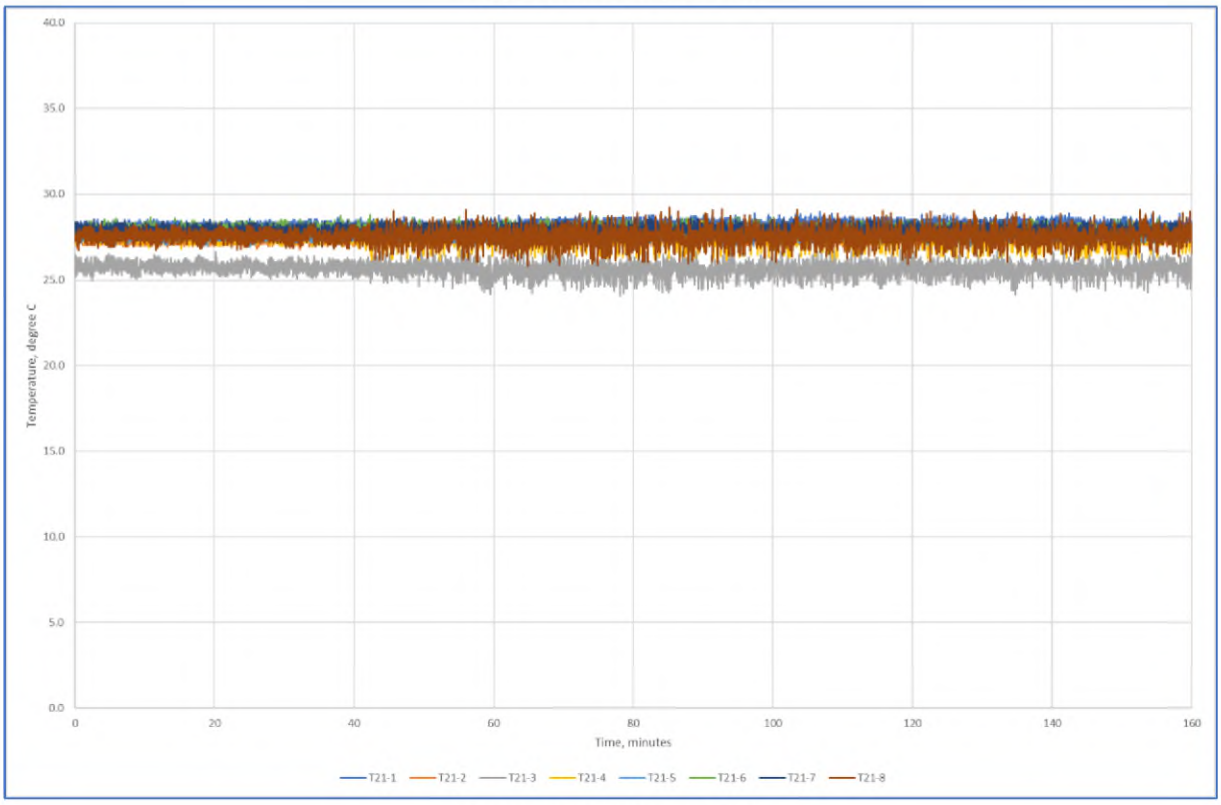
Initiating cell vent and thermal runaway



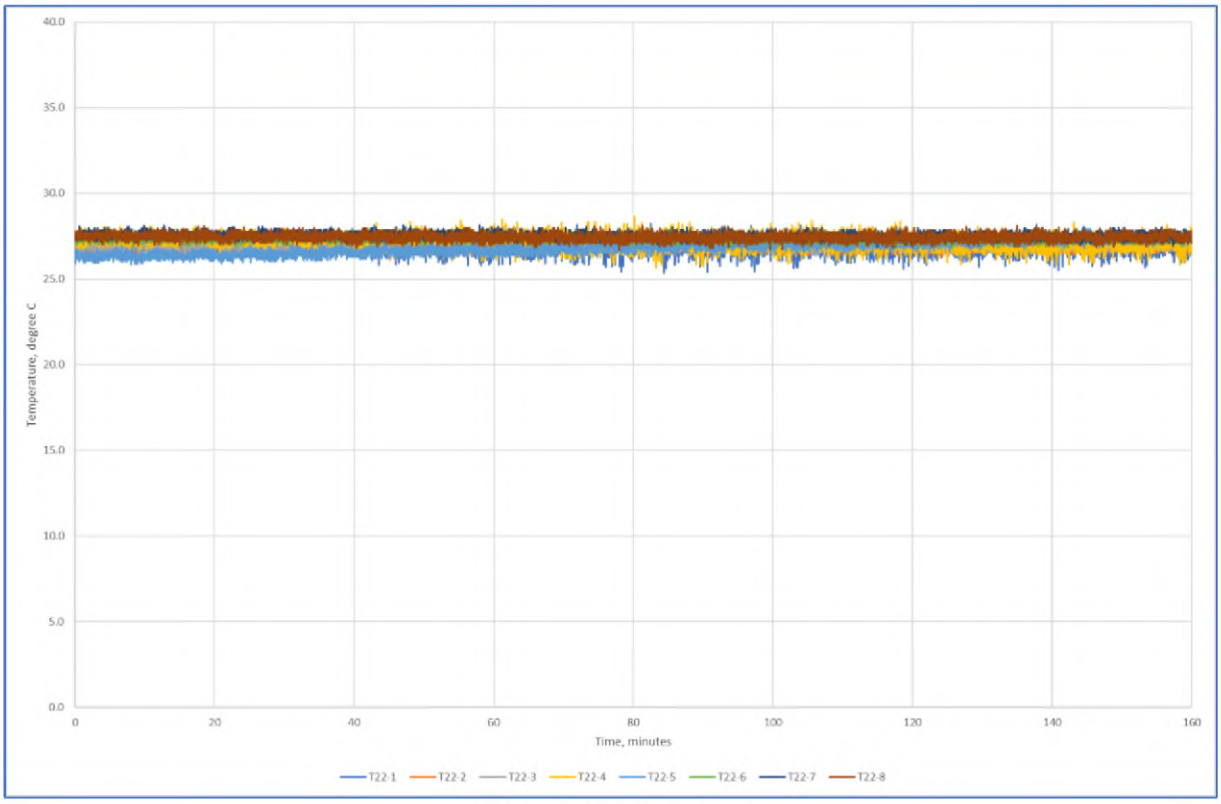
Initiating module temperature



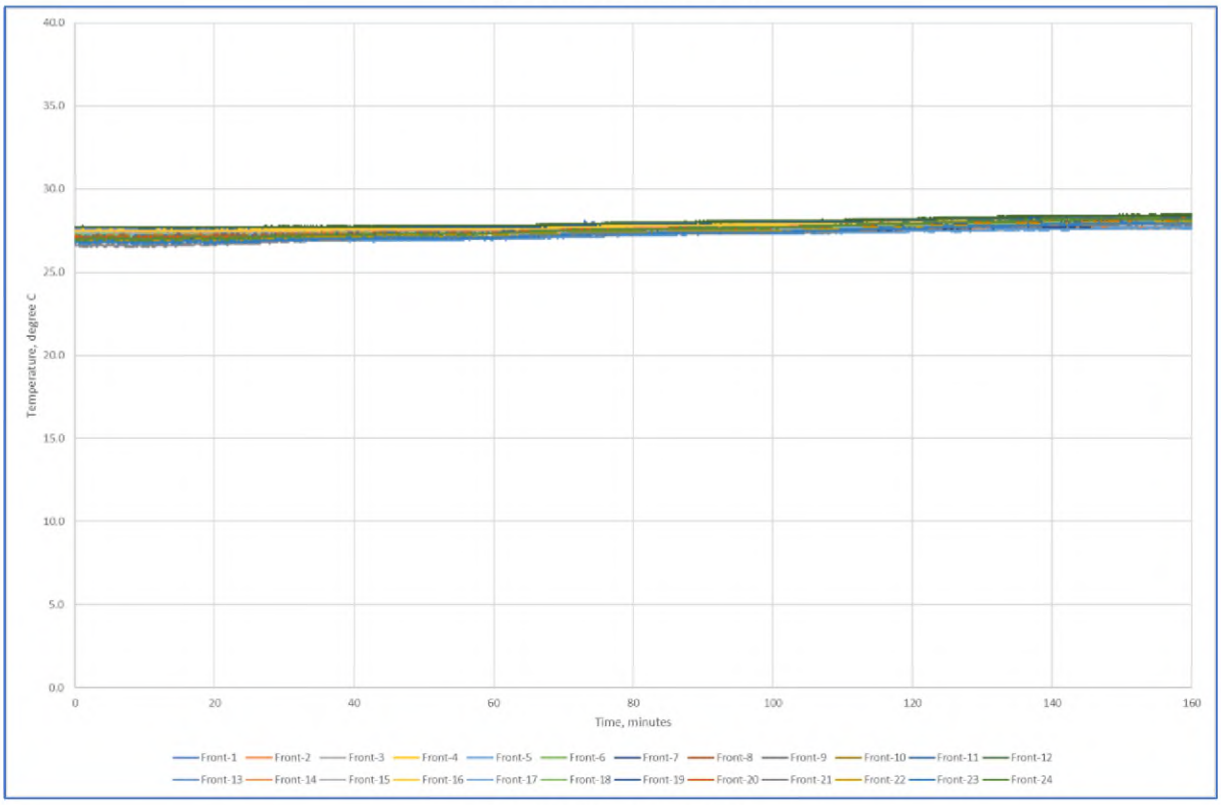
Target unit-1 temperature



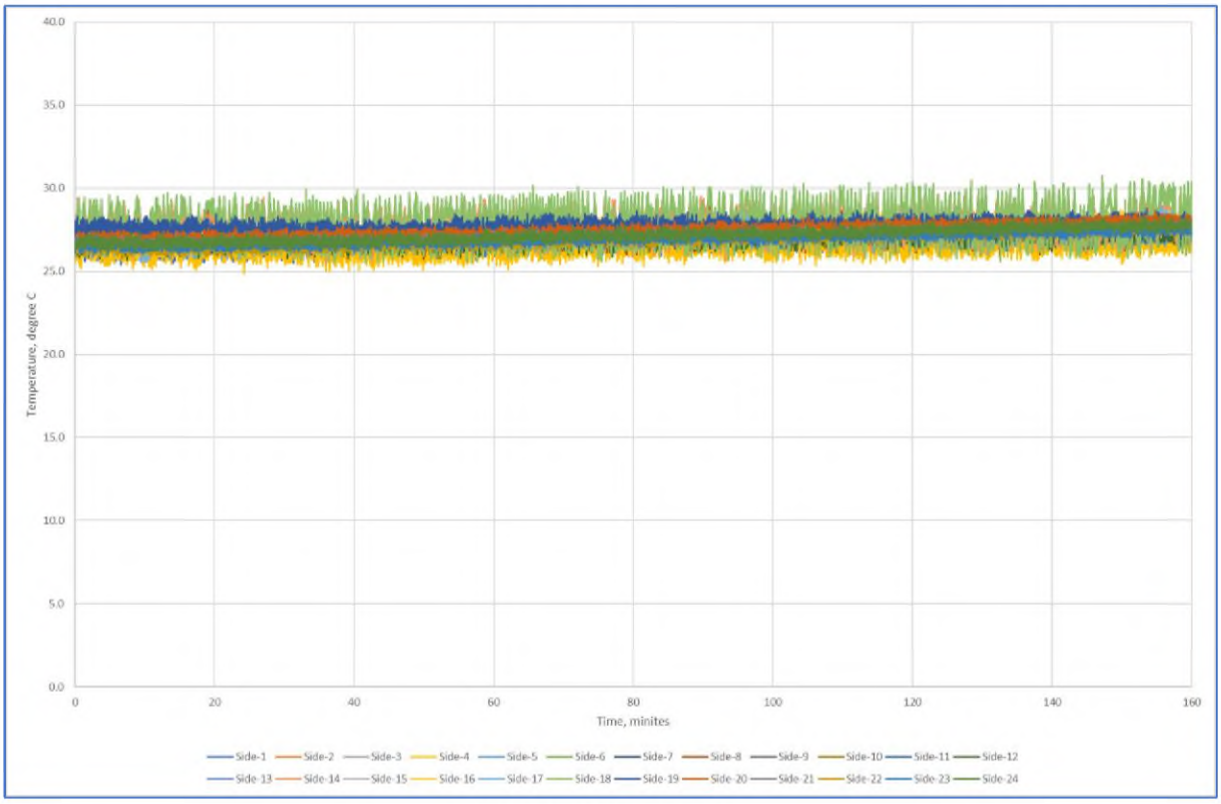
Target unit-2 temperature



Target unit-3 temperature



Front wall temperature



Side wall temperature

Attachment E: BESS Unit Testing and Post Testing Photos - (*Pages **36** through **38***)



(a) Test Start
[00:00:00]



(b) Vent of initiating cell
[00:39:16]



(c) Initiating cell thermal runaway
[00:41:42]



(d) Cell 19 thermal runaway
[00:43:12]



(e) Cell 21 thermal runaway
[00:44:19]



(f) Cell 18 thermal runaway
[01:13:24]



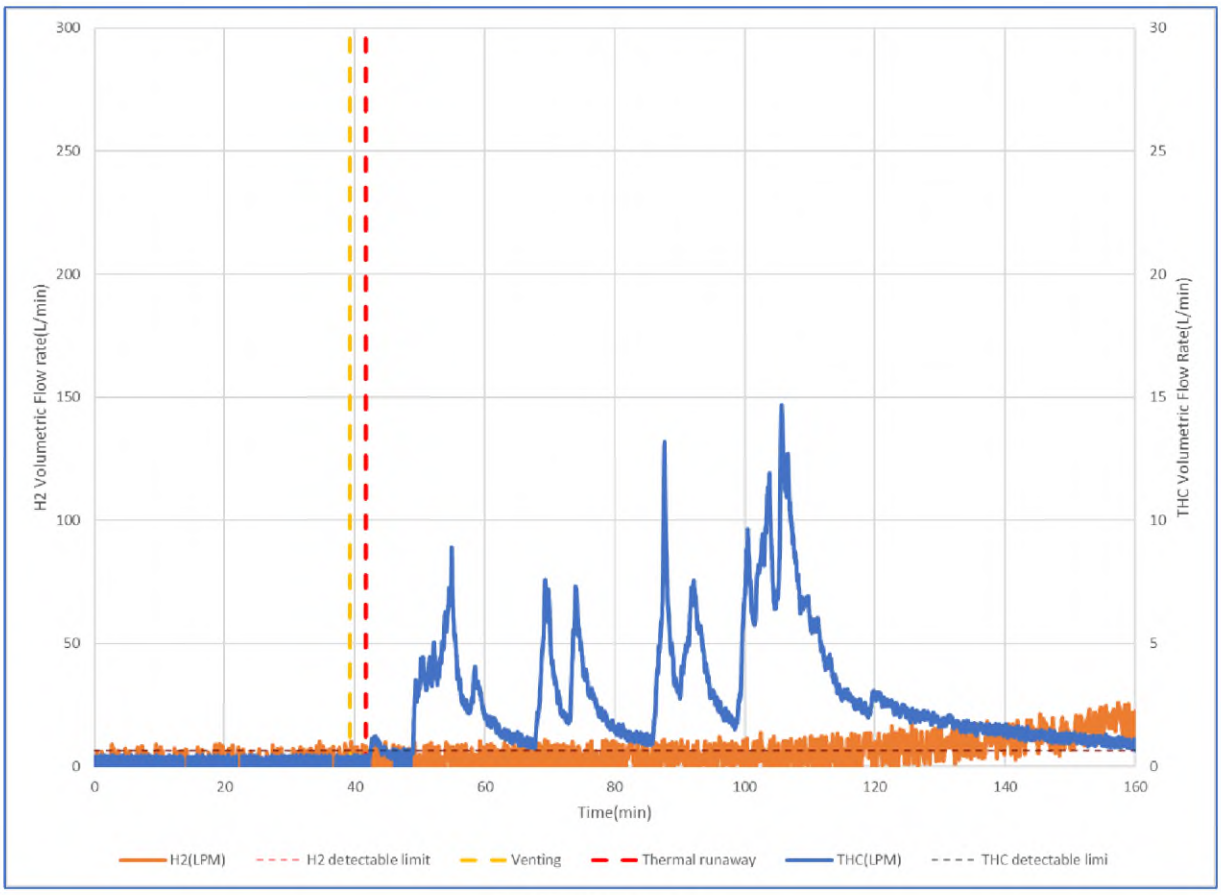
(g) Event description
[02:00:00]



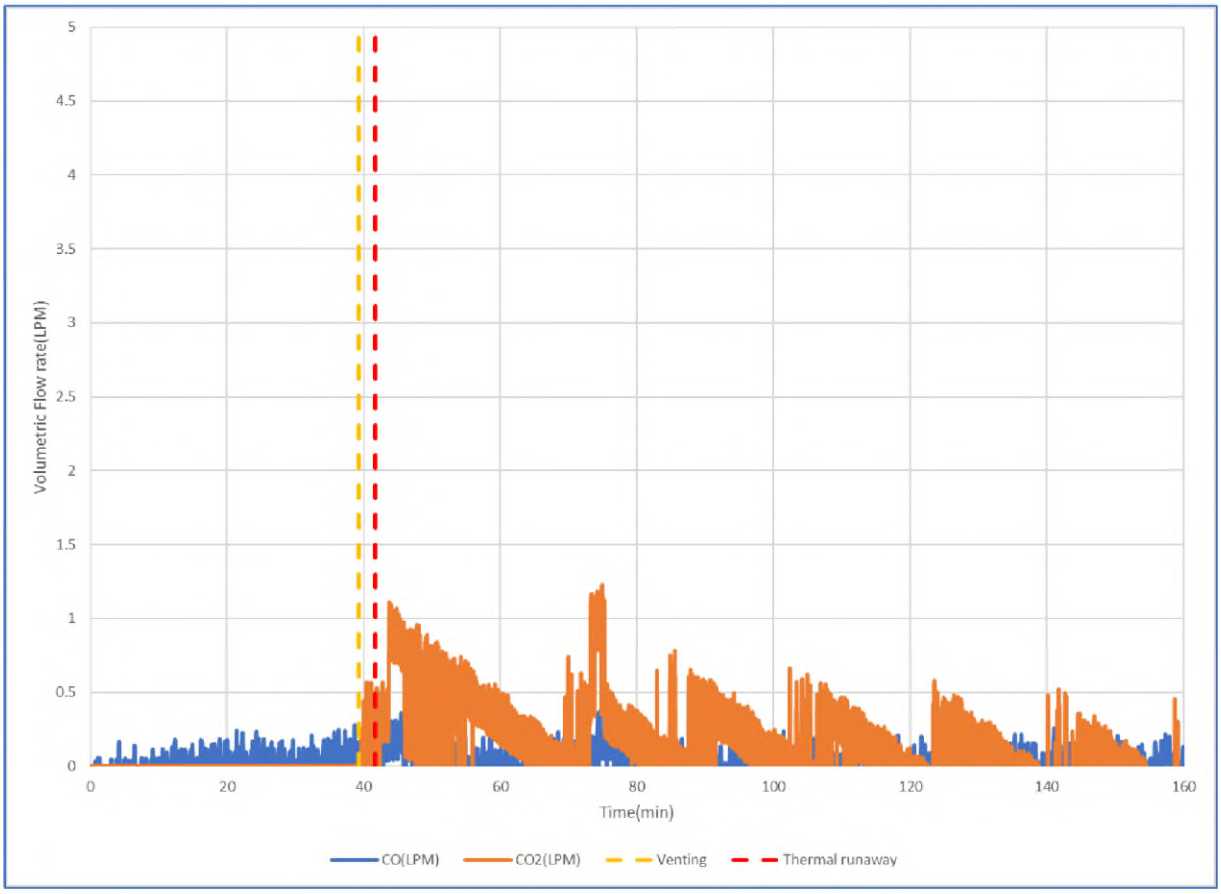


Photos after test

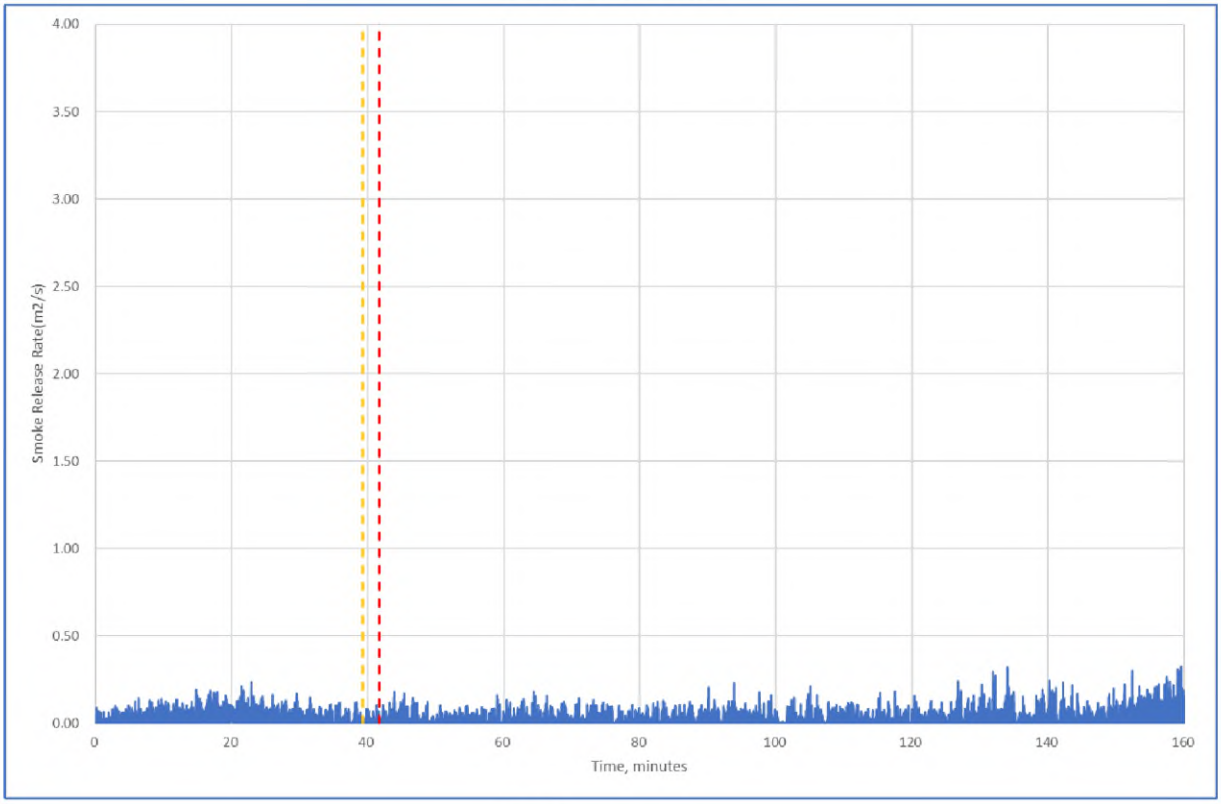
Attachment F: BESS Unit Gas Flow Rate and Heat Release and Smoke Release Profiles - (*Pages **39** through **41***)



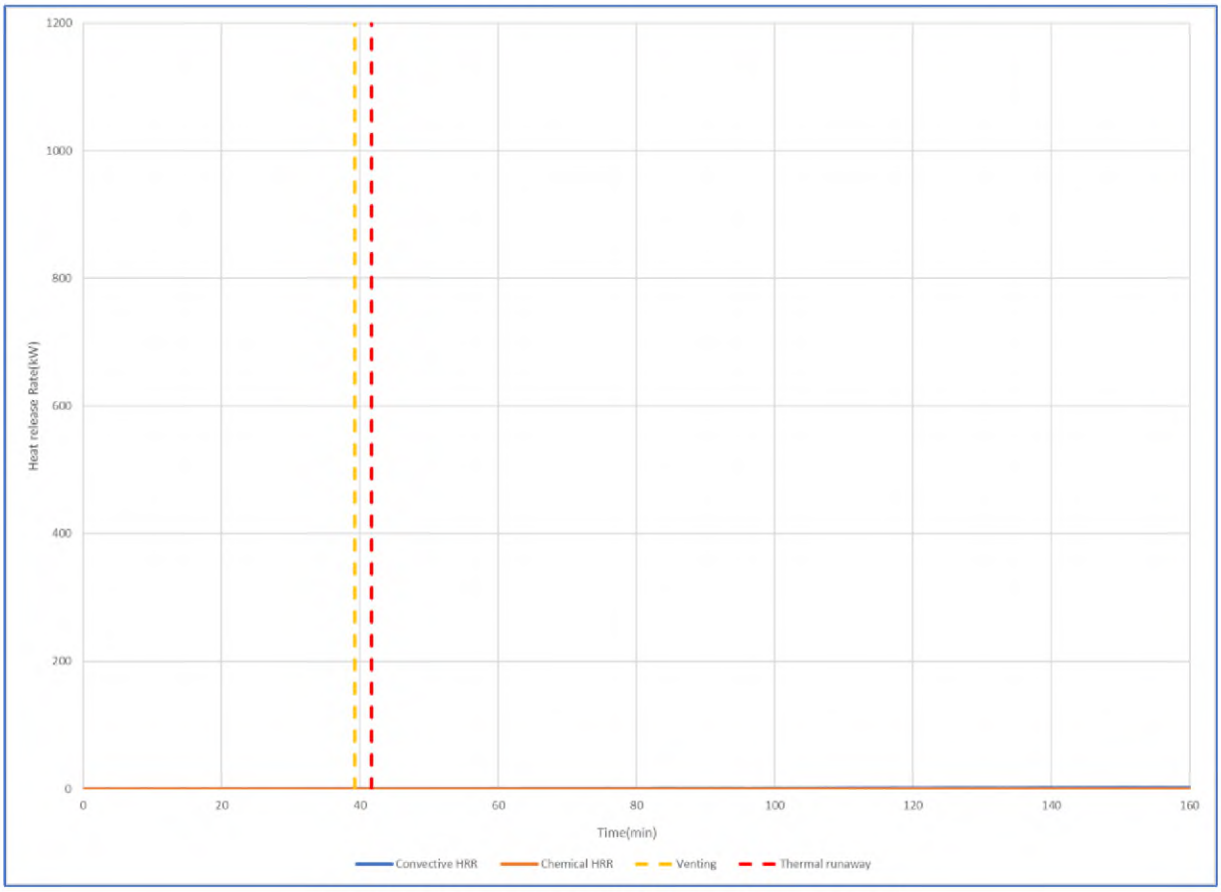
THC, H2 flow rates



CO, CO2 flow rates



Smoke release rate



Chemical heat release rate (No flaming observed)