Prüfbericht-Nr.: *Test report no.:*	CN23AYBH 001	**Auftrags-Nr.:** *Order no.:*	168447779	Seite 1 von 38 *Page 1 of 38*
Kunden-Referenz-Nr.: *Client reference no.:*	2544823	**Auftragsdatum:** *Order date:*	2023-05-15	
Auftraggeber: *Client:*	Discover Energy Systems corp. #7-13511 Crestwood Place, Richmond, BC V6V 2E9 Canada			
Prüfgegenstand: *Test item:*	Energy Storage System			
Bezeichnung / Typ-Nr.: *Identification / Type no.:*	950-0053_6			
Auftrags-Inhalt: *Order content:*	Test report			
Prüfgrundlage: *Test specification:*	UL 9540A: 2019 (Fourth Edition)			
Wareneingangsdatum: *Date of sample receipt:*	2023-10-17			
Prüfmuster-Nr.: *Test sample no:*	Engineering samples			
Prüfzeitraum: *Testing period:*	2023-10-17 - 2023-10-20			
Ort der Prüfung: *Place of testing:*	See to clause 1.1 of main report			
Prüflaboratorium: *Testing laboratory:*	See to clause 1.1 of main report			
Prüfergebnis*: *Test result*:*	See main report			

erstellt von: *created by:*		**genehmigt von:** *authorized by:*	
Datum: *Date:* 2024-01-08	Jason Zhu	**Ausstellungsdatum:** *Issue date:* 2024-01-08	Xun Yu
Stellung / *Position:*	Project Engineer	**Stellung** / *Position:*	Reviewer

Sonstiges / *Other:*

This report is based on previous report CN23PVP9 001. The changes as follow:
1. The Client name and address are changed.
2. The model number are changed.
In addition to the above changes, no additional tests needed.

This report does not evidence compliance of the provided sample with the relevant standards but only with the referred tests. This test report documents the findings of examination conducted on the delivered product mentioned above only. This report does not entitle the applicant to carry any safety mark on this or similar products. Further for sales or other application purposes of the tested product, any reference to TÜV Rheinland or a test through TÜV Rheinland is only permissible with prior written consent of TÜV Rheinland.

Zustand des Prüfgegenstandes bei Anlieferung: *Condition of the test item at delivery:* Prüfmuster vollständig und unbeschädigt *Test item complete and undamaged*

* Legende:	P(ass) = entspricht o.g. Prüfgrundlage(n)	F(ail) = entspricht nicht o.g. Prüfgrundlage(n)	N/A = nicht anwendbar	N/T = nicht getestet
** Legend:*	*P(ass) = passed a.m. test specification(s)*	*F(ail) = failed a.m. test specification(s)*	*N/A = not applicable*	*N/T = not tested*

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Remarks

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INTRODUCTION

Model fire codes and energy storage system standards require energy storage systems to comply with UL 9540, which in turn requires battery cells and modules to comply with UL 1973. Compliance with these standards reduces the risk of batteries and battery energy storage systems (BESS) creating fire, shock or personal injury hazards. However, they don't evaluate the ability of the BESS installed as intended and with fire suppression mechanisms in place if necessary, from contributing to a fire or explosion in the end use installations.

To address these fire and explosion hazards associated with the installation of a BESS, the fire and other codes require energy storage systems to meet certain location, separation, fire suppression and other criteria. Those codes also provide a means to provide an equivalent level of safety based on large scale fire testing of anticipated BESS installations.

UL 9540A is intended to provide a test method that can be used as a basis for validating the safety of a BESS installation in lieu of meeting the specific criteria provided in those codes. The data generated can be used to determine the fire and explosion protection required for installation of a BESS.

The test method is initiated through the establishment of a thermal runaway condition that leads to combustion within the BESS. The test method outlined in UL 9540A consists of several steps – cell level testing, module level testing, unit level testing and installation level testing. The cell and module level testing steps are information gathering steps to inform the unit and installation level testing.

The following outlines the information that may be gathered as part of the testing:

a) Cell level – An individual cell fails in a manner that leads to thermal runaway and fire through a suitable method such as external heating. Data such as off-gassing contents, temperatures at venting and temperatures at thermal runaway are recorded.

b) Module level – One or more cells within a BESS module fail in the manner determined during the cell level testing. Data such as fire propagation in the module, temperatures on the failed cells and surrounding cells, off-gassing contents and heat release data are gathered.

c) Unit level – A complete BESS is installed surrounded by target (e.g. dummy) BESS and walls separated at a distance as intended in its installation. The module level test is repeated on a module located in the BESS in the most unfavorable location. Data such as temperature within the BESS, on surrounding walls and target BESS; incident heat flux on walls and target BESS; observation of fire propagation from BESS to target units and walls as well as observance of explosions or evidence of re-ignition within the BESS; and heat release and off-gassing contents are gathered.

d) Installation level – This test is a repeat of the unit level test with the test conducted within a test room and with the intended fire suppression system installed as well as any overhead cables (that can lead to fire propagation) installed. This test is intended to validate the fire suppression system for the BESS installation. Data such as temperature within the BESS, on surrounding walls and target BESS; incident heat flux on walls and target BESS; fire propagation from the BESS to target units, walls or overhead cables and any observable explosion incidents or re-ignition within the BESS; and off-gassing contents (if needed) and heat release are gathered.

Contents

1 General information

1.1 Test specification

Standard: ANSI/CAN/UL 9540A: 2019 (Fourth Edition)

Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems

This report presents the result of unit level tests of UL 9540A: 2019.

All tests were conducted at TUV Rheinland (Shenzhen) Co., Ltd. and TUV Rheinland's partner labs that were under supervision of TÜV Rheinland's engineer.

Testing period: 2023-10-17 to 2023-10-20

Refer to Clause 4 for test and measurement instruments.

1.2 General remarks

This report is descriptive and provide the test data only.

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

This report shall not be reproduced, except in full, without the written approval of the testing laboratory.

Throughout this report a ☐ comma / ☒ point is used as the decimal separator.

1.3 Revision information

New report, not applicable.

1.4 Definitions

CELL – The basic functional electrochemical unit containing an assembly of electrodes, electrolyte, separators, container, and terminals. It is a source of electrical energy by direct conversion of chemical energy.

MODULE – A subassembly that is a component of a BESS that consists of a group of cells or electrochemical capacitors connected together either in a series and/or parallel configuration (sometimes referred to as a block) with or without protective devices and monitoring circuitry.

UNIT – A frame, rack or enclosure that consists of a functional BESS which includes components and subassemblies such as cells, modules, battery management systems, ventilation devices and other ancillary equipment.

BATTERY SYSTEM (BS) – Is a component of a BESS and consists of one or more modules typically in a rack configuration, controls such as the BMS and components that make up the system such as cooling systems, disconnects and protection devices.

BATTERY ENERGY STORAGE SYSTEM (BESS) – Stationary equipment that receives electrical energy and then utilizes batteries to store that energy to supply electrical energy at future time. The BESS, at a minimum consists of one or more modules, a power conditioning system (PCS), battery management system (BMS) and balance of plant components.

a) INITIATING BATTERY ENERGY STORAGE SYSTEM UNIT (INITIATING BESS) – A BESS unit which has been equipped with resistance heaters in order to create the internal fire condition necessary for the installation level test.

b) TARGET BATTERY ENERGY STORAGE SYSTEM UNIT (TARGET BESS) – The enclosure and/or rack hardware that physically supports and/or contains the components that comprise a BESS. The target BESS unit does not contain energy storage components, but serves to enable instrumentation to measure the thermal exposure from the initiating BESS.

Note: Depending upon the configuration and design of the BESS (e.g. the BESS is composed of multiple separate parts within separate enclosures), the unit level test can be done at battery system level. In such case, the BESS is be read as BS throughout this report.

NON-RESIDENTIAL USE – Intended for use in commercial, industrial or utility owned locations.

RESIDENTIAL USE – In accordance with this standard, intended for use in one or two family homes and town homes and individual dwelling units of multi-family dwellings.

THERMAL RUNAWAY- The incident when an electrochemical cell increases its temperature through self-heating in an uncontrollable fashion. The thermal runaway progresses when the cell's generation of heat is at a higher rate than the heat it can dissipate. This may lead to fire, explosion and gas evolution.

STATE OF CHARGE (SOC) – The available capacity in a BESS, pack, module or cell expressed as a percentage of rated capacity.

2 General Product Information

The product information and parameters were provided by the client as below.

2.1 Cell

Manufacturer:	**Ruipu Energy Co., Ltd.** No.205, Binhai 6th Road, konggang New District, Longwan District, Wenzhou Zhejiang, P.R. China	
Model number:	CB27173204EA	
Chemistry:	☒ $LiFePO_4$ ☐ NMC ☐ NCA ☐ LTO ☐ Other:	
Physical configuration:	☒ Prismatic ☐ Cylindrical ☐ Pouch	
	Weight(kg):	2.1±0.1kg
Electrical rating :	Rated capacity (Ah):	100
	Nominal voltage (V):	3.2
Standard charge method:	Charge current (A):	100
	Standard Charge Voltage (V):	3.65
	Cut off current (A):	5
Standard discharge method:	Discharge current (A):	100
	End of discharge voltage (V):	2.5
Maximum continuous charge current (A):	100	
Maximum continuous discharge current (A):	100	
Compliance with UL 1973:	☒ Yes TUV Rheinland: CN212RU5 001 ☐ No	

2.2 Module

Manufacturer:	**Discover Energy Systems corp.** #7-13511 Crestwood Place Richmond BC V6V 2E9 Canada	
Model number:	48-48-5120 / 900-0062, 48-48-5120-H / 900-0067	
Physical configuration:	Metal enclosure	
	Weight:	Approx. 44 kg
	Cells in series/parallel:	1P16S
Cooling method:	Air cooling	
Separation between cells:	-	
Electrical rating:	Rated capacity:	100 Ah
	Nominal voltage:	51.2 Vdc
Standard charge method:	Charge power:	70A
	End of charge:	The highest voltage reaches 55.2V
Standard discharge method:	Discharge power:	70A
	End of discharge:	The lowest voltage reaches 48 V
Compliance with UL 1973:	☒ Yes	☐ No TUV Rheinland: CN233MYV 004

2.3 Unit

Product name	Energy Storage System
Model	950-0053_6
Voltage range	48V ~ 55.2V
Nominal voltage	51.2 Vdc
Maximum charge Current	500A
Maximum discharge Current	500A
Rated capacity	600 Ah
Operating Temperature	Charge: 4°C to 52°C Discharge: -17°C to 52°C
Recommend charging method declared by the manufacturer	Charge at a constant current 420A until voltage reaches 55.2V then charge at constant voltage of 55.2V until charge current is 15A.
Recommend discharging method declared by the manufacturer	Discharged with 420A constant current to discharge cut-off voltage 48V
Nominal mass	360 kg
External dimensions (mm)	Max. D*L*H: 350*680*1721

Unit diagram with overall dimension

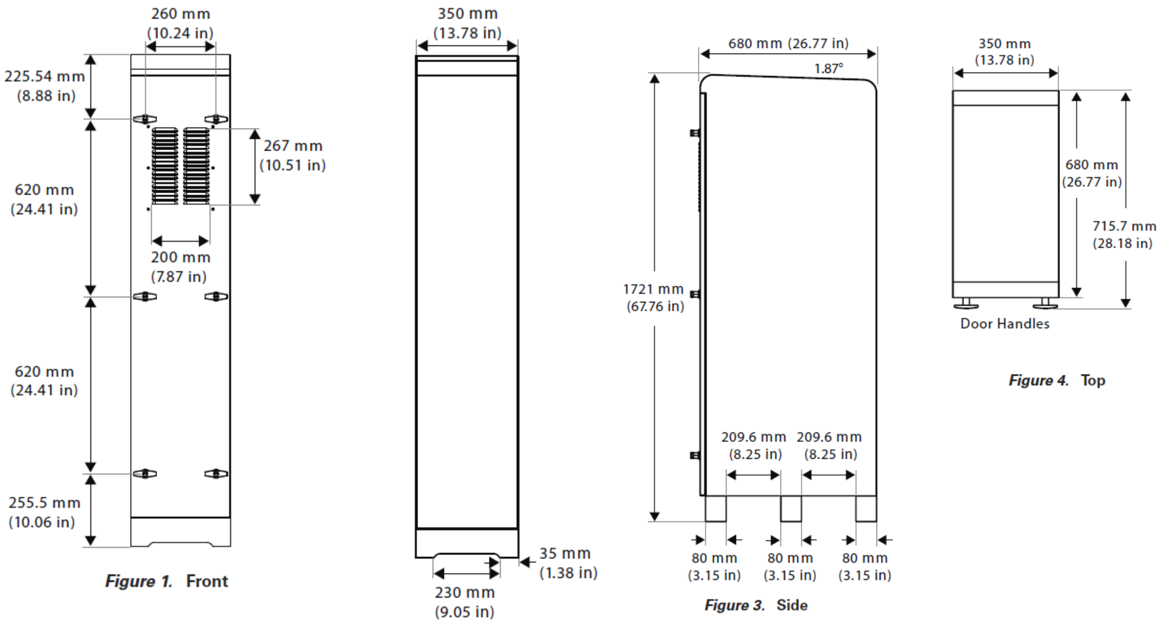


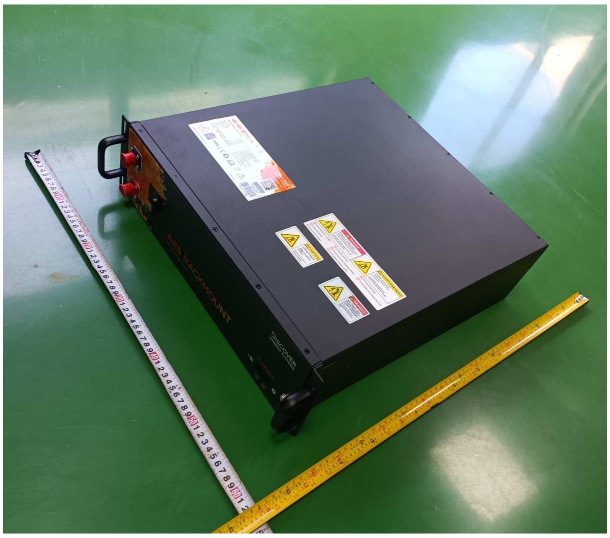
Figure 1. Front

Figure 3. Side

Figure 4. Top

Unit: mm

2.4 Photo



Module

Unit

3 Unit level test (section 9 of UL 9540A)

3.1 General

Unit level testing corresponds with the testing anticipated by fire codes and other codes impacting energy storage system installations to evaluate the large scale fire performance of BESS units installed in, on or adjacent to buildings or in other areas and their resultant performance to qualify for exceptions to limits in the codes imposed on these installations. The limitations where exceptions may be sought are limitations on the size of the individual BESS units, the total number of BESS units installed within a room, and the separation distances between BESS units and between BESS units and walls of the building.

In this test the initiating BESS unit is placed a set distance from target BESS units simulating BESS units identical to the initiating BESS unit, and from simulated walls representative on the installation. A thermal runaway is induced in cells, using the same approach as used in the module level testing within one of the modules in the initiating BESS, and a variety of measurements are taken. The results are intended to be used to verify that a fire within a single BESS unit will not spread to other units, nor breach the walls or the BESS enclosure (if provided), and there shall be no flying debris or explosive discharge of gases.

The test arrangement include the largest (energy) BESS unit for the installation to be represented by the test, and minimum spacing to adjacent walls and BESS units. The BESS may be tested with an internal fire suppression system provided by the manufacturer if that fire suppression system is required to be installed in the BESS. Optional internal fire suppression systems are not included in the unit level testing.

The test monitors the fire behavior of the BESS unit and measures heat release rates (convective and chemical); gas generation and composition; smoke release rate; maximum heat flux on the target BESS units, wall surfaces and within the accessible means of egress; maximum surface temperatures of the walls and modules within the target BESS units; and documents any explosions, deflagrations and flying debris from the BESS under test.

3.2 Unit sample preparation

The battery system is constructed with 6 modules that was considered as a unit for purposes of the test.

All 6 modules samples through 2 charge/discharge cycles per the manufacturer's instructions to verify that the module was functional. Each cycle was defined as a charge to 100% SOC and allowed to rest 30 minutes and then discharged to an end of discharge voltage (EODV) determined by the module specification. Refer to 2.2 for the end of condition of charge and discharge.

3.3 Setup of the test

3.3.1 Battery system installation information

The installation information was provided by the client as below.

Intended use location .... :	☒ Residential	☒ Non-residential
	☒ Non-residential rooftop	
	☒ Non-residential open garage use	
Type of installation............................ :	☒ Indoor	☒ Outdoor
	☒ Floor/ground mounted	☐ Wall mounted
Row(s) of installation	☒ Single	☒ Multiple

3.3.2 Test site setup

Two instrumented wall with 3.66 m height, 4.1 m length. Walls were constructed of 16-mm (5/8-in) gypsum wall board and painted flat black.

Three units were used for the purpose of the test.

The initiating unit was positioned adjacent to the two instrumented wall sections.

Minimum separation distance from the unit to wall and between unit were provided by the client, separation distance: A=B=C=D=G=44.45mm, E=300mm.

Unit's layout can be seen in Figure 1.

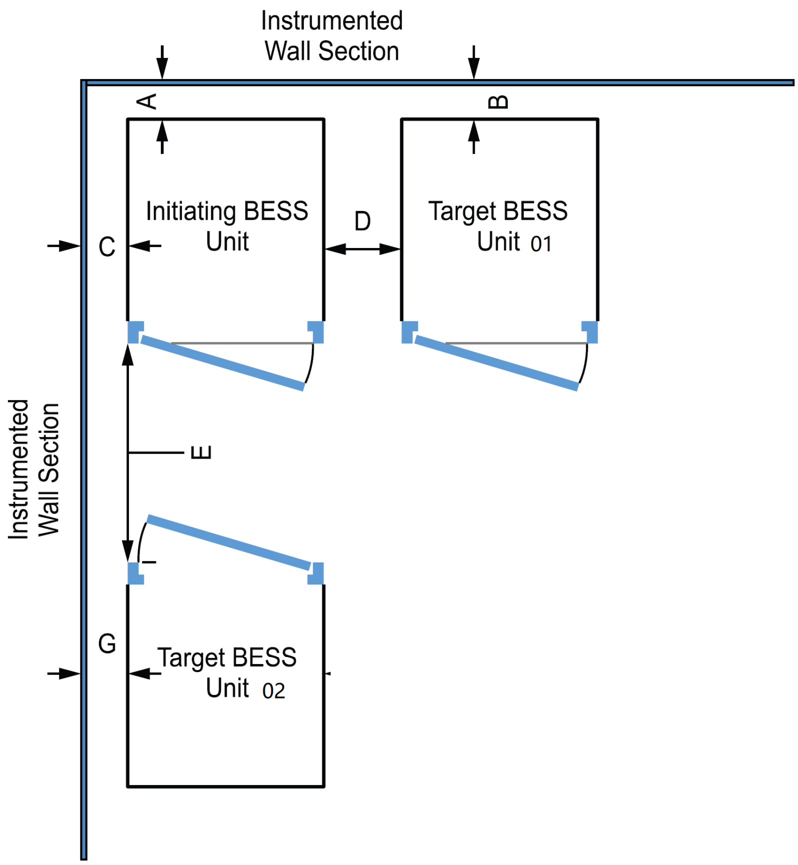


Figure 1. Top view of sub-unit's layout

3.3.3 Thermal runaway setup

Setup of Unit:

There were three units were marked as initiating unit and target unit, one was initiating unit, and the others were target units. Each unit was installing 6 modules.

Modules 4 in initiating unit was selected as “initiating module” for the test.

Modules 02, 03, 06 in initiating unit and modules in target unit 01 and target unit 02 were used to check the possible propagation between modules in initiating unit and target unit. Figure 2 show the details.

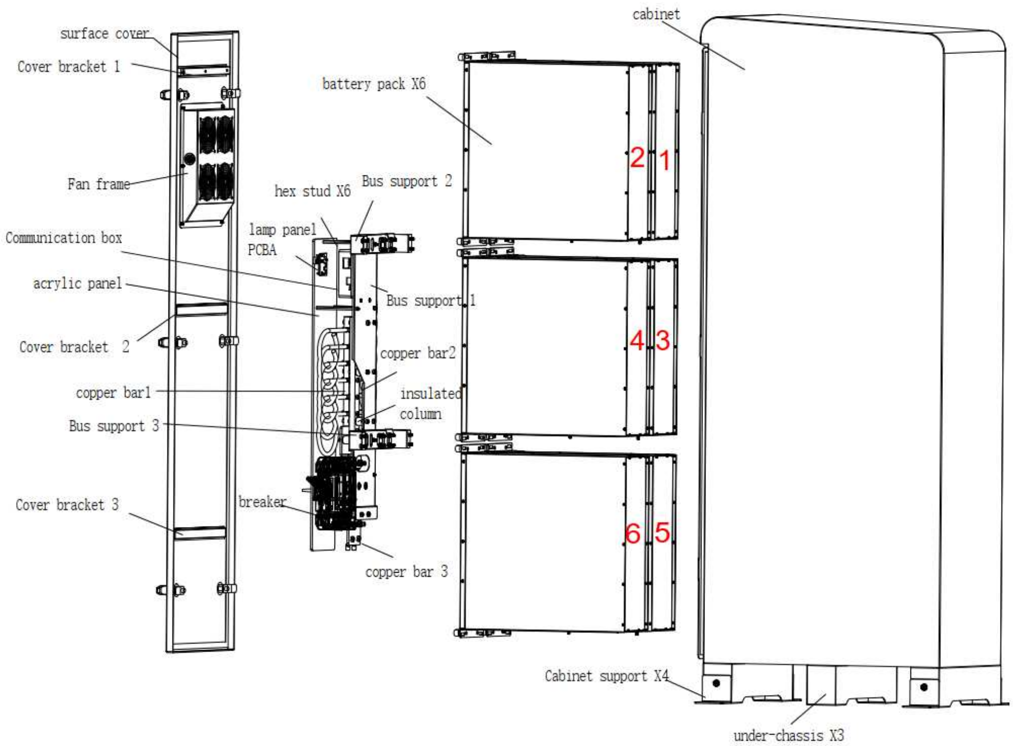


Figure 2. Module numbering in unit

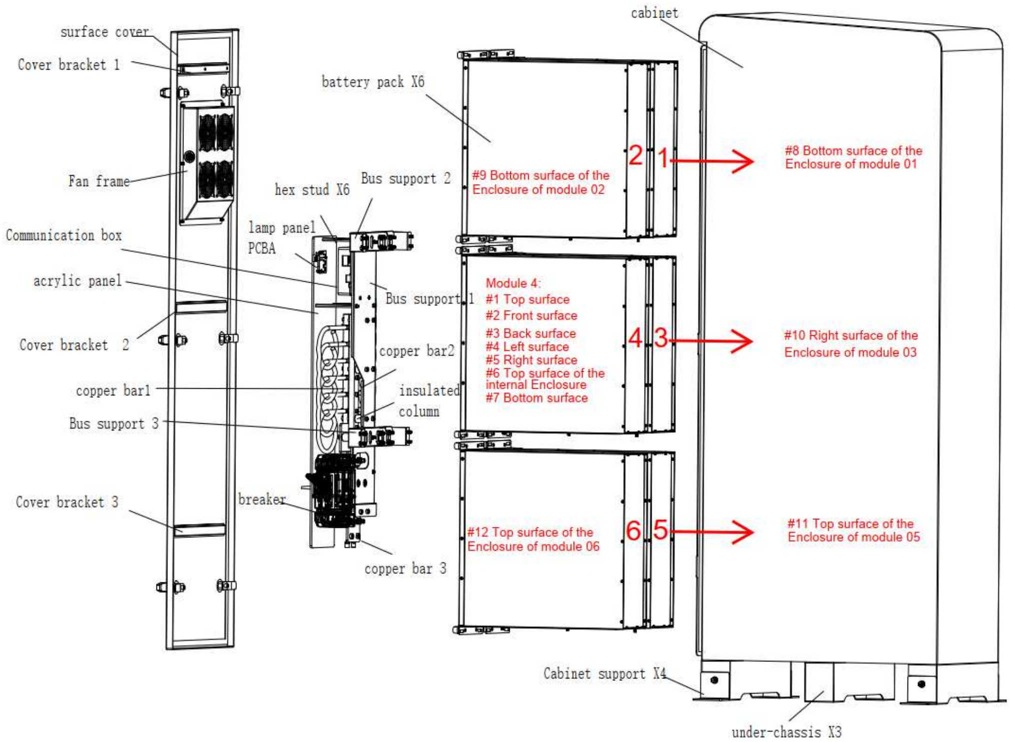


Figure 3. Thermocouple in initiating unit

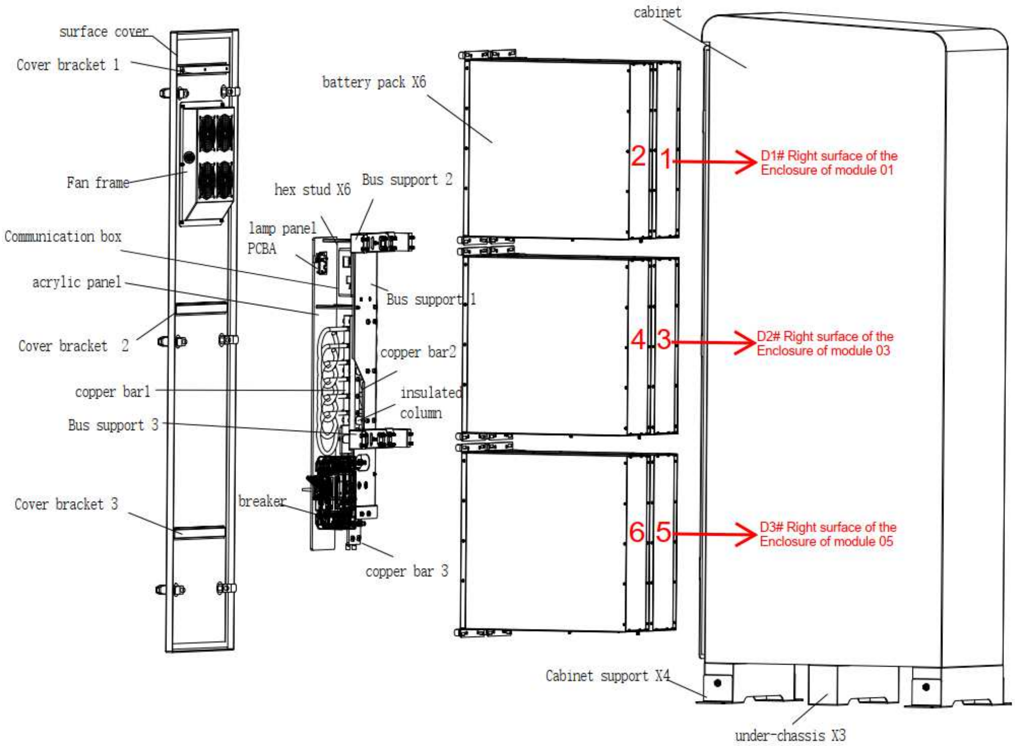


Figure 4. Thermocouple in target unit 01

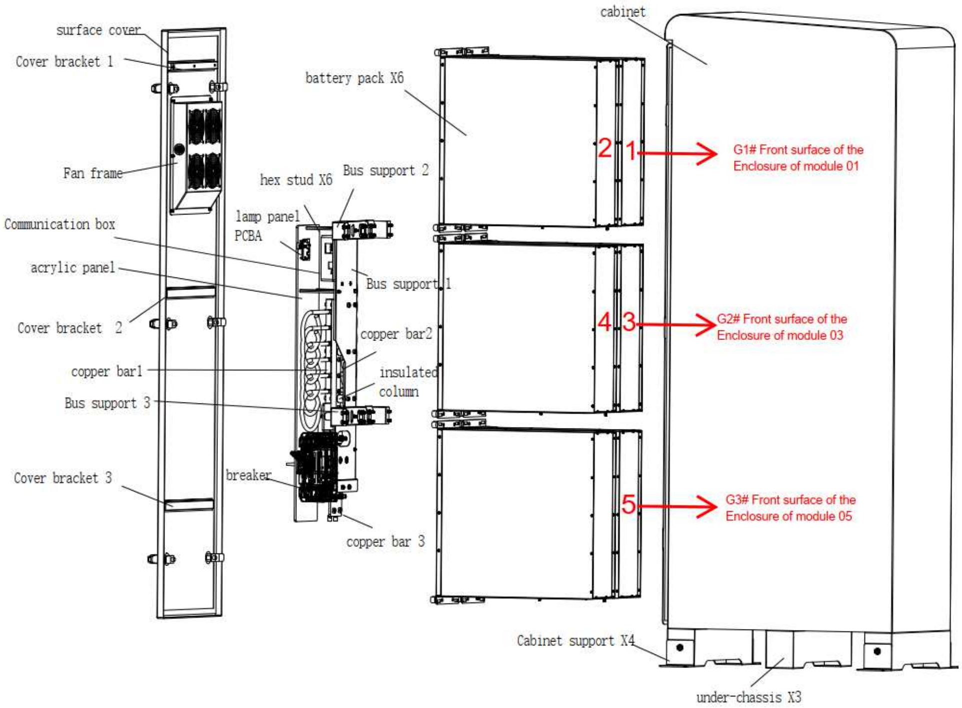


Figure 5. Thermocouple in target unit 02

One heater, controlled by a PID heating controller; The PID controller were used to control the voltage supply to the heater and maintain a 4°C/min to 7°C/min heating rate.

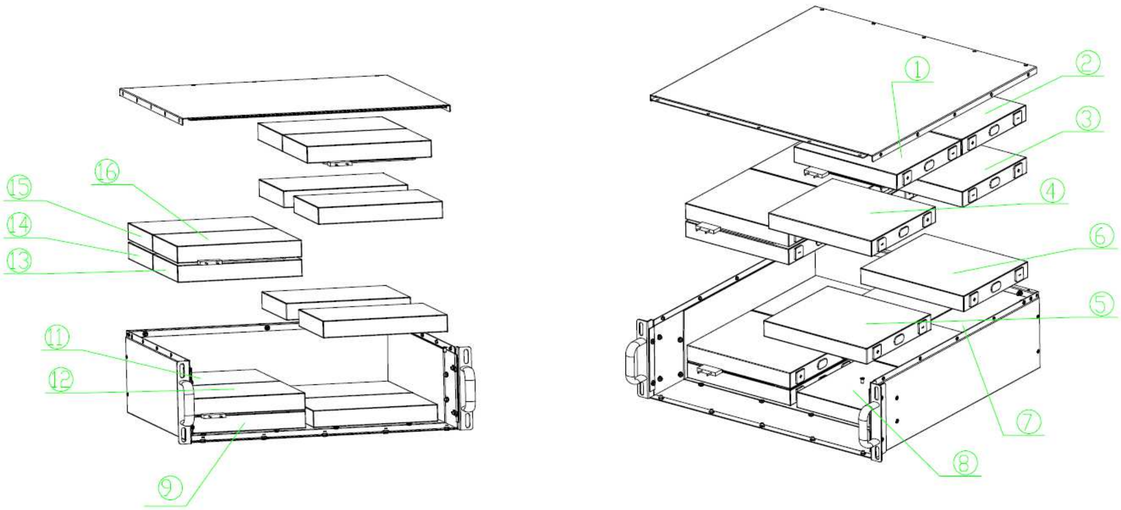
The heater was de-energized immediately and independently as the thermal runaway observed on the cell that is heat by the heater.

Setup of module:

The module was consisted of 16 cells (1P16S). All cells in the pack were numbered as below picture.

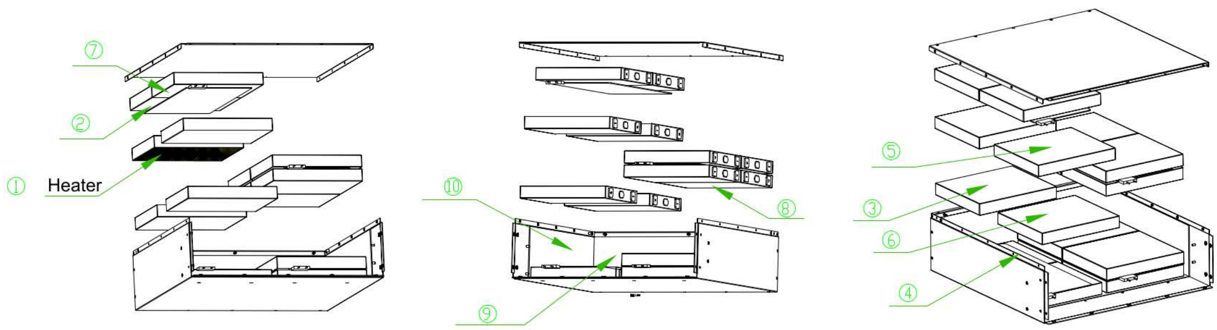
External heating method was used to initiate thermal runaway in the module. One PET heater, rated 220V ac/429 W, size 165 x 200 x 0.33 mm, was fitted on cell.

1 thermocouple, Type K, 24AWG, were attached between the cells and under the heating surface. Temperature of both sides were monitored during test. See Figure 6 to 7 for the detail locations.



Remark: The number 1~16 means Cell #1~#16 distributed in modules.

Figure 6. Internal view of module



Remark: The number 1~10 means Thermocouple no. T1~T10 distributed in modules.

Figure 7. Location of heater and thermocouple

3.4 Observations and records

Before test:

The initiating module was charged to 100% SOC and allowed to stabilize for a minimum of 1 h and a maximum of 8 h before the start of the test.

Ambient condition at the initiation of the test was 26.8°C, 60.5% R.H.

Test was performed on 2023.10.19, started at 19:58 PM.

Before the test, Module 16 in Initiating unit	
OCV (V)	52.54
Weight (kg)	44.45

Observations during test:

Time	1	2
Vent time	20:59:15 PM	21:01:32 PM
Thermal runaway	21:00:40 PM	21:02:58 PM

No flying debris or explosive discharge of gases during test.

No sparks, electrical arcs, or other electrical events during test.

No external flaming was observed.

Observations after test:

No damage on target walls.

No damage on target units.

The initiating cell (cell 14) of Module 04 were damaged (thermal runway) after the test. Cell 11 was damaged because of the cell to cell propagation.

After the test, Module 04 in Initiating unit	
OCV (V)	45.66
Weight (kg)	44.05
Weight loss (kg)	0.4

3.5 Temperature measurement

3.5.1 Temperature measurement of initiating module

Multiple thermocouples, Type K, 24AWG, were attached on all module and unit. See Figure 3 to Figure 6 for the detailed locations.

The thermocouple temperature of the module 04 in initiating unit was shown in the figure 7 as below.

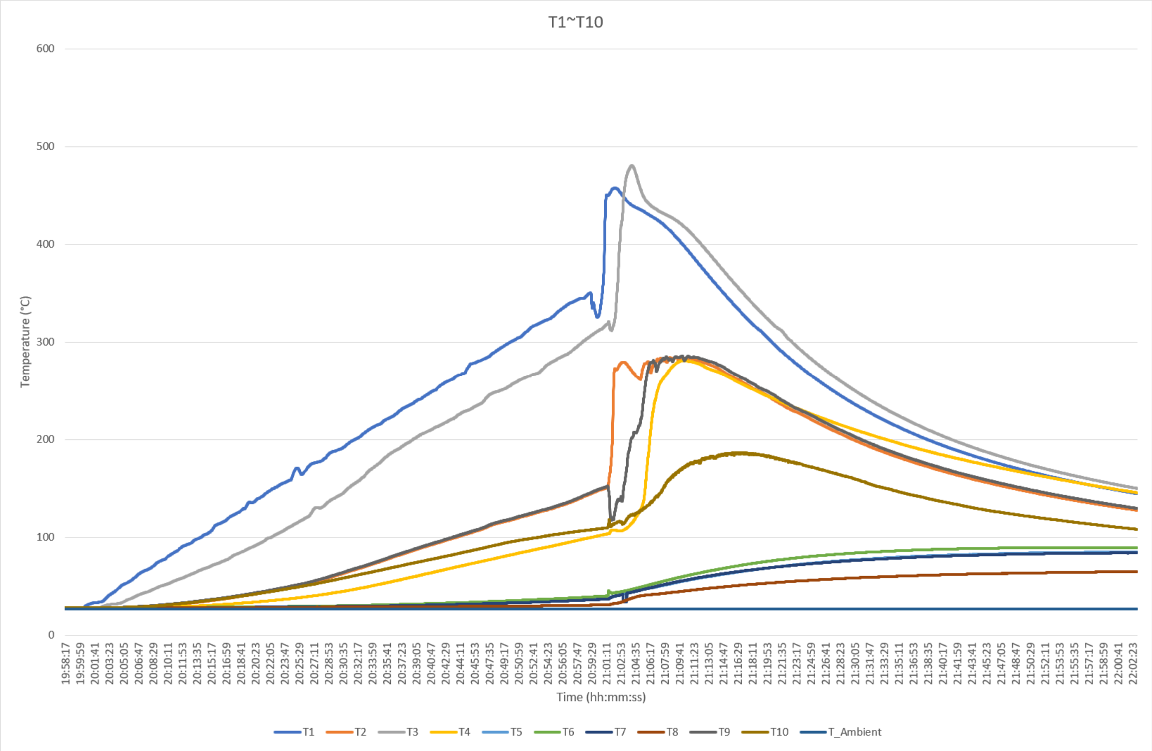


Figure 8. Temperature vs time curve of module 04 in initiating unit.

Thermocouple no.	Location	Maximum temp. °C
T1	Between cell_14 and Heater	457.6
T2	Bottom surface of cell_15	284.8
T3	Top surface of cell_11	480.5
T4	Top surface of cell_10	281.1
T5	Top surface of cell_13	84.8
T6	Top surface of cell_12	89.6
T7	Bottom surface of cell_16	84
T8	Bottom surface of cell_03	64.9
T9	Back surface of the internal Enclosure	285.9
T10	Right surface of the internal Enclosure	186.4
T_Ambient	Ambient temperature	26.8

3.5.2 Temperature measurement of modules surface in unit

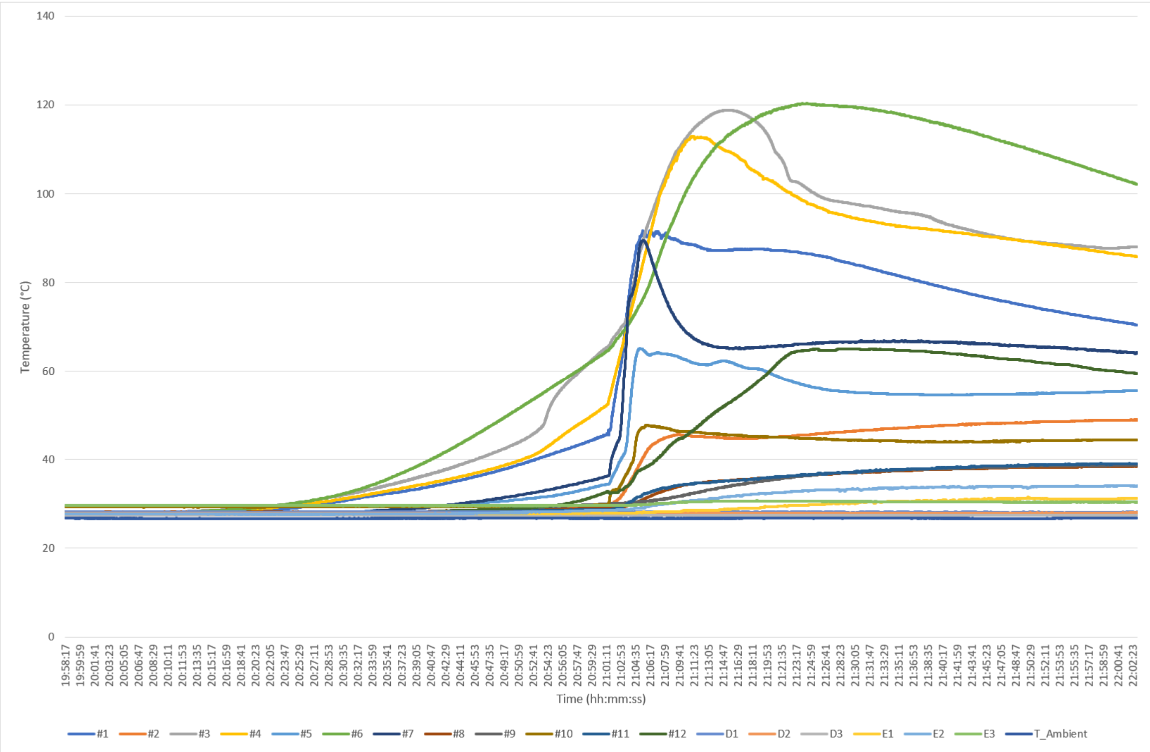


Figure 9. Surface temperatures of module in unit

Unit	Channel Number	Location	Max Temp. (°C)
Initiating Unit	#1	Top surface of the Enclosure of module 04	91.7
	#2	Front surface of the Enclosure of module 04	49.0
	#3	Back surface of the Enclosure of module 04	118.9
	#4	Right surface of the Enclosure of module 04	113.0
	#5	Left surface of the Enclosure of module 04	65.2
	#6	Top surface of the internal Enclosure of module 04	120.4
	#7	Bottom surface of the Enclosure of module 04	89.5
	#8	Bottom surface of the Enclosure of module 01	38.5
	#9	Bottom surface of the Enclosure of module 02	38.8
	#10	Right surface of the Enclosure of module 03	47.8
	#11	Top surface of the Enclosure of module 05	39.2
	#12	Top surface of the Enclosure of module 06	65.1
Target unit 01	D1	Right surface of the Enclosure of module 01	28.3
	D2	Right surface of the Enclosure of module 03	28.1
	D3	Right surface of the Enclosure of module 05	27.6
Target unit 02	G1	Front surface of the Enclosure of module 01	31.5
	G2	Front surface of the Enclosure of module 03	34.1
	G3	Front surface of the Enclosure of module 05	30.8

3.5.3 Temperature measurement of instrumented wall

Wall surface temperatures were measured in vertical array at 152 mm intervals for the full height of the instrumented wall sections using Type K, 24 AWG thermocouple. The thermocouple array were collinear with the center line of initiating unit and target unit.

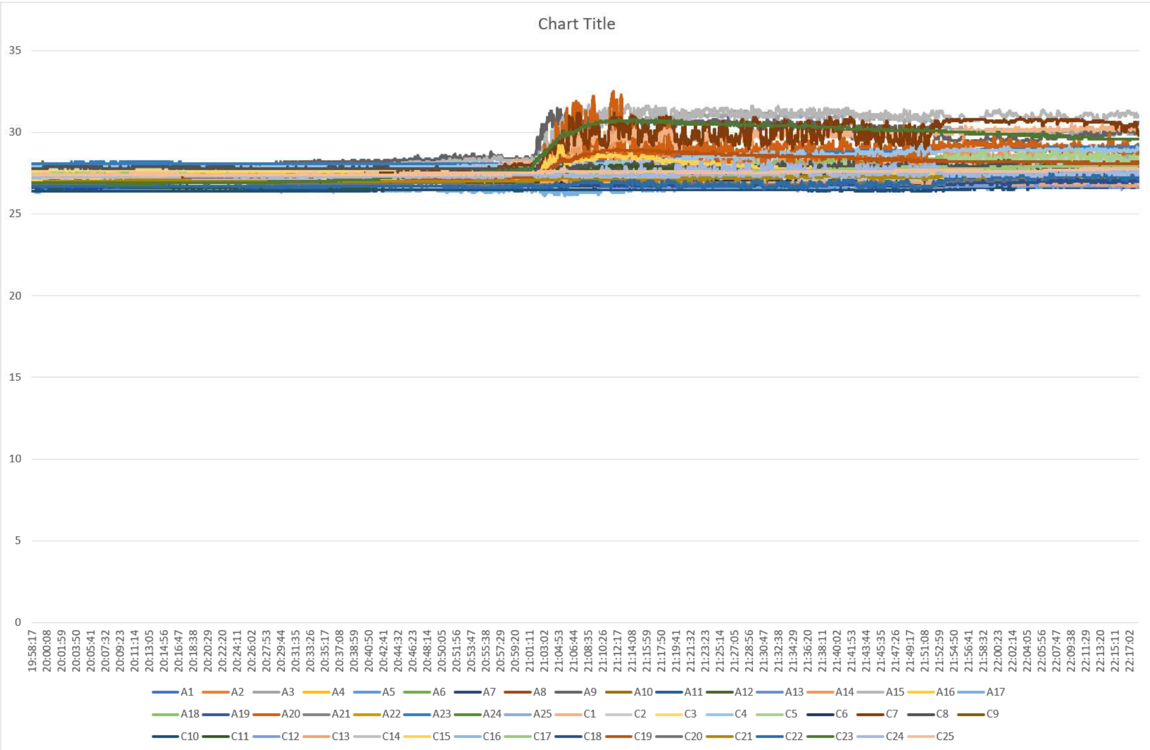


Figure 10. Temperature of instrumented wall A and C

Number	Location	Channel	Max Temp. (℃)
1	Wall A. Vertical array at 152 mm intervals. Left side of Unit1_sub-unitA in the horizontal direction.	A1~A25	32.5
2	Wall C. Vertical array at 152 mm intervals. In front of Unit1_sub-unitA in the horizontal direction.	C1~C25	

3.6 Heat flux measurement

Five sensors were placed on the instrument wall A, wall C and target units to measure the heat flux, see below table and figure 10 for details.

Channel Number	Location
HF1, HF2	on the surface of instrumented wall A
HF3	on the surface of instrumented wall C
HF4	on target unit 01 surface that facing initiating unit
HF5	on target unit 02 surface that facing initiating unit

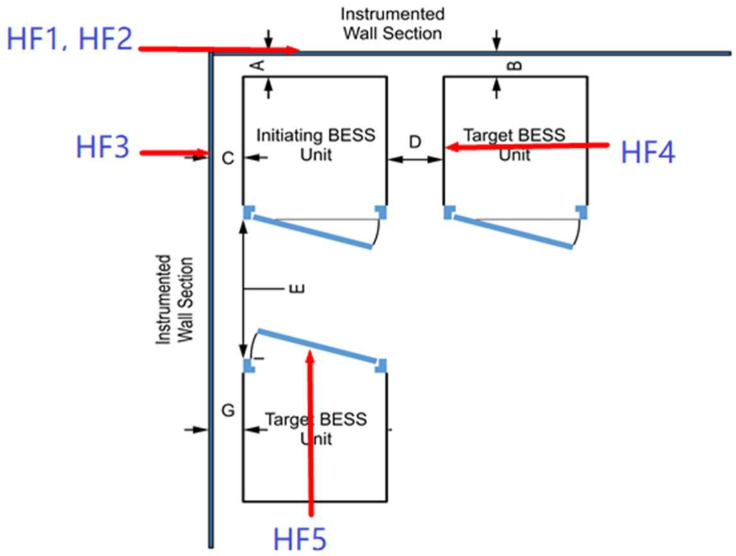


Figure 11. Heat flux sensor layout

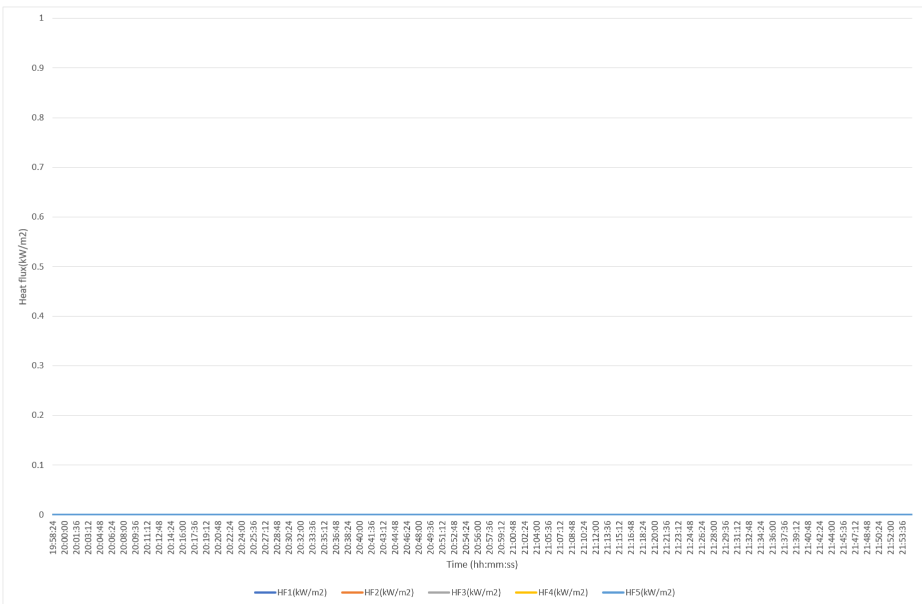


Figure 12. The measured heat flux of target walls and target unit

3.7 Chemical heat release rate measurement

The chemical heat release rates were measured by an oxygen consumption calorimeter measurement system consisting of a paramagnetic oxygen analyzer, non-dispersive infrared carbon dioxide and carbon monoxide analyzer, velocity probe, and a Type K thermocouple.

The instrumentations are located in the exhaust duct of the heat release rate calorimeter.

The chemical heat release rate was calculated at each of the flows as follows:

$$HRR_1 = \left[E \times \varphi - (E_{co} - E) \times \frac{1-\varphi}{2} \times \frac{X_{co}}{X_{O_2}} \right] \times \frac{\dot{m}_e}{1 + \varphi \times (\alpha - 1)} \times \frac{M_{O_2}}{M_a} \times (1 - X^o_{H_2O}) \times X^o_{O_2}$$

In which:

HRR_t = total heat release rate, as a function of time (kW)

E = Net heat released for complete combustion per unit of oxygen consumed (adjusted for oxygen contained within cell chemistry, 13,100 kJ/kg)

E_{CO} = Net heat released for complete combustion per unit of oxygen consumed, for CO (adjusted for oxygen contained within cell chemistry, 17,600 kJ/kg)

φ = Oxygen depletion factor (non-dimensional), where:

$$\varphi = \frac{X^o_{O_2} \times [1 - X_{CO_2} - X_{CO}] - X_{O_2} \times [1 - X^o_{CO_2}]}{X^o_{O_2} \times [1 - X_{O_2} - X_{CO_2} - X_{CO}]}$$

X_{CO} = Measured mole fraction of CO in exhaust flow (non-dimensional)

X_{CO_2} Measured mole fraction of CO_2 in exhaust flow (non-dimensional)

$X°_{CO_2}$ = Measured mole fraction of CO_2 in incoming air (non-dimensional)

$X°_{H_2O}$ = Measured mole fraction of H_2O in incoming air (non-dimensional)

X_{O_2} = Measured mole fraction of O_2 in exhaust flow (non-dimensional)

$X°_{O_2}$ = Measured mole fraction of O_2 in incoming air (non-dimensional)

α = Combustion expansion factor (non-dimensional; normally a value of 1.105)

M_a = Molecular weight of incoming and exhaust air (29 kg/kmol)

M_{O_2} = Molecular weight of oxygen (32 kg/kmol)

$\dot{m}_e$ = Mass flow rate in exhaust duct (kg/s), in which:

$$\dot{m}_e = C \times \sqrt{\frac{\Delta p}{T_e}}$$

or

$$\dot{m}_e = 26.54 \times \frac{A \times k_c}{f(\text{Re})} \times \sqrt{\frac{\Delta p}{T_e}}$$

C = Orifice plate coefficient (in $kg^{1/2}m^{1/2}K^{1/2}$)

Δp = Pressure drop across orifice plate or bidirectional probe (Pa)

T_e = Combustion gas temperature at orifice plate or bidirectional probe (K)

A = Cross sectional area of the duct (m^2)

k_c = Velocity profile shape factor (non-dimensional)

$f(Re)$ = Reynolds number correction (non-dimensional)

Measured peak chemical heat release rate HRR was 2.547 kW

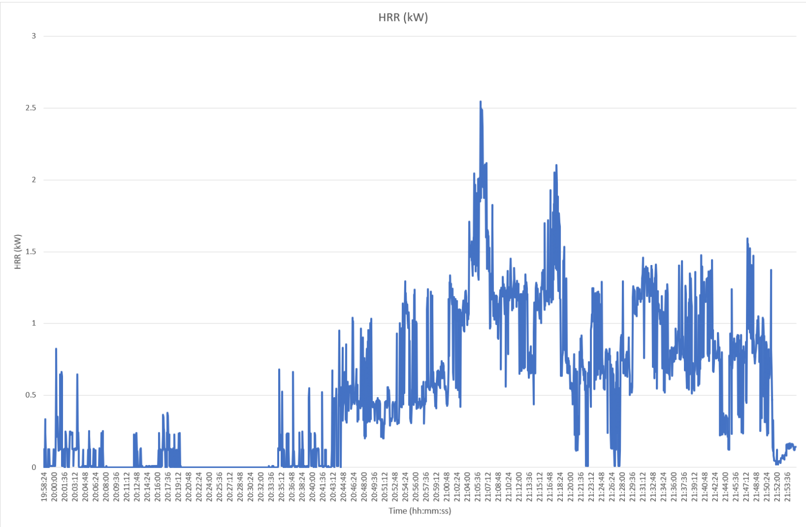


Figure 13. HRR curve

Measured total heat release THR through the test was 2.738 MJ

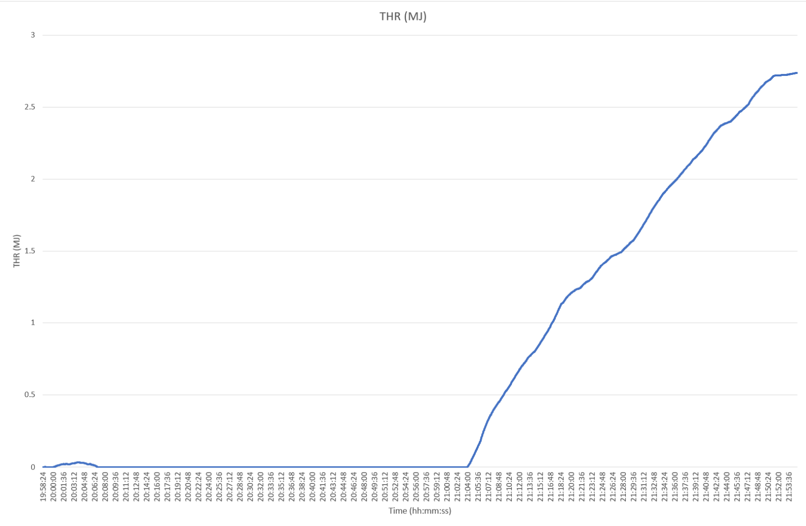


Figure 14. THR curve

3.8 Convective heat release rate measurement

The convective heat release rate were measured using thermopile, a velocity probe, and a Type K thermocouple, located in the exhaust system of the exhaust duct.

The convective heat release rate was calculated at each of the flows as follows:

$$HRR_c = V_e A \frac{353.22}{T_e} \int_{T_o}^{T} C_p dT$$

Where:

HRR_c = *The convective heat release rate (kW)*

V_e = *The exhaust velocity (m/s)*

A = The exhaust duct cross sectional area (m^2)

T_e = *The temperature at the location where exhaust velocity is measured (K)*

$353.22/T_e$ = *The density of air at the velocity measurement location* (kg/m^3)

T_o = *The ambient temperature (K) in the test room*

T = The thermopile temperature (K)

$$\int_{T_o}^{T} C_p dT = A_0(T - T_o) + A_1/2(T^2 - T_o^2) + A_2/3(T^3 - T_o^3) + A_3/4(T^4 - T_o^4)$$

Cp = Specific heat of air (kJ/kg-K), given as $C_p = A_0 + A_1 T + A_2 T^2 + A_3 T^3$, where:

$A_0 = 0.9950$

$A_1 = -5.29933E-05$

$A_2 = 3.21022E-07$

$A_3 = -1.22004E-10$

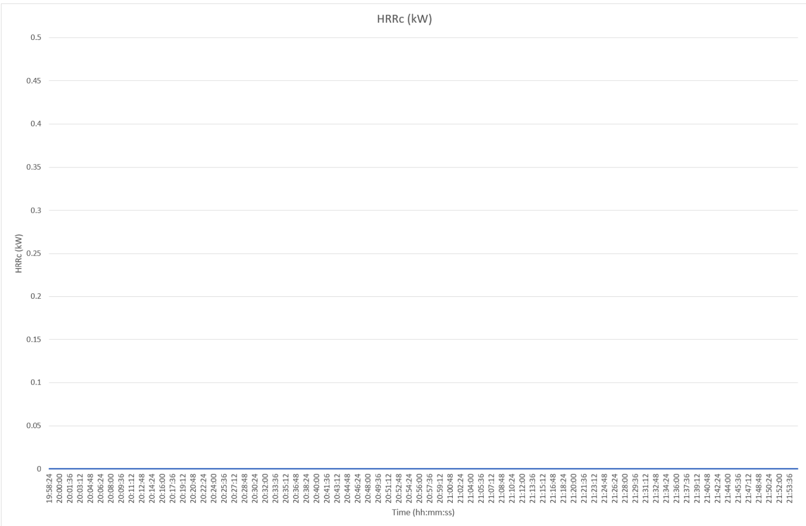


Figure 15. HRRc curve

3.9 Smoke release rate measurement

3.9.1 Test method

The light transmission in the calorimeter's exhaust duct was measured using a white light source and photo detector for the duration of the test.
The smoke release rate was calculated as follows:

The whole smoke release rate measurement system were self-checked using calibrated light filter before test. The self-check were performed at 100%, 79%, 50%, 32%, 13%, and 0% light transmittance.

3.9.2 Test result

Peak smoke release rate SRR: 0.7136 m^2/s

Total smoke release TSR: 135.4 m^2

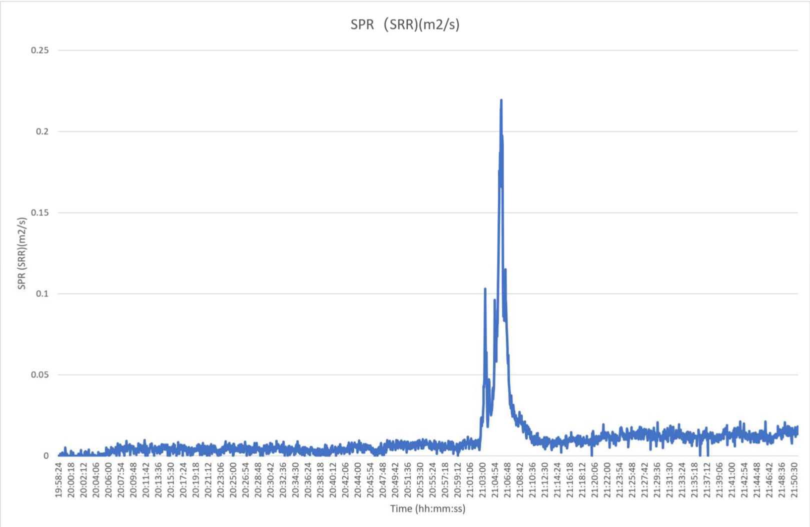


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Figure 16. SRR curve

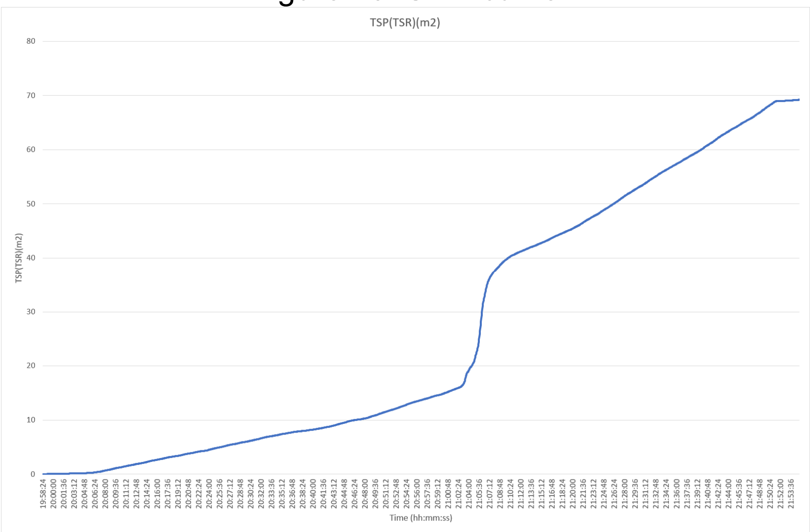


Figure 17. TSR curve

3.10 Gas generation measurement

3.10.1 Test method

The composition, velocity and temperature of the vent gases were measured within the calorimeter's exhaust duct.

Gas composition were measured using a Fourier-Transform Infrared Spectrometer with a resolution of 1 cm^{-1} and a path length of 4.2 m within the calorimeter's exhaust duct.

The hydrocarbon content of the vent gas was measured using flame ionization detection.

Hydrogen gas was measured with a palladium-nickel thin-film solid state sensor.

Composition, velocity and temperature instrumentation were collocated with heat release rate calorimetry instrumentation

3.10.2 Total gas release

Gas type	Gas components		Total volume of gas (L)
Hydrocarbon species	Methane	CH_4	1.7
Others	Carbon Monoxide	CO	2.0
	Carbon Dioxide	CO_2	10.0
	Hydrogen	H_2	107.1
Total Hydrocarbons (equivalent to CH_4, measured by FID)			17.3

3.10.3 Gas components

Concentration of different gas components were present according to gas species classification in Figures 17 to 22. Average flow rate was 2.55 m^3/s during test.

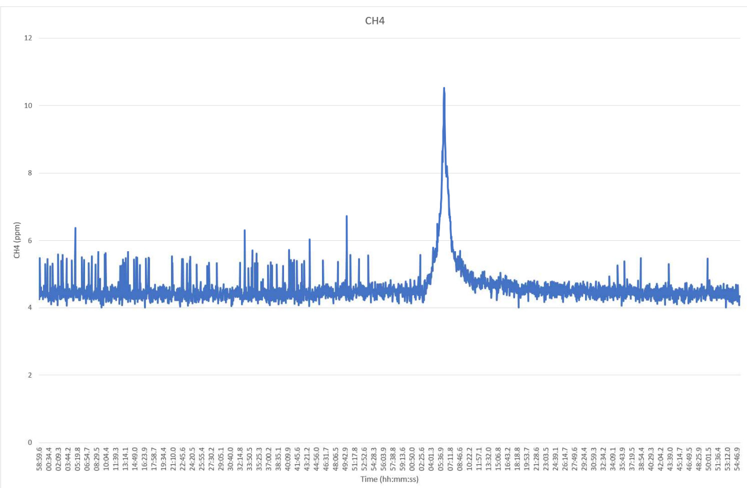


Figure 18 Hydrocarbon species

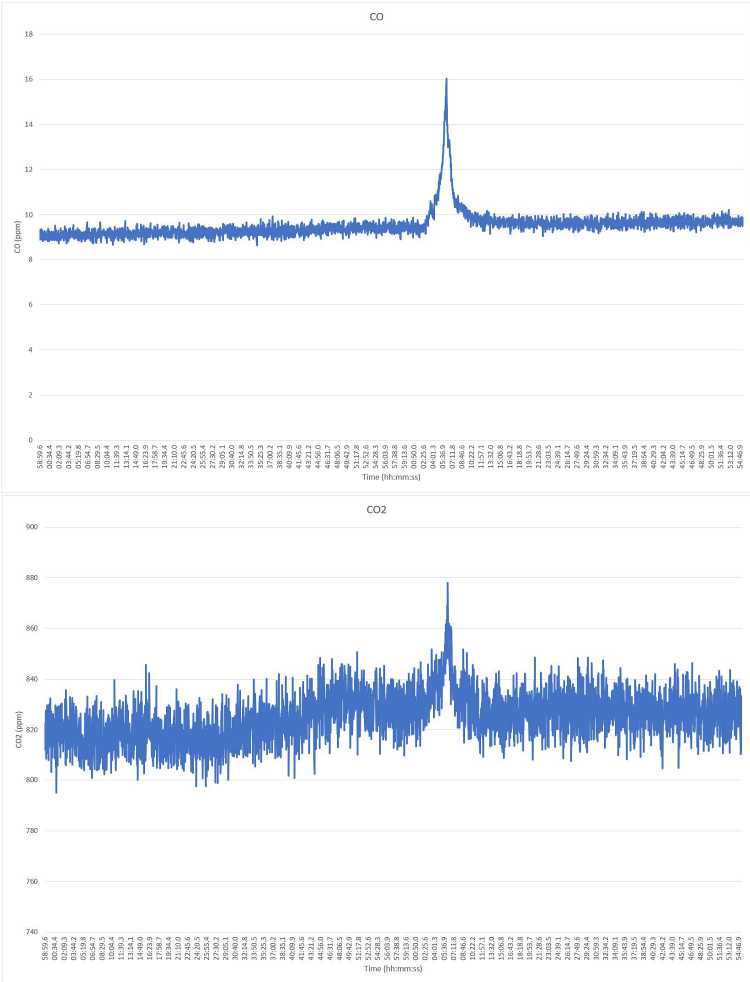


Figure 19 CO and CO2 concentration

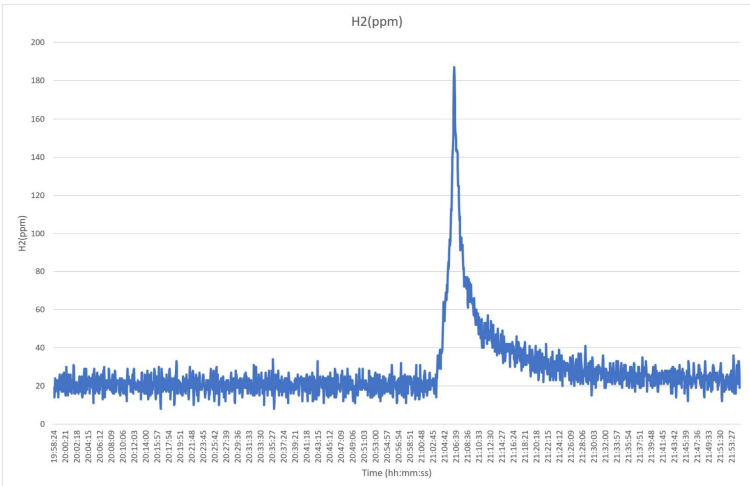


Figure 20 Hydrogen

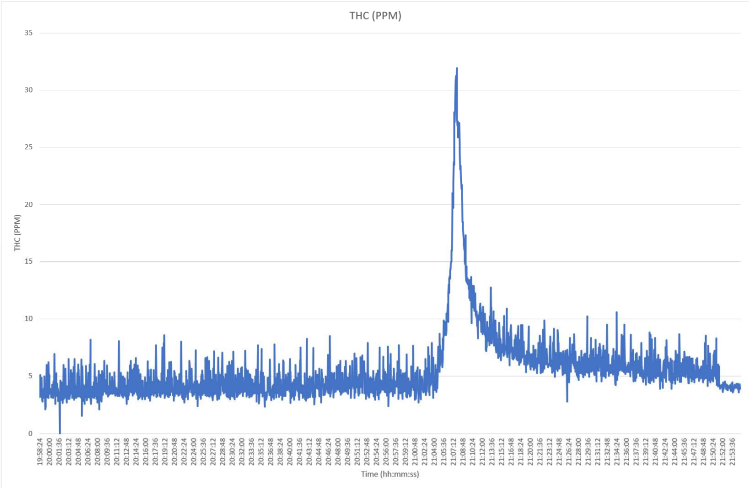


Figure 21 Total Hydrocarbons

3.11 Performance Summary Remark Against Criteria

Installation level testing was not required as the following performance conditions were met during the unit level test.

Performance conditions	Remark
a) If flaming outside of the unit observed, separation distances to exposures shall be determine by greatest flame extension observed during test. *(No flaming)*	No flaming observed in both external and internal of unit during the test. No flaming or charring of the cheesecloth indicating observed.
b) Surface temperatures of modules within the target units adjacent to the initiating unit do not exceed the temperature at which thermally initiated cell venting occurs.	Surface temperatures of modules within the target units adjacent to the initiating unit was 34.1 °C, which is far below the cell venting temperature 209.4°C (From TUV RH cell 9540A report No.: CN21GRDU 001).
c) For units intended for installation near exposures, surface temperature measurements on wall surfaces do not exceed 97°C of temperature rise above ambient. *(Temp. measured on wall 1, wall 2 and unit3 surface close to unit 1 shall not exceed 97°C+ambient temp.)*	Surface temperature rise measurements on wall surfaces and target unit surface adjacent to unit1 was 5.7°C, far below the 97°C.
d) Explosion hazards are not observed, including deflagration, detonation or accumulation of battery vent gases; *(The explosion shall not be observed)*	Explosion hazards were not observed in both external and internal of unit, during the test.

e) Heat flux in the center of the accessible means of egress shall not exceed 1.3kW/m^2	No attributable heat flux detected, see clause 3.6 of this report.
f) The concentration of flammable gas does not exceed 25% LFL in air for the smallest specified room installation size.	Based on final installation conditions

3.12 Photos

See photo documents

Before the test:

Two units

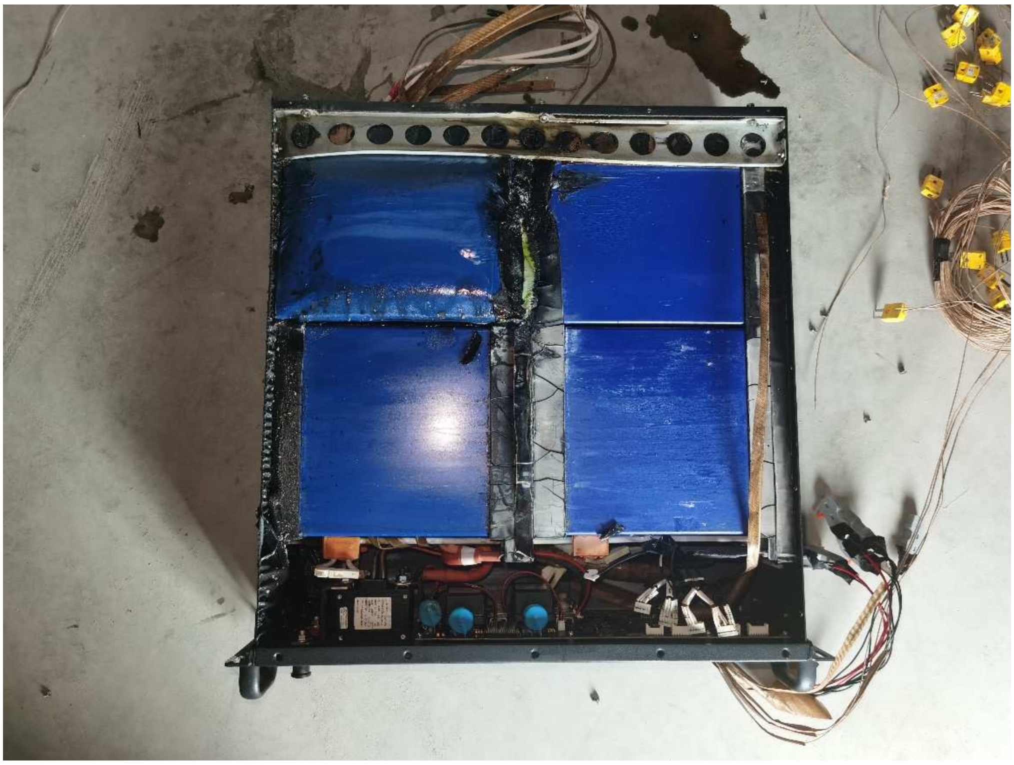
Three units

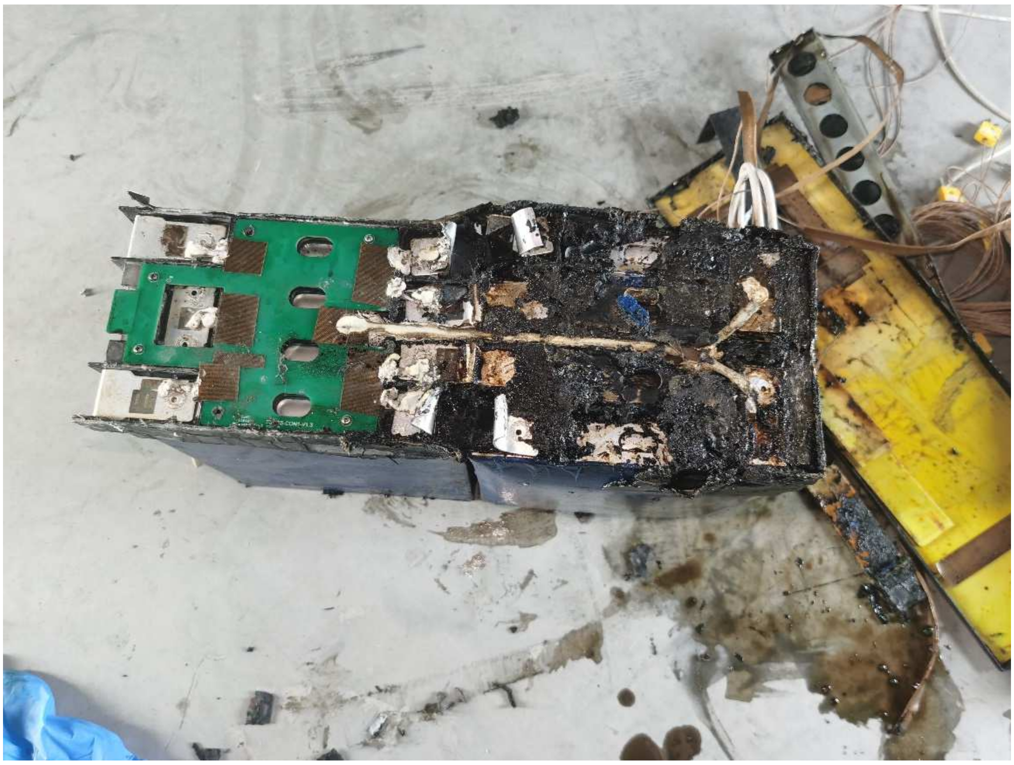
During the test:

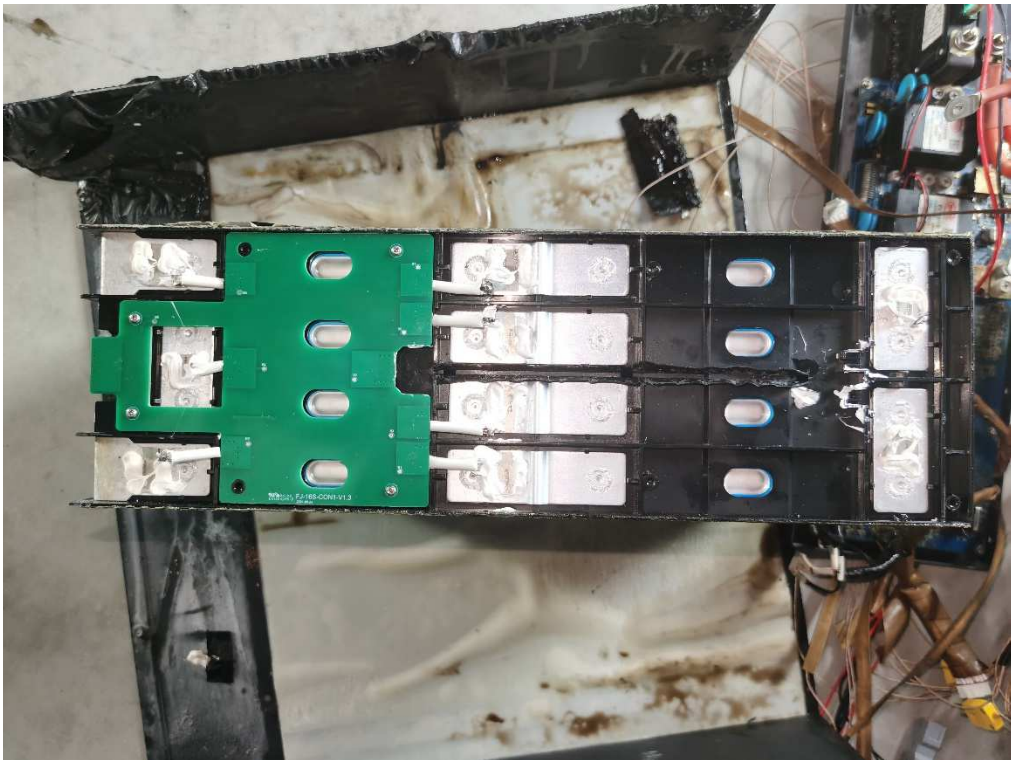
After the test:
Units

Initiating module

Damage of the internal components







3.13 List of Test and Measurement Instruments

No.	Equipment		Model	Rating	Inventory no.	Last Cal. date
1	Ambient monitor		WSB-2-H1	0-40°C, 10-90%RH	S-055	2022.07.11
2	Ambient monitor		WSB-2-H1	0-40°C, 10-90%RH	S-050	2023.01.03
3	Ambient monitor		WSB-2-H1	0-40°C, 10-90%RH	S-044	2023.01.03
4	Digital multi-meter		FLUKE101	0-600V	S-038	2023.02.08
5	Tape		1000mm 5000mm	0-1000mm 0-5000mm	S-040 S-042	2022.12.19 2022.12.19
6	Electronic scale		TCS-500	0-500kg	S-039	2023.02.09
7	Charge /ischarge equipment		RCDS-100V300A	100V/300A	S-045	2023.02.08
8	Heating control equipment		DTB4824	0-1000°C	S-060-3	2022.07.11
9	Data acquisition equipment		ADAM-4117 ADAM-4118 MT4W MT4W DTM	0-10V 0-1000°C 0-100V 0-500V 0-1000°C	S-060-1 S-060-2 S-060-4~5 S-060-6~7 S-061	2022.07.11 2022.07.11 2022.07.11 2022.07.11 2022.07.11
10	Oxygen consumption calorimeter measurement system	Paramagnetic oxygen analyzer	OXYMAT 61	O2:0-21%	S-024-09	2022.08.11
		CO and CO2 sensor	ULTRAMAT 23	CO2:0-10% CO:0-1%	S-024-08	2022.08.11
		Micro-differential pressure transmitter (20MW)	DP101MD	-100~100Pa	S-024-4	2023.02.08
		Thermopile (20MW)	TTI20-CAXL-II 6U-10-SPW-M	0~200°C	S-024-1~3	2023.01.03
11	Palladium-nickel thin-film solid state sensor		710B	0.05%~100%	S-023-1	2022..08.11
13	Electrochemical hydrogen sensors		H_2-2000/H_2-40000	0~0.2%/0~4%	S-023-2~3	2022.08.11
14	Fourier-Transform Infrared Spectrometer		MG6000	0.01ppm-100%	S-019	2023.01.30
15	Flame Ionization Detector		AO2040	0-30000mgC/m^3	S-025-1	2022.08.11

16	Heat flux measurement equipment	64-5-20	0-50kW	S-031-1 S-031-2 S-031-3 S-031-4 S-031-5 S-031-6 S-031-7 S-031-8	2022.06.10 2022.06.10 2022.06.10 2022.09.09 2022.06.10 2022.06.10 2021.09.09 2021.09.09

End of Test Report