

DOCKETED	
Docket Number:	25-OPT-02
Project Title:	Prairie Song Reliability Project
TN #:	266065
Document Title:	UL9540A Test Reports
Description:	N/A
Filer:	Erin Phillips
Organization:	Dudek
Submitter Role:	Applicant Consultant
Submission Date:	9/18/2025 12:53:37 PM
Docketed Date:	9/18/2025

MEMORANDUM

To: California Energy Commission Staff
From: Prairie Song Reliability Project LLC
Subject: Prairie Song Reliability Project (25-OPT-02) Non-Confidential UL9540A Test Reports
Date: September 18, 2025
Attachment(s): Non-Confidential UL9540A Test Reports

On September 4, 2025, Prairie Song Reliability Project LLC (the “Applicant”) filed an Application for Confidential Designation for Opt-In Application for Certification for Confidential UL9540A Test Reports (TN: 265875). Since filing TN: 265875, the Applicant has sought and received permission from the manufacturer to publicly disclose the UL9540A test reports. The Applicant retracts its prior Application for Confidential Designation for Opt-In Application for Certification for Confidential UL9540A Test Reports (TN: 265875) and provides the non-confidential UL9540A test reports herein.

Master Contract: N/A
Report: 80184345
Project: 80184345

Nov. 17, 2023

Mr. Pengcheng Cui
Certification Engineer
CALB Group Co., Ltd.
No.1 Jiangdong Avenue,
Jintan District,
Changzhou, Jiangsu 213251
China

Subject: Rechargeable Lithium-ion cell, model L173F314 (UL 9540A Test Report)

Dear Mr. Pengcheng Cui

We are pleased to inform you that testing of your product per UL 9540A has been completed. Applicable test(s) was witnessed at ChuWeiNeng Testing Co.,Ltd , and witnessed by CSA Group – Kunshan. Cell level of test was conducted on the sample provided and the results are enclosed in the test report.

Note: This Test Report is not an Authorization to apply the CSA Mark to the product. The results contained in the report(s) provided are contingent upon the characteristics of the actual sample(s) used in the investigation. In the absence of a continuing inspection service, CSA provides no assurance, expressed or implied, that the contents of the report are applicable to reproductions of the sample(s). Use or reproduction of the CSA name, logo, or trademark is not permitted without the prior written consent of CSA. No references can be made to this report when using the results of this investigation for the purposes of advertising, promotion or litigation, without the prior written consent of CSA.

Please examine the enclosed documents and contact me if you have any questions or would like us to make any changes.

On behalf of CSA, I would like to thank you for your business and offer our services for your future needs.

Yours truly,

Evan Zhang
CSA –CCIC-CSA International Certification Co., Ltd. Kunshan Branch
Building 8, Tsinghua Science Park, No. 1666 Zu chongzhi Rd (S) , Kunshan, Jiangsu (215347)

Encl. [UL 9540A Test Report]
Att.1 – Cell UL 1973 certification
Att.2 – Cell charge/discharge conditioning graphs
Att.3 – Photos
Att.4 – Cell temperature/voltage graph during testing
Att.5 – Cell gas analysis report

Standard(s): ANSI/CAN/UL 9540A:2019 Fourth Edition, Dated November 12, 2019 - Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems

Testing Laboratory Name: CCIC-CSA International Certification Co.,Ltd. Kunshan Branch
Address: Building 8, Tsinghua Science Park, No. 1666 Zu chongzhi Rd(S), Kunshan, Jiangsu(215347)
Testing Program: Custom Test : Cover Latter ☒, Testing Only ☐

If tests were performed at another facility, then described below:

Testing Laboratory Name: ChuWeiNeng Testing Technology (Shanghai) Co.Ltd
Address: Building 3, No.1065 Beihe Gonglu, Jiading District, Shanghai
Facility Qualification Number: N/A

Customer: As above / or describe otherwise
CALB Group Co., Ltd.
Address: No.1 Jiangdong Avenue, Jintan District, Changzhou, Jiangsu 213251, China

Tested By: Jiaming Huang, Technician
Name, Title
Jiaming Huang 2023-09-28
Signature Date (YYYY-MM-DD)

☒ **Reviewed by:** Austin Chen, Certifier
☒ **Witnessed by:** Name, Title
Evan Zhang/Javis Shen 2023-11-17
Signature Date (YYYY-MM-DD)

Version 6.1 : 2022-08-02

Cell Level Test Summary		
Manufacturer:		CALB Group Co., Ltd.
Brand name / Trademark:		N/A
Model number:		L173F314
Nominal cell voltage, (V)		3.2
Cell capacity, (Ah)		314
Cell chemistry:		LFP
Physical format of cell:		Prismatic
Approximate dimension, (mm)		Thickness:71.4±1.5;Width:174.4±1.5;Height:207.0±1.0
Mass, (g)		5560±150
Cell certification available?, (Yes/No)		Yes
Standard(s) used to certify product:		UL 1973,3 rd Edition
Certification organization name and its certificate number:		UL, File MH65785
Method used to initiate thermal runaway:		External Heating
Average temperature at which cell first vented excluding gas collection sample, (°C)		140.5
Average temperature prior to thermal runaway excluding gas collection sample, (°C)		210.6
Location of maximum temperature:		Cell wide surface not covered by heater film
Flammable gas generation, (Liter)		140
Total gas generation, (Liter)		192
Lower flammability limit (LFL) at ambient temperature (25 ± 5°C), (%)		6.2
Lower flammability limit (LFL) at average gas vent temperature, (%)		5.6
Burning velocity, (Cm/Sec)		63.8
Maximum pressure P _{max} , (MPa)		0.68
Gas composition:		
Gas Component	Gas Type	Gas Volume in percentage (%)
Carbon monoxide	CO	13.924
Carbon dioxide	CO ₂	27.237
Hydrogen	H ₂	44.925

"Highly Confidential, Limited Use for Entity: [REDACTED],

Customer Contact: [REDACTED] Date: 12 Jan 2024"

Cell Level Test Summary		
Methane	CH ₄	6.421
Ethane	C ₂ H ₆	0.996
Ethylene	C ₂ H ₄	3.827
Propane	C ₃ H ₈	0.322
Propylene	C ₃ H ₆	1.227
Isobutane	C ₄ H ₁₀	0.013
Acetylene	C ₂ H ₂	0.339
Butane	C ₄ H ₁₀	0.091
Isobutene	C ₄ H ₈	0.085
Trans butene	C ₄ H ₈	0.322
n-Butene	C ₄ H ₈	0.140
Isopentane	C ₅ H ₁₂	0.007
Pentane	C ₅ H ₁₂	0.110
2-methyl-1,3-butadiene	C ₅ H ₈	0.014
Total	---	100
Additional Information:		N/A

Performance - Cell Level Test		
Requirement	Comments	Verdict
Thermal runaway cannot be induced in the cell.	The thermal runaway was initiated with external heater on the cells during the test	F
Cell does not present a flammability hazard when mixed with any volume of air, as determined in accordance with ASTM E918 at both ambient and vent temperature.	As a result of gas analysis, the gas generated from the cell were identified flammable	F
Summary of Result: Module level testing is required based on above performance condition indicated in Section 7.7 of UL 9540A 4 th Edition.		

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)

Clause	Requirement + Test	Result - Remark	Verdict
Construction			
5	General	---	---
5.1	Cell	---	---
5.1.1	Cell chemistry:	LFP	---
	Physical format of cell:	Prismatic	---
	Nominal voltage rating, (V)	3.2	---
	Nominal capacity rating, (Ah)	314	---
	Approximate dimension, (mm)	Thickness:71.4±1.5;Width:174.4±1.5;Height:207.0±1.0	---
	Mass, (g)	5560±150	---
5.1.2	Cell certification available?, (Yes/No)	Yes	---
	Standard(s) used to certify product:	UL 1973,3 rd Edition	---
5.1.3	Cell Level Test Report	See below	---
Performance			
7	Cell Level	---	---
7.1	General	---	---
7.1.1	Establish effective method by forcing a cell into a thermal runaway in a repeatable manner.	Test Method: External Heating	P
	Vent gas composition was gathered and analyzed.	See below	P
	Cell temperature was monitored to determine the temperature when cell vents.	See below	P
	Cell temperature was monitored to determine thermal runaway as defined in UL 9540A 4 th Edition.	See below	P
7.2	Sample	---	---
7.2.1	Prior to testing, cell samples were conditioned for minimum 2 charge (100% SOC) - discharge (Specified end of discharge voltage) cycle as per manufacturer specified method.	See attachment 2 for details	P
	Cells were functional after minimum 2 charge discharge cycle.	See attachment 2 for details	P
	During conditioning a relationship between open circuit voltage and SOC was determined through measurement of voltage and SOC.	Confirmed	P
	Ambient temperature during cell conditioning.	See table 2 for details	P
7.2.2	The tested cells had 100% SOC at the start of the test. The samples were allowed to stabilize for a minimum of one	See table 2 for details	P

Clause	Requirement + Test	Result - Remark	Verdict
	hour and a maximum of 8 h before the start of the test.		
7.2.3	Cells with flexible laminate casings were constrained during test in manner that simulate constraint in the BESS module to prevent excessive swelling during test.	See attachment 3 for details and the manufacturer claims that the fixing torque of pressure plate is 1.5 N·m	P
7.3	Determination of thermal runaway methodology	---	---
7.3.1	General	See below	P
7.3.1.1	Ambient temperature during cell testing.	See table 3 for details	P
7.3.1.2	Propensity of cell to exhibit thermal runaway demonstrated by externally applied film heater.	Heater type: Polyimide thin film heater Heater dimension (mm): 185×160 Number of heaters used: 2	P
	A surface heating rate of 4° C (7.2° F) to 7° C (12.6° F) per minute shall be applied to the cell.	☒ 5° C/min	P
	Maximum surface temperature endpoint criteria was determined based on cell design and cell chemistry.	Considered	N/A
	Thermal runaway method used, when external heating with flexible heater was not able to cause the cell to exhibit thermal runaway.	☐ Mechanical: ☐ Electrical Stress: ☐ Alternate heating sources: ☐ Other(explain):	N/A
7.3.1.3	Detail of thermal runaway test method when another method used as reference in 7.3.1.2.	External heating was used for testing	N/A
7.3.1.4	Monobloc battery such as lead acid or nickel cadmium, was treated as individual cell for this testing.	---	N/A
7.3.1.5	Surface temperature at which internal short circuiting within the cell will occur that could lead to thermal runaway.	See below	N/A
	Surface temperature hold point. For lithium ion cell, hold point was between 5°C (9°F) and 15°C (27°F) greater than the melting temperature of the cell separator material as determined from differential scanning calorimetry (DSC) data of the separator in accordance with UL 2591 (UL 746A).	Not used, the cells are heated until the thermal runaway achieved. According to the Certification Requirement Decision: Test Method for Evaluating Thermal Runaway Fire Propagation in Battery. Holding temperature was not utilized during the test and the cell was continuously heated until thermal runaway occurred.	N/A

Clause	Requirement + Test	Result - Remark	Verdict
	If thermal runaway is not achieved at holding temperature after period of 4h, heating rate according to 7.3.1.3 was reestablished.	See above	N/A
7.3.1.6	If cell is susceptible to thermal runaway by external heating, cell was heated until thermal runaway has occurred.	Confirmed, External heating was used for testing	P
	If cell is not susceptible to thermal runaway by external heating, another method included in 7.3.1.2 was used.	---	N/A
	If using another external heating method, temperature ramp and maximum surface temperature as outlined in 7.3.1.2 and 7.3.1.5 was used.	---	N/A
7.3.1.7	Cell's exterior surface temperature was measured continuously, averaging over every 60 seconds	Confirmed	P
	The maximum of these averages was documented for each thermocouple location.	Confirmed	P
	Location of thermocouple during test.	☒ Below the heater film at center of cell surface ☒ Near positive cell terminal ☒ Other(explain): wide surface not covered by heater film, narrow side surface	P
7.3.1.8	The temperature at which the cell case vents due to internal pressure rise.	Confirmed	P
	The thermocouple located below the heater film at the center of the cell surface is used for this measurement.	Confirmed	P
	If using the other cell abuse methods, the thermocouples would be located at the same locations on the cells as noted in 7.3.1.7.	---	N/A
7.3.1.9	The temperature at the onset of thermal runaway was documented.	Confirmed	P
	Onset of thermal runaway was determined by the point at which the rate of change of the surface temperature of the cell exceeds that of the externally applied heat input if utilizing the external heater method.	Confirmed	P

Clause	Requirement + Test	Result - Remark	Verdict
	In cases where cell venting may occur first, cell was heated continuously until thermal runaway occurs.	Confirmed	P
	With other stress methods, it was necessary to continue applying the stress such as mechanical or electrical stress until onset of thermal runaway occurs.	---	N/A
	Separator information was available or at the manufacturer's discretion, the thermal ramp was conducted continuously without a hold point until thermal runaway.	Thermal ramp was conducted continuously without holding point considered	P
7.3.1.10	When using methods other than the heater method, the stresses (i.e. electrical or mechanical) were applied to the cell until thermal runaway occurs.	---	N/A
7.3.1.11	If the cell exhibits thermal runaway behavior (using any method), 3 additional samples were tested using the same method and exhibit thermal runaway to demonstrate repeatability.	See table 3 for details	P
	The vent temperature and thermal runaway onset temperatures were averaged over the tested samples (Excluding the gas vent capture sample).	See table 3 for details	P
7.3.2	Flow battery thermal runaway determination tests	---	N/A
7.4	Cell vent gas composition test	---	---
7.4.1	Cell vent gas was generated and captured by forcing a cell into thermal runaway with the methodology developed in 7.3, inside a pressure vessel, which is large enough to accommodate cells, but not so large as to influence measurement of the gas composition.	Confirmed, the test container volume is 92 L	P
	The test was initiated with an initial condition of atmospheric pressure and less than 1% oxygen by volume.	See table 4 for details	P
	The initial atmospheric conditions prior to testing was noted.	See table 4 for details	P
7.4.2	Cell vent gas composition was determined using Gas Chromatography (GC)	Confirmed	P
	Hydrogen gas was measured with a sensor capable of measuring in excess of 30% by volume.	Use TCD detector to measurement hydrogen concentration	P

Clause	Requirement + Test	Result - Remark	Verdict
	The initial atmospheric conditions prior to testing was noted.	See table 4 for details	P
7.4.3	The lower flammability limit of the cell vent gas was determined in accordance with ASTM E918, testing at both ambient and cell vent temperatures.	See table 4 for details	P
7.4.4	The burning velocity of the cell vent gas was determined in accordance with Annex in ISO 817.	Confirmed, See table 4 for details	P
7.4.5	The P_{max} of the cell vent gas was determined in accordance with EN 15967.	Confirmed, See table 4 for details	P
7.5	Off gas composition for flow battery systems.	---	---
7.5.1	The off gas composition from the flow battery testing of 7.3.2 shall be determined by conducting the test method of 7.3.2.2: 1. In a closed container and capturing the off gasses generated, and 2. By collecting the off gasses generated at vent openings and vent ducts during the overcharge and short circuit testing of 7.3.2.4 and 7.3.2.6 as applicable to the flow battery technology	---	N/A
	Composition of these captured gases and their flammability limit shall be determined through the methods outlined in 7.4.2 and 7.4.3 at both ambient temperature and the maximum temperature measured.	---	N/A
7.5.2	The volume of flammable gases measured during the testing were scaled to the maximum energy reservoir for the intended flow battery system.	---	N/A
7.6	Cell level test report	---	---
7.6.1	Cell level report include information indicated in item a) through m)	Confirmed	P
7.6.2	Flow battery report include information indicated in item a) through k)	---	N/A

Table 1 – Cell charge/discharge specification			
Charging method	CP	Discharging method	CP
Charge power, (W)	502.4W	Discharge power, (W)	502.4W
Charge voltage, (Vdc)	---	---	---
Charge end voltage, (Vdc)	3.65V	Discharge end voltage, (Vdc)	2.5V
Manufacturer recommended charge temperature, (°C)	0~+55	Manufacturer recommended discharge temperature, (°C)	-30~+55

Table 2 – Cell rest duration				
Sample Number	Final charge end time		Test start time	
	Date (YYYY-MM-DD)	Time (HH:MM AM/PM)	Date (YYYY-MM-DD)	Time (HH:MM AM/PM)
202308015-3	2023-09-07	09:43 AM	2023-09-07	17:06 PM
202308015-4	2023-09-07	14:16 PM	2023-09-07	18:47 PM
202308015-8	2023-09-08	08:19 AM	2023-09-08	11:46 AM
202308015-5	2023-09-22	06:08 AM	2023-09-22	13:36 PM
202308015-6	2023-09-28	06:32 AM	2023-09-28	09:13 AM
Ambient temperature during cell conditioning				
Ambient Lab Temperature, (°C)		Relative Humidity, (%RH)		
23.9 to 25.5		45.0 to 62.0		

Table 3 – Determination of thermal runaway methodology					
Sample Number	Note 1				Note 2
	202308015-3	202308015-8	202308015-5	202308015-6	202308015-4
Open circuit voltage before test, (Vdc)	3.353	3.348	3.341	3.341	3.372
Cell charge capacity after final charge cycle, (Ahr)	325.4	327.3	323.7	326.2	328.0
External film heat ramp rate, (°C/min)	5.0	5.0	5.0	5.0	5.0
Temperature at which gases are first vented, (°C)	142.3	134.2	143.9	141.5	142.5
Temperature prior to thermal runaway, (°C)	204.5	214.4	207.3	216.2	208.5
Location of maximum temperature prior to thermal runaway	Cell wide surface not covered by heater film	Cell wide surface not covered by heater film	Cell wide surface not covered by heater film	Cell wide surface not covered by heater film	Cell wide surface not covered by heater film
Average temperature at which gases are first vented, (°C)	140.5				---
Average temperature prior to thermal runaway, (°C)	210.6				---

"Highly Confidential, Limited Use for Entity: [REDACTED],

Customer Contact: [REDACTED] Date: 12 Jan 2024"

Table 3 – Determination of thermal runaway methodologyOther method used to initiate thermal runaway: [N/A](#)**Ambient temperature during cell testing**

Ambient Lab Temperature, (°C)	Relative Humidity, (%RH)
23.6 to 27.2	52.0 to 65.0

Note 1: Sample tested outside pressure vessel

Note 2: Sample tested inside pressure vessel for cell vent gas composition test

Table 4 – Cell vent gas composition test

Sample Number:	202308015-4
Pressure vessel volume (liter):	92
An initial condition of atmospheric pressure (kPa):	101.32(absolute pressure)
An initial condition of oxygen by volume (%):	0.392
Flammable gas generation volume(Liter):	140
Total gas generation volume (Liter):	192
LFL limit at ambient temperature (%):	6.2
LFL limit at cell vent temperature (%):	5.6
Burning velocity (cm/sec):	63.8
Maximum pressure P _{max} (MPa):	0.68

Ambient temperature during cell testing

Ambient Lab Temperature, (°C)	Relative Humidity, (%RH)
26.1 to 27.3	51.0 to 55.0

Gas composition

Gas Component		Volume Released (After thermal runaway) (%)
Carbon Monoxide	CO	13.924
Carbon dioxide	CO₂	27.237
Hydrogen	H₂	44.925
Methane	CH₄	6.421
Ethane	C₂H₆	0.996
Ethylene	C₂H₄	3.827
Propane	C₃H₈	0.322
Propylene	C₃H₆	1.227

Table 4 – Cell vent gas composition test

Isobutane	C_4H_{10}	0.013
Acetylene	C_2H_2	0.339
Butane	C_4H_{10}	0.091
Isobutene	C_4H_8	0.085
Trans butene	C_4H_8	0.322
n-Butene	C_4H_8	0.140
Isopentane	C_5H_{12}	0.007
Pentane	C_5H_{12}	0.110
2-methyl-1,3-butadiene	C_5H_8	0.014
Total	---	100

Attachments

Index of Attachments

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Attachment 1 - Cell UL 1973 certification

CERTIFICATE OF COMPLIANCE

Certificate Number: UL-CA-2328034-0
Report Reference: MH65785-20230801
Date: 3-Aug-2023

Issued to: CALB Group Co., Ltd
No. 1 Jiangdong Avenue, Jintan District
Changzhou, Jiangsu 213200
China

This is to certify that representative samples of BBGA8 - Battery Cells for Use in Stationary and/or Transport Applications Certified for Canada - Component
See Addendum Page for Product Designation(s).

Have been evaluated by UL in accordance with the component requirements in the Standard(s) indicated on this Certificate. UL Recognized components are incomplete in certain constructional features or restricted in performance capabilities and are intended for installation in complete equipment submitted for investigation to UL LLC.

Standard(s) for Safety: ANSI/CAN/UL 1973:2022, 3rd Ed., Issue Date: 2022-2-25

Additional Information: See the UL Online Certifications Directory at <https://iq.ulprospector.com> for additional information

This Certificate of Compliance indicates that representative samples of the product described in the certification report have met the requirements for UL certification. It does not provide authorization to apply the UL Recognized Component Mark. Only the Authorization Page that references the Follow-Up Services Procedure for ongoing surveillance provides authorization to apply the UL Mark.

Only those products bearing the UL Recognized Component Mark should be considered as being UL Certified and covered under UL's Follow-Up Services.

Look for the UL Recognized Component Mark on the product.

William Jennings

Deborah Jennings-Corcoran, VP Regulatory Services

UL LLC

Any information and documentation involving UL Mark services are provided on behalf of UL LLC (UL) or any authorized licensee of UL. For questions, please contact a local UL Customer Service Representative at ULCustomerService@ul.com.



Attachment 1 - Cell UL 1973 certification

CERTIFICATE OF COMPLIANCE

Certificate Number UL-CA-2328034-0
Report Reference MH-65785-20230801
Date 3-Aug-2023

This is to certify that representative samples of the product as specified on this certificate were tested according to the current UL requirements

Model	Category Description
L173F314	Rechargeable Li-Ion Cell

Deborah Jennings-Cox
Deborah Jennings-Cox, VP Regulatory Services
UL LLC

Any information and documentation involving UL Mark service are provided on behalf of UL LLC (UL) or any authorized licensee of UL. For questions, please contact a local UL Customer Service Representative at ULCustomerService@ul.com.



Attachment 1 - Cell UL 1973 certification

CERTIFICATE OF COMPLIANCE

Certificate Number: UL-US-2332565-0
Report Reference: MH65785-20230801
Date: 3-Aug-2023

Issued to: CALB Group Co., Ltd
No. 1 Jiangdong Avenue, Jintan District
Changzhou, Jiangsu 213200
China

This is to certify that
representative samples of

BBGA2 - Battery Cells for Use in Stationary and/or
Transport Applications - Component
See Addendum Page for Product Designation(s).

Have been evaluated by UL in accordance with the
component requirements in the Standard(s) indicated on
this Certificate. UL Recognized components are incomplete
in certain constructional features or restricted in
performance capabilities and are intended for installation in
complete equipment submitted for investigation to UL LLC.

Standard(s) for Safety: ANSI/CAN/UL 1973:2022, 3rd Ed., Issue Date: 2022-2-25

Additional Information: See the UL Online Certifications Directory at
<https://iq.ulprospector.com> for additional information

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and covered under UL's Follow-Up Services.

Look for the UL Recognized Component Mark on the product.



Deborah Jennings-Corson, VP Regulatory Services

UL LLC

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Attachment 1 - Cell UL 1973 certification

CERTIFICATE OF COMPLIANCE

Certificate Number UL-US-2332565-0
Report Reference MH65785-20230801
Date 3-Aug-2023

This is to certify that representative samples of the product as specified on this certificate were tested according to the current UL requirements

Model	Category Description
L173F314	Rechargeable Li-ion Cell

Deborah Jennings Conner

Deborah Jennings Conner, VP Regulatory Services

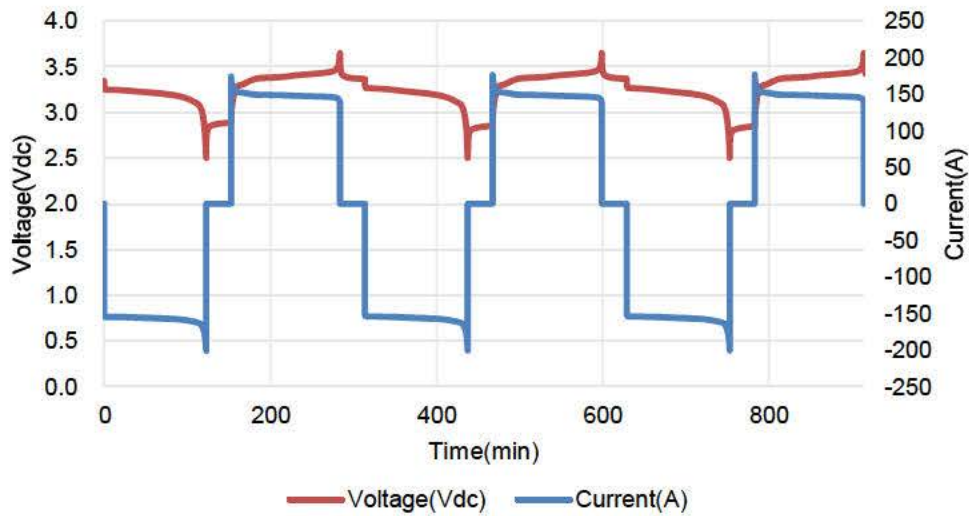
UL LLC

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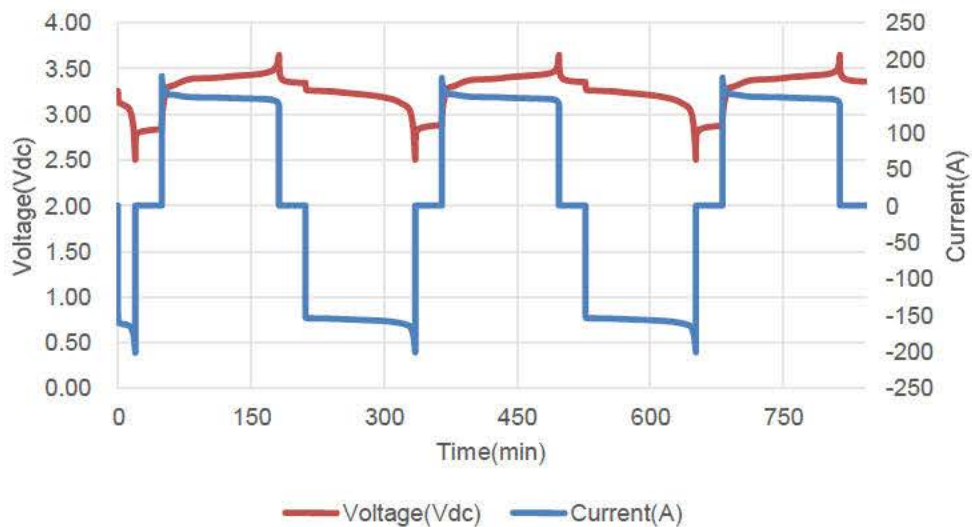


Attachment 2 - Cell charge/discharge conditioning graphs

Sample Number: 202308015-3

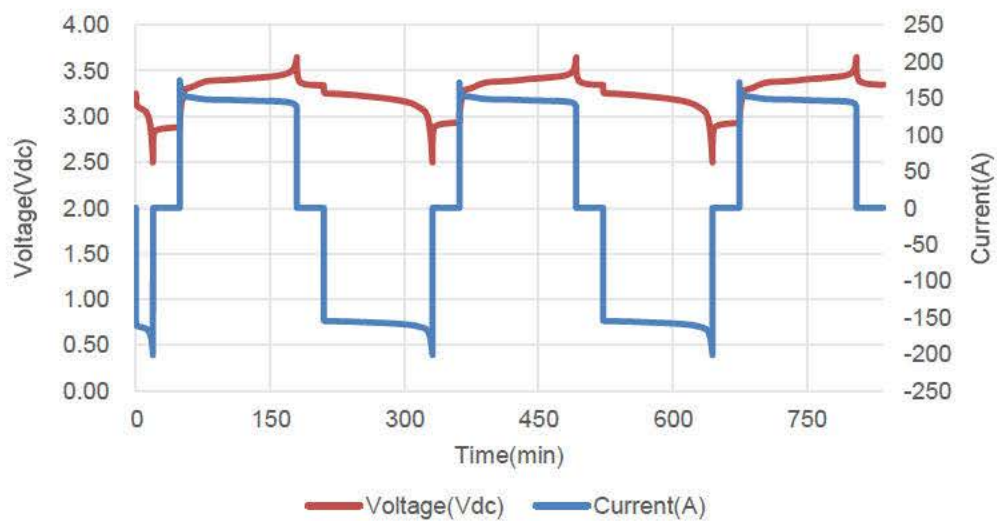


Sample Number: 202308015-8

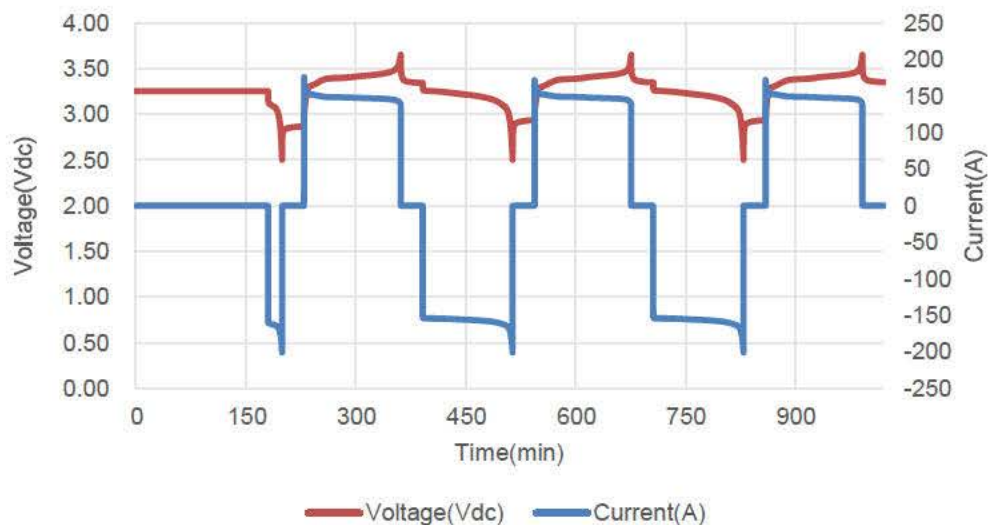


Sample Number: 202308015-5

Attachment 2 - Cell charge/discharge conditioning graphs

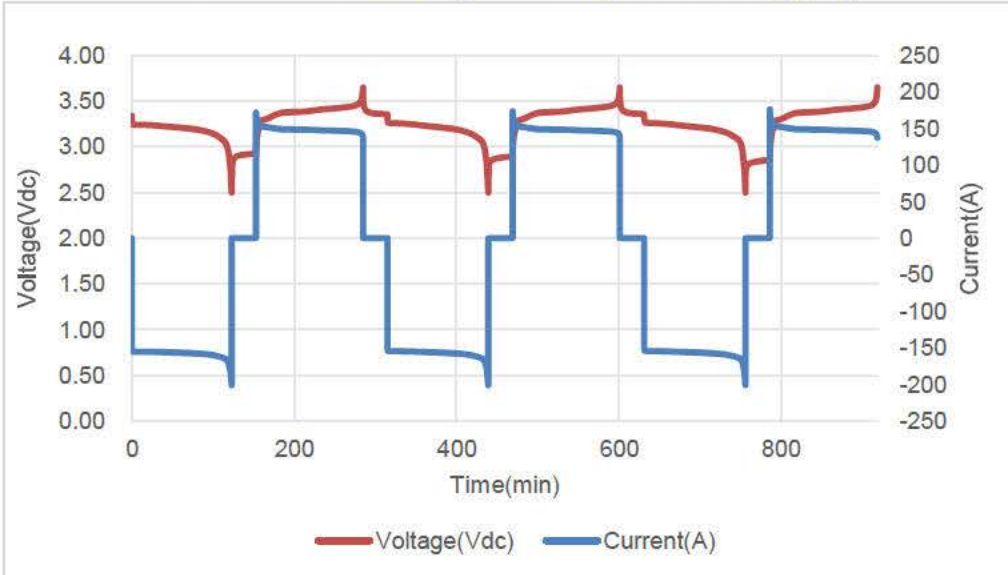


Sample Number: 202308015-6



Sample Number: 202308015-4

Attachment 2 - Cell charge/discharge conditioning graphs



Attachment 3 – Photos

General sample photos

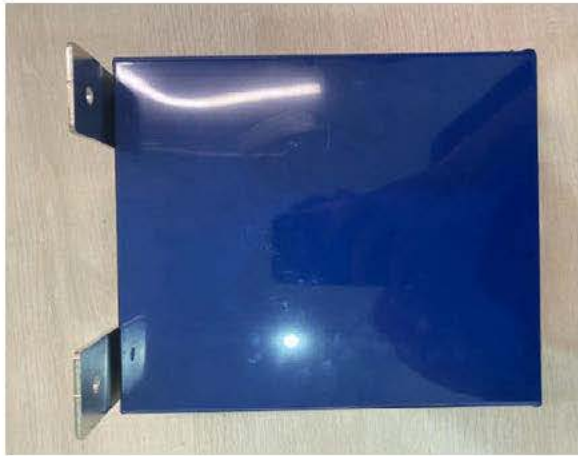


Figure 1: Wide surface of cell

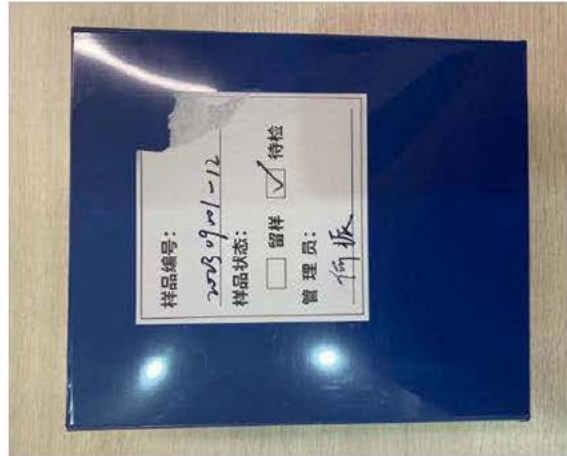


Figure 2: Another wide surface of cell



Figure 3: Side surface of cell



Figure 4: Top surface of cell

Photos with heater and thermocouple installation

Attachment 3 – Photos

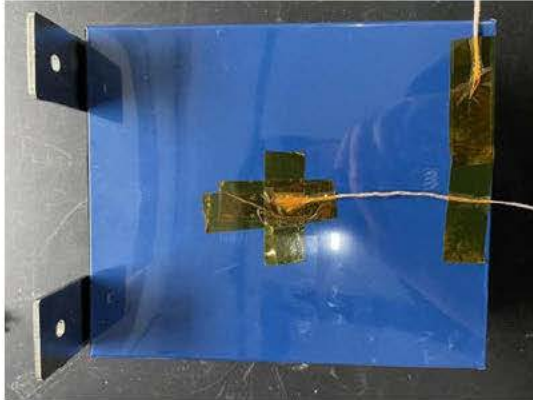


Figure 5: TC on wide surface

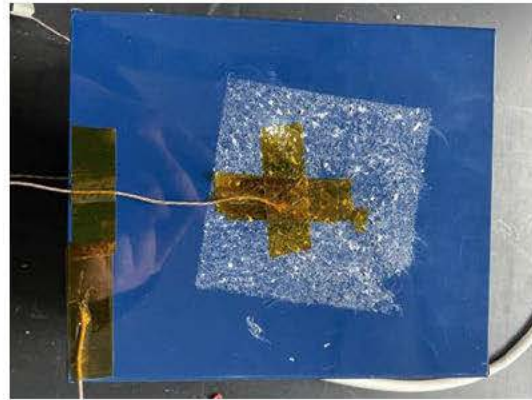


Figure 6: TC on another wide surface

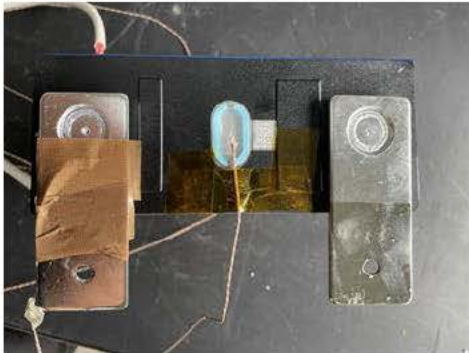


Figure 7: TC on positive tab and Vent

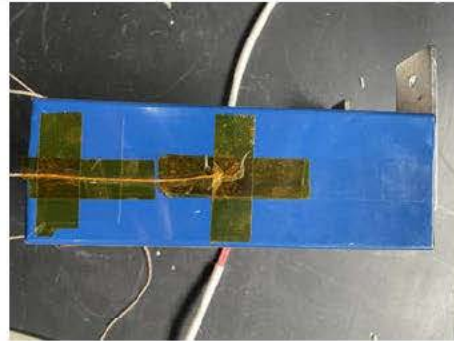


Figure 8: TC on side surface

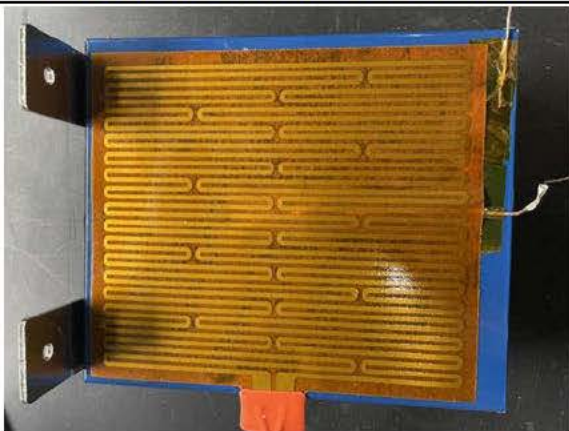


Figure 9: Heater film on wide surface

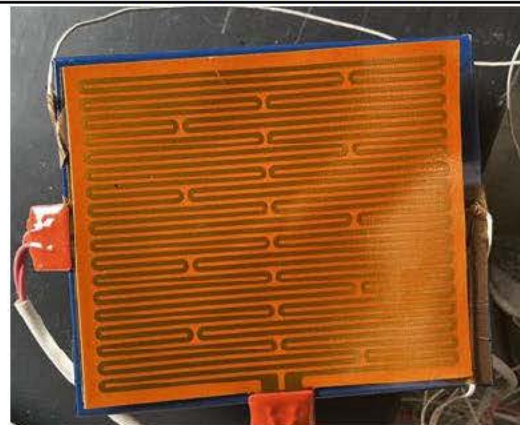


Figure 10: Heater film on another wide surface

Sample Number: 202308015-3

Attachment 3 – Photos

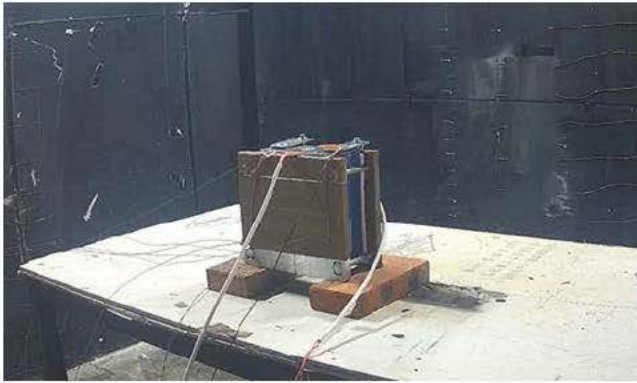


Figure 11: At test start (Time in 17:06)



Figure 12: During cell venting (Time in 17:48)



Figure 13: During thermal runaway (Time in 18:03)



Figure14: After thermal runaway-1



Figure 15: After thermal runaway-2



Figure 16: After thermal runaway-3

Sample Number: 202308015-8

Attachment 3 – Photos

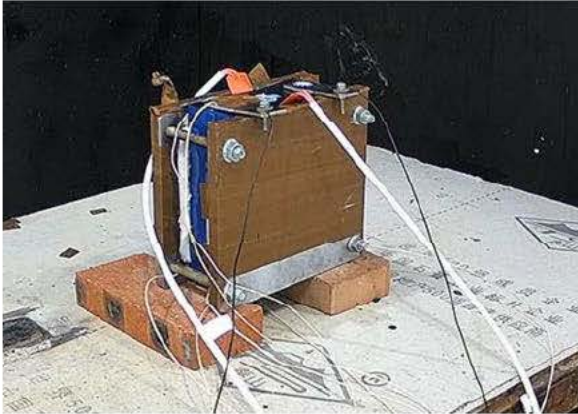


Figure 17: At test start (Time in 11:46)

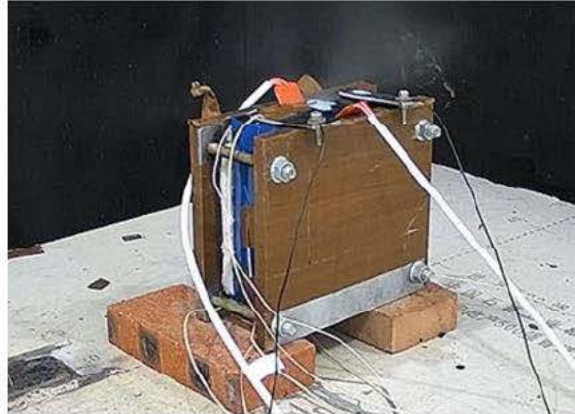


Figure 18: During cell venting (Time in 12:31)

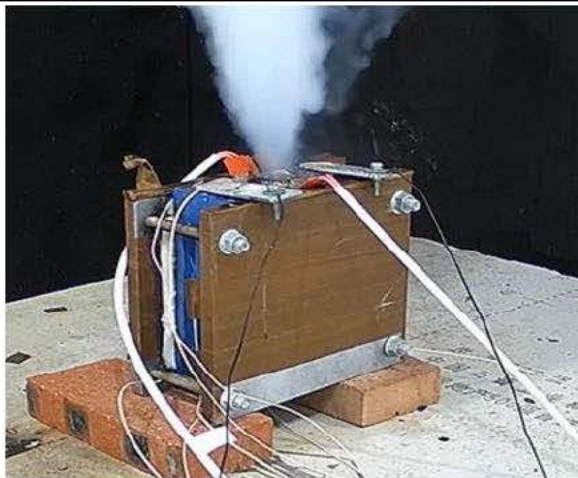


Figure 19: During thermal runaway (Time in 12:51)



Figure 20: After thermal runaway-1



Figure 21: After thermal runaway-2



Figure 22: After thermal runaway-3

Attachment 3 – Photos

Sample Number: 202308015-5



Figure 23: At test start (Time in 13:36)



Figure 24: During cell venting (Time in 14:22)



Figure 25: During thermal runaway (Time in 14:35)



Figure 26: After thermal runaway-1



Figure 27: After thermal runaway-2



Figure 28: After thermal runaway-3

Attachment 3 – Photos

Sample Number: 202308015-6

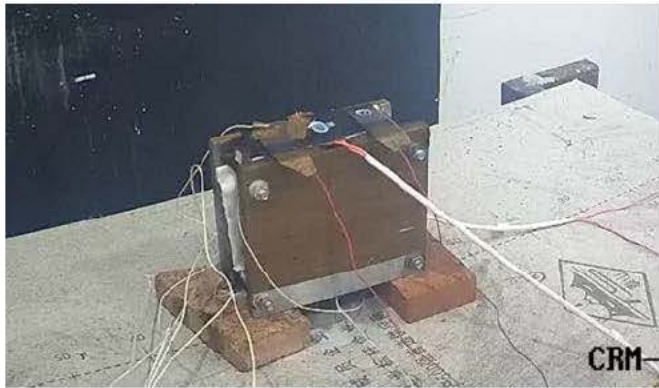


Figure 29: At test start (Time in 09:13)



Figure 30: During cell venting (Time in 09:54)



Figure 31: During thermal runaway (Time in 10:11)



Figure 32: After thermal runaway-1



Figure 33: After thermal runaway-2



Figure 34: After thermal runaway-3

Sample Number: 202308015-4

Attachment 3 – Photos



Figure 35: Test layout

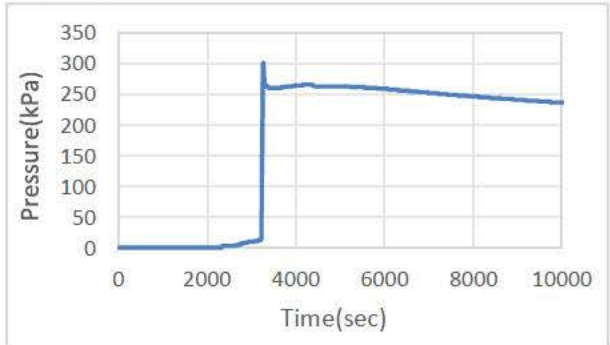


Figure 36: Container pressure during test

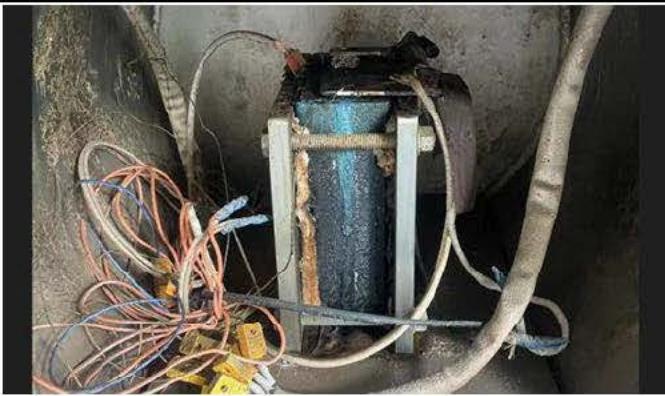


Figure 37: After thermal runaway-1



Figure 38: After thermal runaway-2



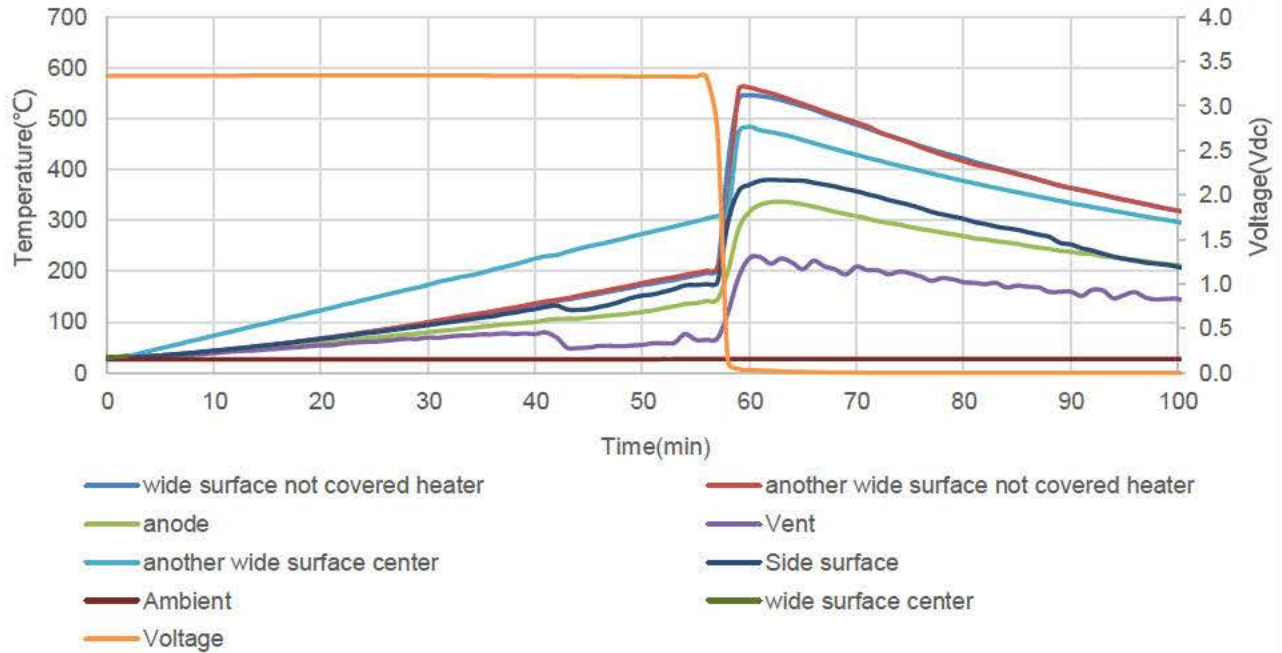
Figure 39: After thermal runaway-3



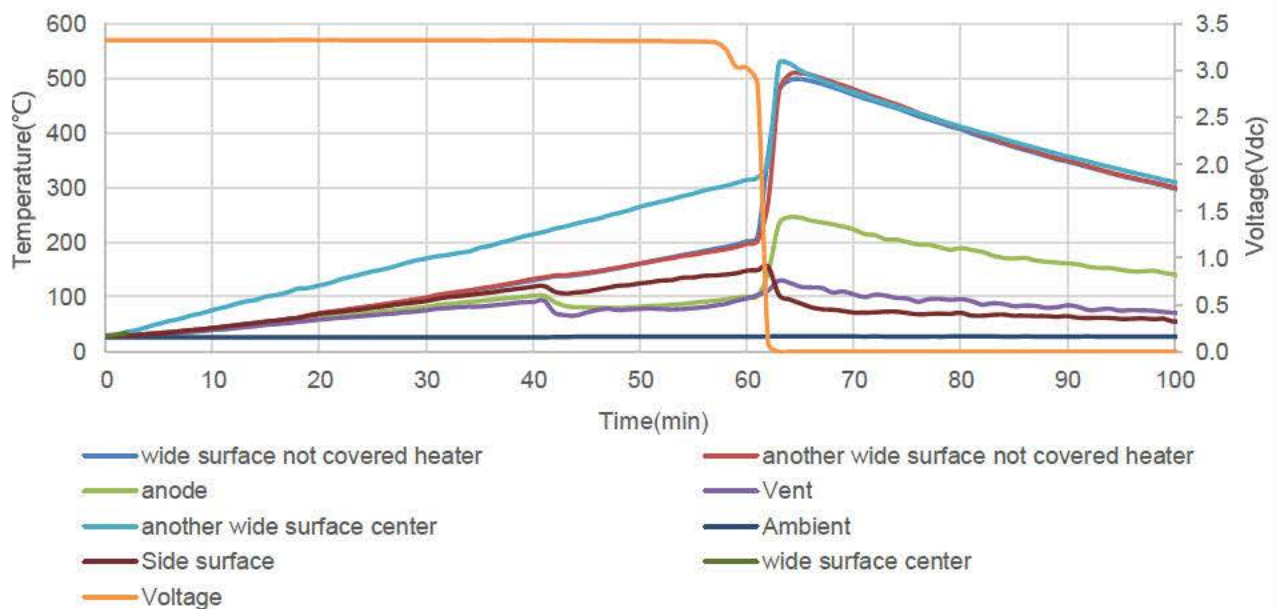
Figure 40: After thermal runaway-4

Attachment 4 - Cell temperature/voltage graph during testing

Sample Number: 202308015-3

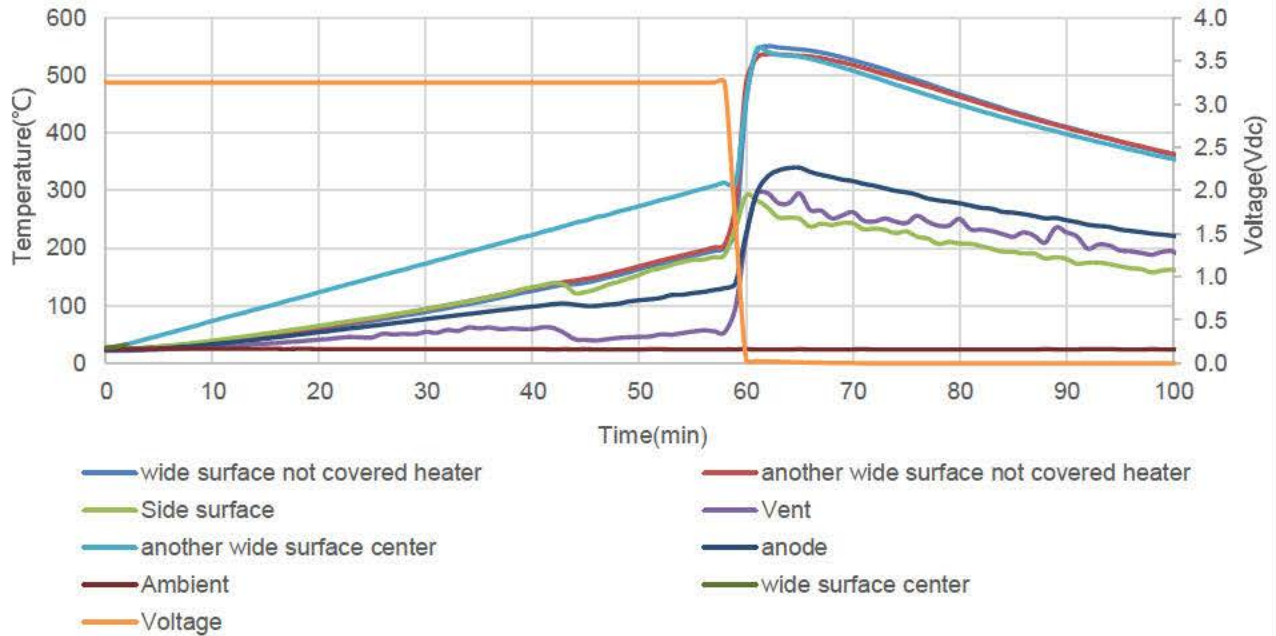


Sample Number: 202308015-8

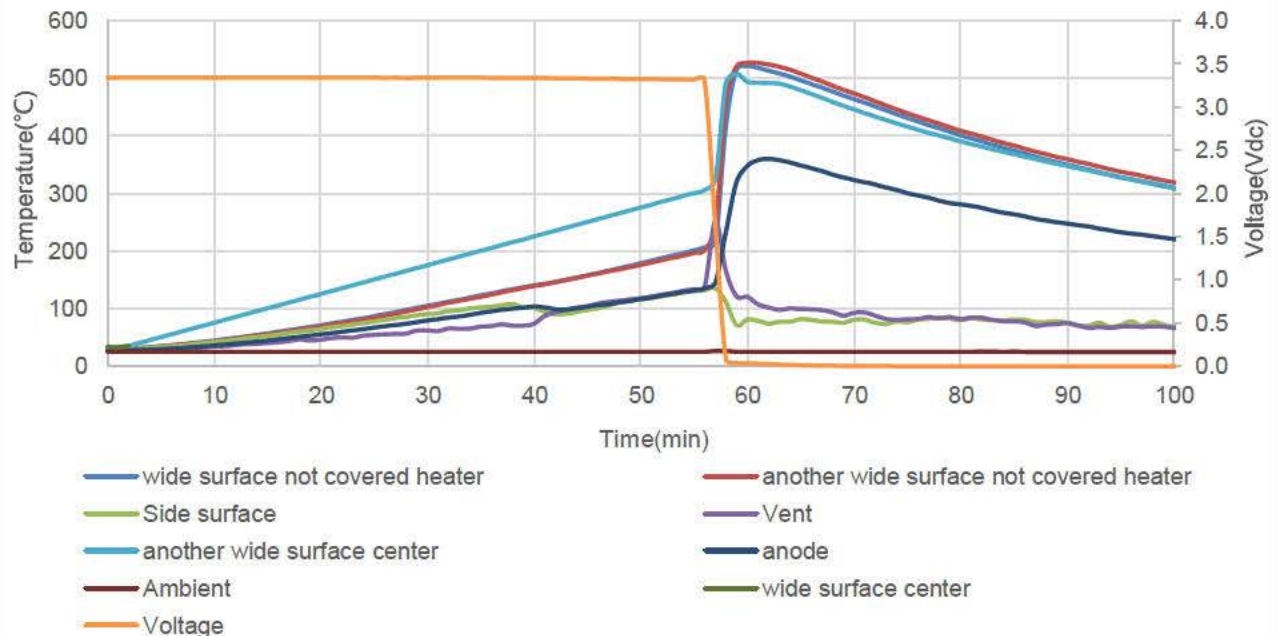


Attachment 4 - Cell temperature/voltage graph during testing

Sample Number: 202308015-5

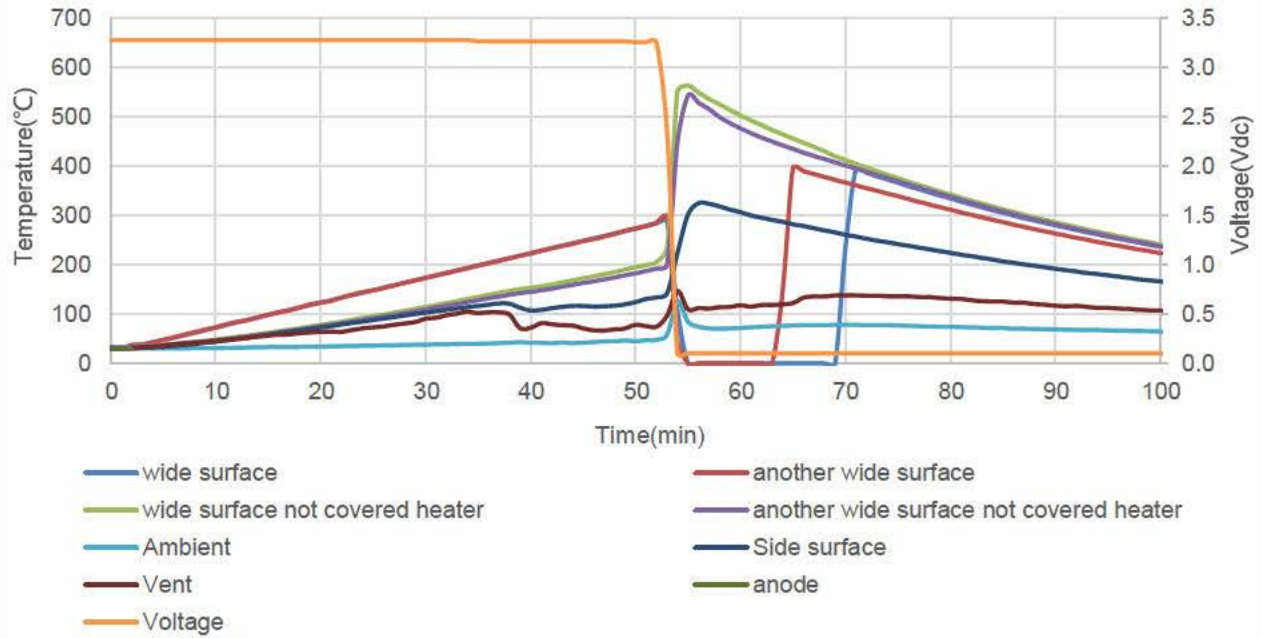


Sample Number: 202308015-6



Attachment 4 - Cell temperature/voltage graph during testing

Sample Number: 202308015-4



Attachment 5 - Cell gas analysis report

上海化工院检测有限公司 检测报告

Shanghai Institute of Chemical Industry Testing Co., Ltd.
Test Report

No1623100089

第 2/14 页 Page 2/14

序号 No.	检测项目名称 Name of Test	标准条款号 Clause of Standard	检测结果 Test Result	备注 Remark
1	气体/蒸气燃烧(爆炸) 极限—下限 Flammable (explosion) limits of gas and vapours - LFL	ASTM E918-19	初始温度: 25(±3)°C, 初始压力: 101(±2)kPa 条件下, LFL=6.2%。 LFL=6.2% at 25(±3)°C and 101(±2) kPa.	详见附表 3 和 4。 See Attached Table 3 and 4.
2	气体/蒸气燃烧(爆炸) 极限—上限 Flammable (explosion) limits of gas and vapours - UFL	ASTM E918-19	初始温度: 140(±2)°C, 初始压力: 101(±4)kPa 条件下, LFL=5.6%。 LFL=5.6% at 140(±2)°C and 101(±4)kPa.	详见附表 5 和 6。 See Attached Table 5 and 6.
3	可燃气体燃烧速度 Burning velocity of flammable gases	ISO 817:2014/Amd 2:2021	在室温和大气压条件下, $S_u = 0.638\text{m/s}$ 。 $S_u = 0.638\text{m/s}$ at room temperature and atmospheric pressure.	详见附表 7 和 8。 See Attached Table 7 and 8.
4	气体/蒸气的最大爆炸 压力 Maximum explosion pressure of gases and vapours	EN 15967:2022	初始温度: 28(±2)°C, 初始压力: 101(±3)kPa 条件下, $p_{max} = 0.68\text{MPa}$ 。 $p_{max} = 0.68\text{MPa}$ at 28(±2) °C and 101(±3)kPa.	详见附表 9 和 10。 See Attached Table 9 and 10.
5	以下空白 Intentionally Left Blank			
6				
检测环境条件 Test Environment Condition		环境温度: 17~26°C, 相对湿度: 46~63% Ambient Temperature: 17~26°C, Relative Humidity: 46~63%		
备注 Remarks		本检测报告的测试数据仅对某种特定情况下的样品有效, 若需将这些测试结果用于产品的生产、加工、运输及储存等过程中的风险评估, 请征求有关专家的意见。 This report is effective under the specific condition, please seek for the advice of expert for risk assessment in producing, processing, transportation and storage.		

End of Report....

Prüfbericht-Nr.: <i>Test report no.:</i>	CN23P68X 001	Auftrags-Nr.: <i>Order no.:</i>	244559560	Seite 1 von 35 Page 1 of 35
Kunden-Referenz-Nr.: <i>Client reference no.:</i>	2003666	Auftragsdatum: <i>Order date:</i>	2023-11-20	
Auftraggeber: <i>Client:</i>	Sungrow Power Supply Co., Ltd. No.1699 Xiyou Rd., New & High Technology Industrial Development Zone, Hefei, 230088 Anhui, P.R. China			
Prüfgegenstand: <i>Test item:</i>	Energy Storage Battery Pack			
Bezeichnung / Typ-Nr.: <i>Identification / Type no.:</i>	P1044AL-AHA			
Auftrags-Inhalt: <i>Order content:</i>	Test report			
Prüfgrundlage: <i>Test specification:</i>	UL 9540A: 2019 (Fourth Edition) Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems			
Wareneingangsdatum: <i>Date of sample receipt:</i>	2023-11-20			
Prüfmuster-Nr.: <i>Test sample no.:</i>	#2023112101			
Prüfzeitraum: <i>Testing period:</i>	2023-11-21 - 2023-12-04			
Ort der Prüfung: <i>Place of testing:</i>	See clause 1.1 of main report			
Prüflaboratorium: <i>Testing laboratory:</i>	TÜV Rheinland (Shanghai) Co., Ltd.			
Prüfergebnis*: <i>Test result*:</i>	See main report			
geprüft von: <i>tested by:</i>	 Minhao Hu		genehmigt von: <i>authorized by:</i>	
Datum: <i>Date:</i>	2023.12.15		Ausstellungsdatum: <i>Issue date:</i>	2023.12.16
Stellung / Position:	Project Engineer/Trainee		Stellung / Position:	Reviewer
Sonstiges / <i>Other:</i>				
Zustand des Prüfgegenstandes bei Anlieferung: <i>Condition of the test item at delivery:</i>		Prüfmuster vollständig und unbeschädigt <i>Test item complete and undamaged</i>		
* 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				
Dieser Prüfbericht bezieht sich nur auf das o.g. Prüfmuster und darf ohne Genehmigung der Prüfstelle nicht auszugsweise vervielfältigt werden. Dieser Bericht berechtigt nicht zur Verwendung eines Prüfzeichens. <i>This test report only relates to the above mentioned test sample as. Without permission of the test center this test report is not permitted to be duplicated in extracts. This test report does not entitle to carry any test mark.</i>				

V05

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 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.

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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 module level tests of UL 9540A: 2019.

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

Testing period: Nov. 21, 2023 ~ Dec. 04, 2023

All tests were under supervision of TÜV Rheinland's engineer.

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 Summary of the test

Two external heaters were placed in the module to initiating thermal runaway. The initiating cells were heated at a rate of 4°C~7°C per minute until the cell thermal runaway.

White smoke was observed during test. No flying debris or explosive discharge of gases during test. No sparks, electrical arcs, or other electrical events during test. No external flaming observed.

Cell thermal runaway was observed.

Cell to cell thermal runaway propagation was observed.

The battery pack weight measured was 658.5 kg (before test) and 653.5 kg (after test).

Measured peak chemical heat release rate HRR_t was 27.26 kW;

Measured peak smoke release rate SRR was 6.785 m²/s;

Total smoke release TSR was 1589.26 m²;

Total hydrocarbons was 973.2 L (equivalent to CH₄, measured by FID);

Detail information see relevant clause of this report.

1.5 List of attachments

Video records of the test from 3 directions was provided in .mp4 format.

Complete records were provided in following documents, file number listed as below:

202301121 Sungrow module UL9540A video ch01 (01-02).mp4

202301121 Sungrow module UL9540A video ch02 (01-02).mp4

202301121 Sungrow module UL9540A video ch03 (01-02).mp4

2. General Product Information

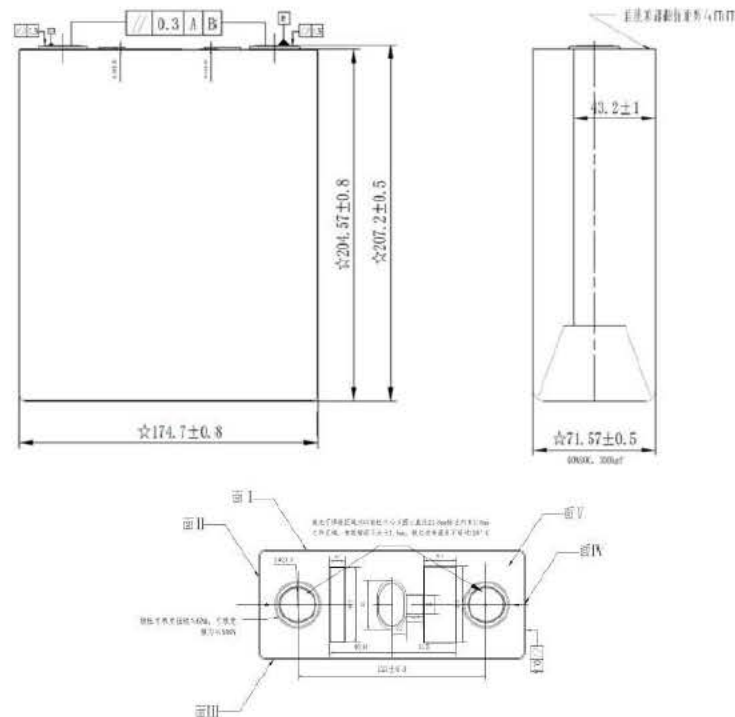
2.1 Cell

2.1.1 Product information and parameters

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

Manufacturer	CALB Group Co., Ltd.
Model number	L173F314
Chemistry	LiFePO4
Physical configuration	Prismatic
	Weight: 5.56±0.15 kg
Electrical rating	Rated capacity: 314 Ah
	Nominal voltage: 3.2 V
Standard charge method	Charge current: 157 A
	End of charge voltage: 3.65 V
Standard discharge method	Discharge current: 314 A
	End of discharge voltage: 2.5 V

Diagram with overall dimension



2.1.2 Cell level test information

Cell level thermal runaway test information is from UL cell level test report 4789795626 provided by the client.

Thermal Runaway Methodology	Two pieces 185 mm by 160 mm heater for each sample
Cell Surface Temperature at Gas Venting ..	140.5°C
Cell Surface Temperature at Thermal Runaway.....	210.6°C

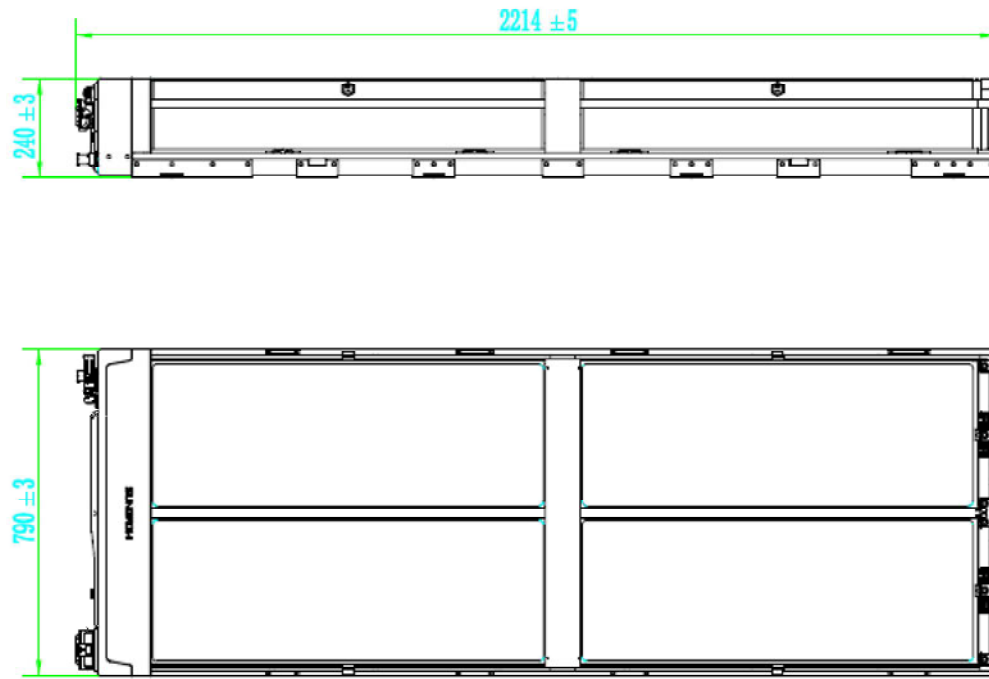
2.2 Module

2.2.1 Product information and parameters

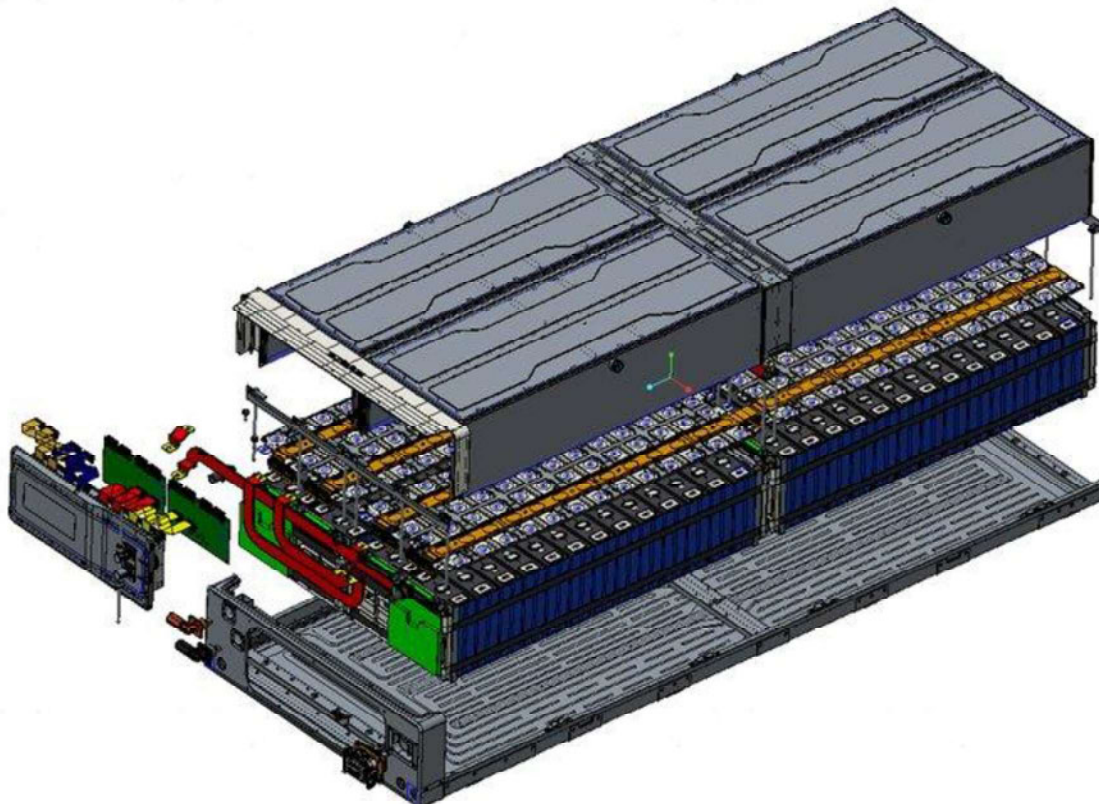
The product information and parameters are provided by the client as below.

Manufacturer name.....		Sungrow Power Supply Co., Ltd.
Model number.....		P1044AL-AHA
Physical configuration.....		Metal enclosure with plastic cover
		Weight: 660±9 kg
		Cells in series/parallel: 104S
Cooling method.....		Liquid cooling
Separation between cells.....		Aerogel
Electrical rating		Rated capacity: 314 Ah
		Nominal voltage: 332.8 V
Standard charge method.....	Charge current:	157 A
	End of charge voltage:	379.6 V
Standard discharge method.....	Discharge current:	157 A
	End of discharge voltage:	280.8 V
Compliance with UL 1973.....		Yes. Report No. : CN232YU5 001 Certificate No. : CU 72303382 0001

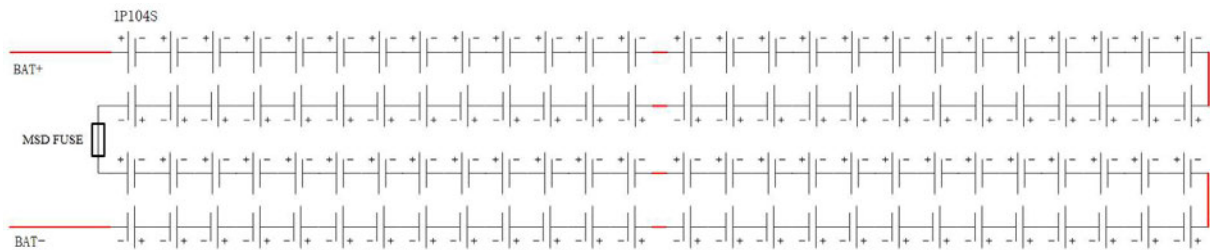
2.2.2 Diagram with overall dimension



2.2.3 Layout of the module contents



2.2.4 Configuration diagram of the module



2.3 Photos



3. Module level test (section 8 of UL 9540A)

3.1 General

This testing is conducted on battery modules, which are in turn installed in an enclosure or in an open rack system to form a BESS unit.

This test uses applied stresses determined during the cell level test to force a selected number of battery cells within the module into thermal runaway. If there is fire that results from the cell being driven into thermal runaway, the fire is allowed to progress within the module.

The test measures the chemical heat release rate, maximum temperature, and vent gas composition; and documents the module enclosure integrity after the test, any explosions or hazardous ejection of parts outside of the module enclosure, and the extent and duration of any flame propagation outside of the module.

The module level testing establishes a base line fire test performance that can be evaluated against the fire performance of other battery modules the BESS manufacturer may choose to use within the system.

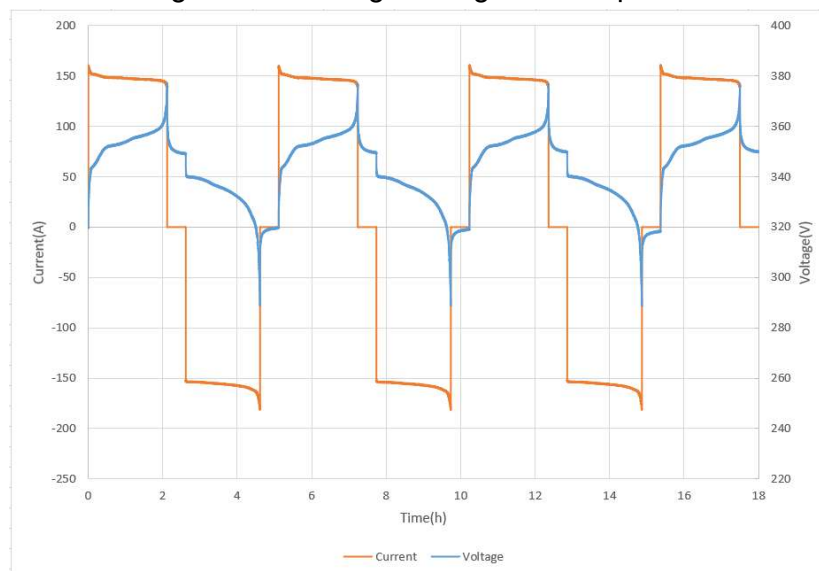
3.2 Sample preparation

Module sample was conditioned, prior to testing, through charge and discharge cycles of 3 cycles to verify that the module was functional.

Each cycle was defined as a charge to 100% SOC and allowed to rest several minutes and then discharged to an end of discharge voltage (EODV) determined by the manufacturer. Refer to 2.1 for charge and discharge profile.

The module sample was put in a climate chamber during charge and discharge. The ambient is kept at $25^{\circ}\text{C} \pm 2^{\circ}\text{C}$ and $50\% \pm 5\%$ R.H.

Figure 1. Module charge and discharge voltage/current profiles



3.3 Module level thermal runaway test

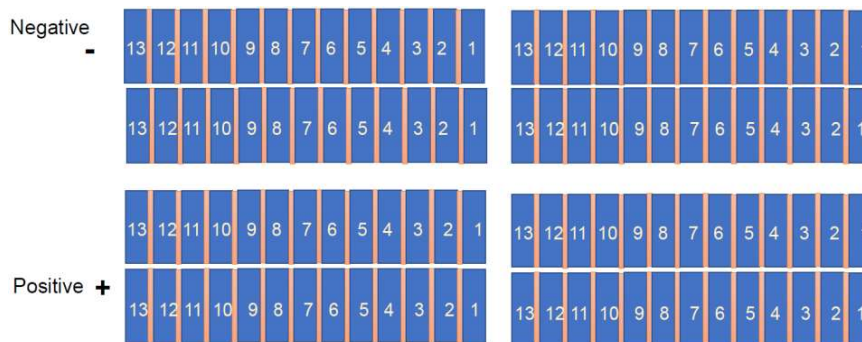
3.3.1 Thermal runaway test method description

The module to be tested were 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.

The external heating method used for initiating thermal runaway in cell level test was used to initiate thermal runaway within the module.

Consider the unit level installation in the module. #2 ~ #4 cells located in the middle of the module was chose as target cell to be forced into thermal runaway.

Figure 2. Cell numbering, initiating cell selecting



The cells were heated by two external heaters rated 220VAC/800 W (size 200*165*1mm).

2 glass fiber thermocouples Type K, 24 AWG were attached on the center of two wide surface of #3 cell. (See 3.3.2 figure 3)

10 glass fiber thermocouples Type K, 24 AWG were attached on the center of each wide surface of #1 to #7 cells and 3 glass fiber thermocouples were attached on the vent of #2 to #4 cells, used for record cell temperature. (See 3.3.2 figure 4)

7 glass fiber thermocouples Type K, 24 AWG were attached on the center of each wide surface of #1 to #7 cells which were beside initiating cell #3 and another 7 glass fiber thermocouples Type K, 24 AWG were attached on the center of each narrow surface of #1 to #7 cells which were opposite initiating cell #3, used for record cell surface temperature. (See 3.3.2 figure 4)

8 glass fiber thermocouples Type K, 24 AWG were attached on the surface of module used for record module external temperature. (See 3.3.2 figure 5)

Manual control the voltage supply to the heater and maintain a 4°C/min to 7°C/min heating rate.

Once thermal runaway was observed, the heaters were immediately de-energized.

Voltage of the modules are monitored during test.

The module was placed on top of a lift with the module orientation representative of its intended final installation.

The module was located under the smoke collection hood of the calorimeter measurement system.

Ambient conditions were within 25±5 °C and 50±25% RH at the initiation of the test.

3.3.2 Location of thermocouples

Figure 3. Thermocouples (no. xx) locations of initiating cell

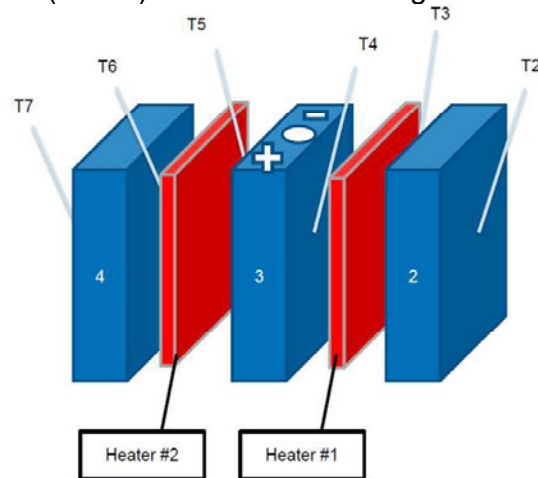


Figure 4. Cell numbering, heater location and thermocouples (no. xx) locations inside the sub-module

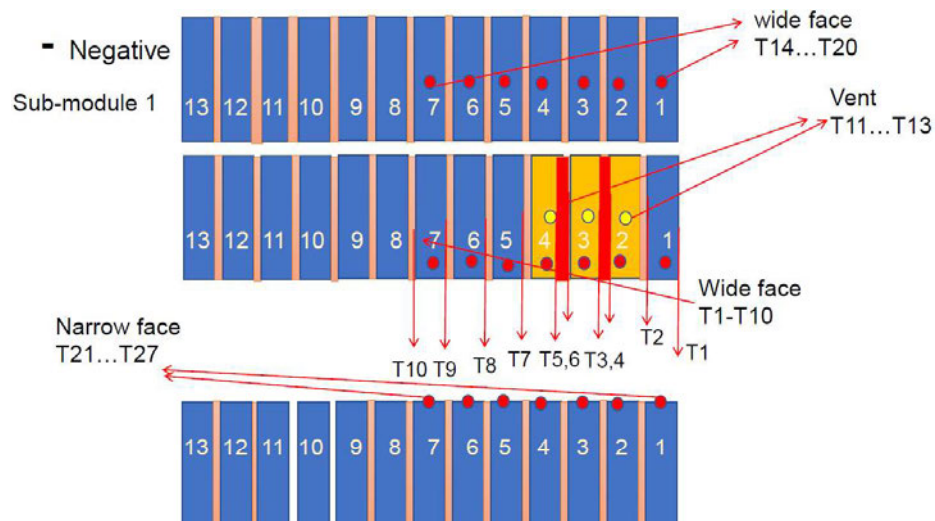
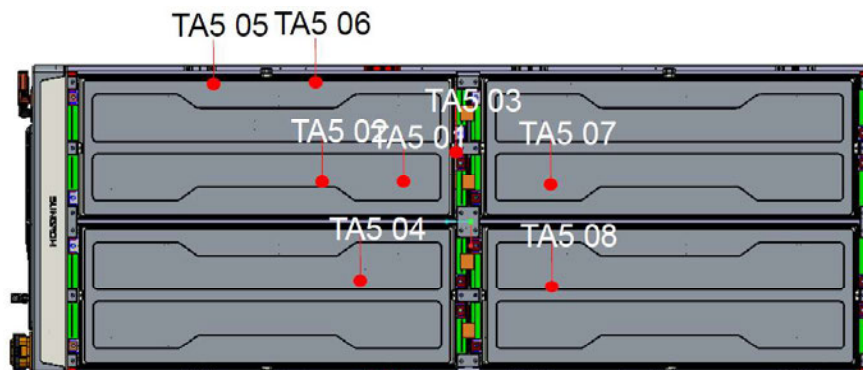


Figure 5. Thermocouples' locations outside module



3.3.3 Observations and records

Ambient conditions at the initiation of the test.....	24.9°C, 61.1% R.H.
Sample number	#2023112101
Open circuit voltage before test (V)	351.0
Weight before test (kg)	658.5 (with thermocouples)
Time initiating the test.....	10:47 start to heat the cells
Observations during test.....	Audible pops were heard at 12:39 (the pressure relief valve burst). Large amount of white smoke was observed on 12:40. Large amount of white smoke was observed on 12:44, 12:51, 13:00 and 13:14. No flying debris or explosive discharge of gases during test. No sparks, electrical arcs, or other electrical events during test. No flaming observed.
Posttest evaluation	Posttest evaluations were performed after 12 hours of test. Total 5 cells were damage after test. 3 of them were initiating cells and another 2 were cell-to-cell thermal propagation. Photos "sample after test" in page 31 show the damage of the module enclosure, electrolyte outside and damage of the components inside enclosure. 329.9 V was measured on the module output terminal.
Weight after test (kg)	653.5 (with thermocouples)
Weight loss (kg).....	5

3.3.4 Temperature measurements

Cell to cell propagation was observed during the test.

Cell thermal runaway occurred on #3 at around 12:40, #2 and #4 cell thermal runaway occurred at around 12:44 and 12:51. Maximum temperature 633.5°C (T4) were measured on the #4 cells wide surface. See figure 6 for the temperature vs time curve. Maximum temperature please see table 1 for detail.

Cell to cell propagation was observed on #1 and #5 in initial module during the test.

Figure 6. Temperatures of cell #2~#4

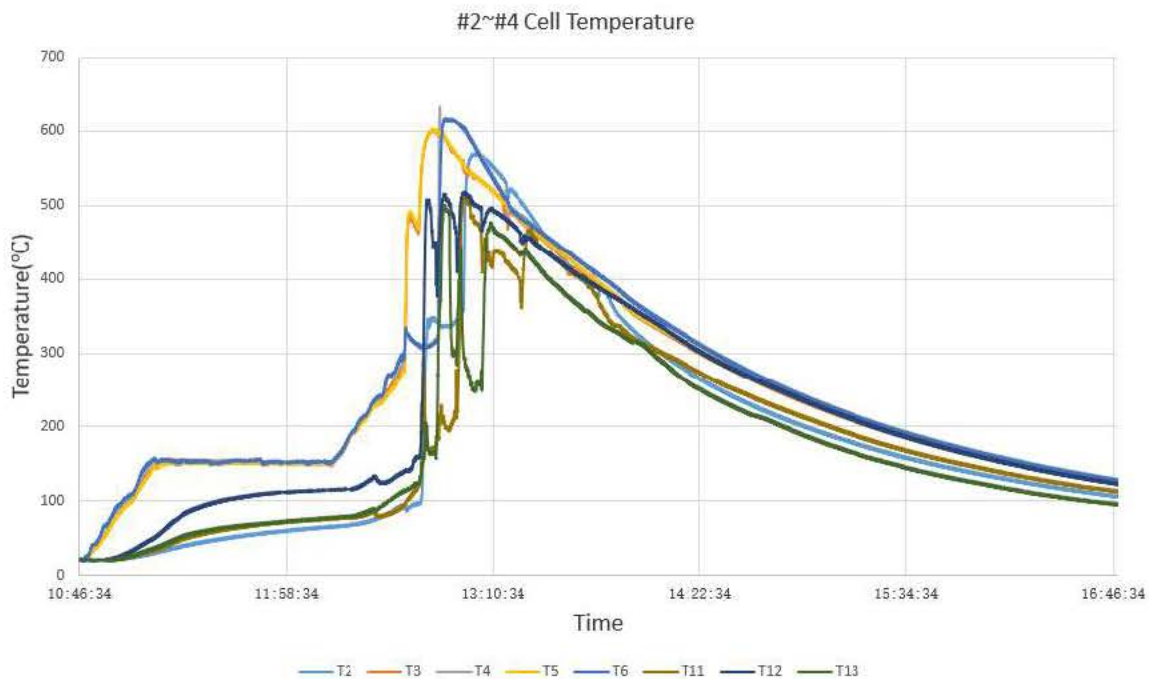


Table 1. Maximum temperature of cell #2~#4

Thermocouple no.	Location	Maximum temp.(°C)
T2	Surface of cell_2	569.0
T3	Surface of cell_2 under heater	600.7
T4	Surface of cell_3 under heater	633.5
T5	Surface of cell_3 under heater	601.8
T6	Surface of cell_4 under heater	618.1
T11	Vent of cell_2	510.5
T12	Vent of cell_3	517.6
T13	Vent of cell_4	500.5

Note: Thermocouples T7 was damaged during the test.

Figure 7. Temperatures of cell #1 and cell #5~#7

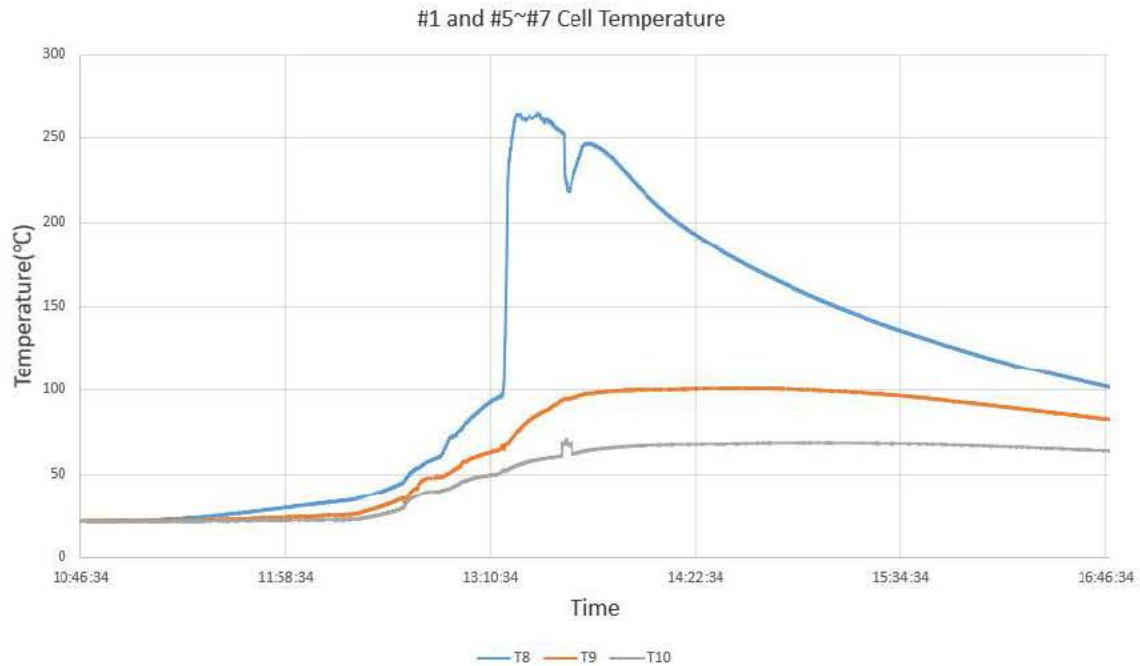


Table 2. Maximum temperature of cell #1 and cell #5~#7

Thermocouple no.	Location	Maximum temp.(°C)
T8	Surface of cell_5	265.5
T9	Surface of cell_6	100.8
T10	Surface of cell_7	70.7

Note: Thermocouples T1 was damaged during the test.

Figure 8. Temperatures of cell #1~#7(beside initiating cell)

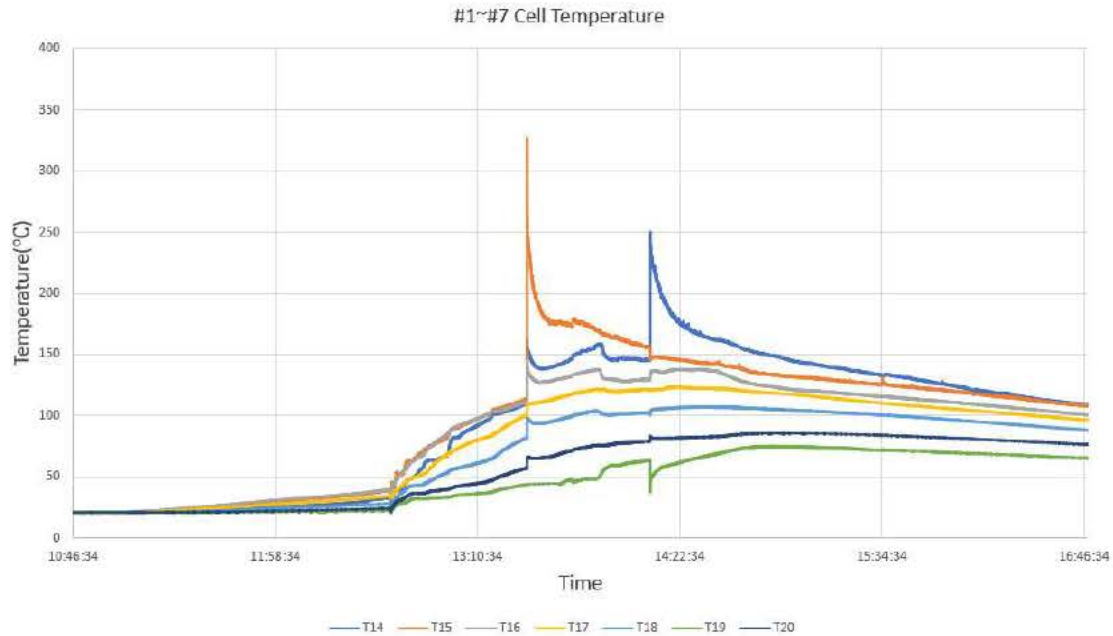


Table 3. Maximum temperature of cell #1~#7(beside initiating cell)

Thermocouple no.	Location	Maximum temp.(°C)
T14	Surface of cell_1	250.3
T15	Surface of cell_2	325.1
T16	Surface of cell_3	144.9
T17	Surface of cell_4	123.1
T18	Surface of cell_5	107.1
T19	Surface of cell_6	75.1
T20	Surface of cell_7	85.6

Figure 9. Temperatures of cell #1~#7(opposite initiating cell)

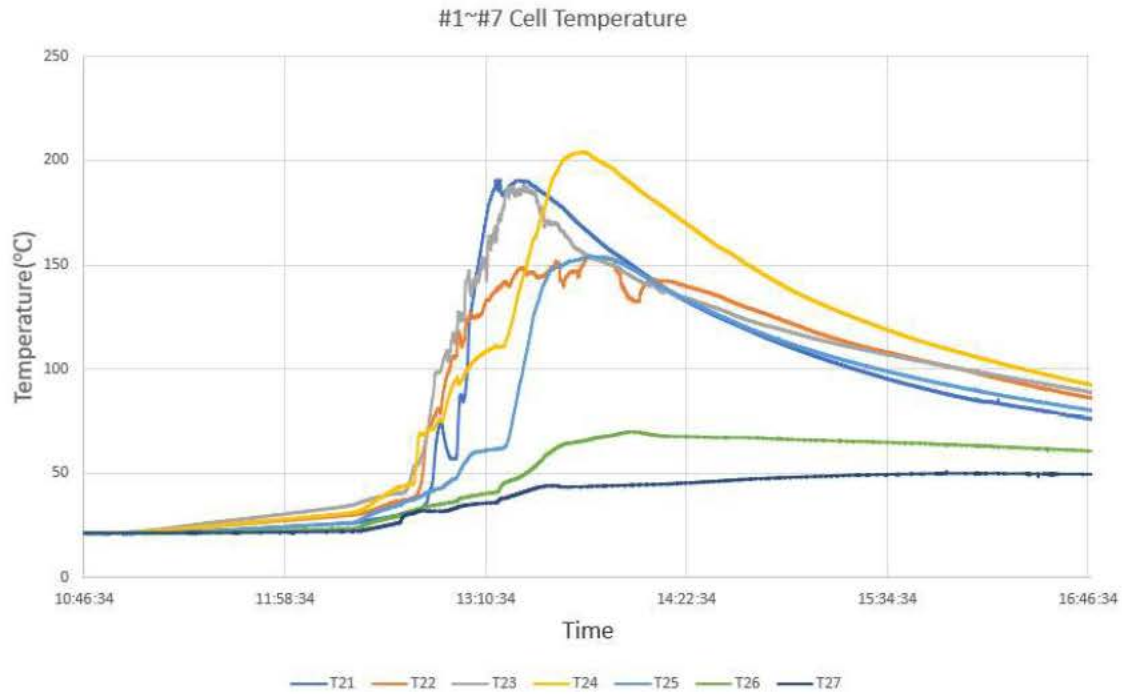


Table 4. Maximum temperature of cell #1~#7(opposite initiating cell)

Thermocouple no.	Location	Maximum temp.(°C)
T21	Surface of cell_1	190.8
T22	Surface of cell_2	154.1
T23	Surface of cell_3	188.4
T24	Surface of cell_4	204.3
T25	Surface of cell_5	154.3
T26	Surface of cell_6	69.9
T27	Surface of cell_7	51.2

Figure 10. Module voltage

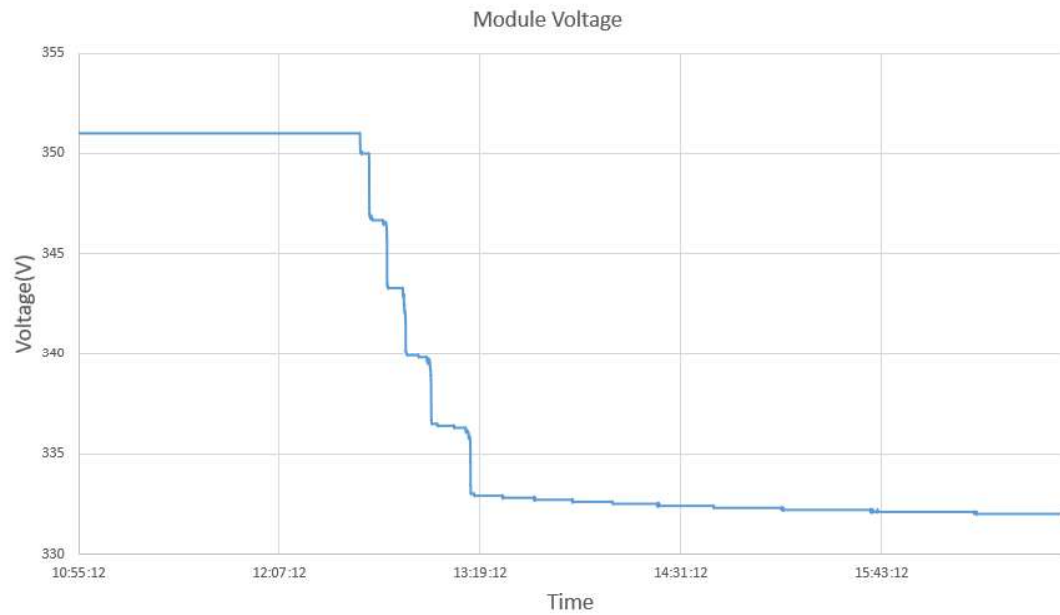
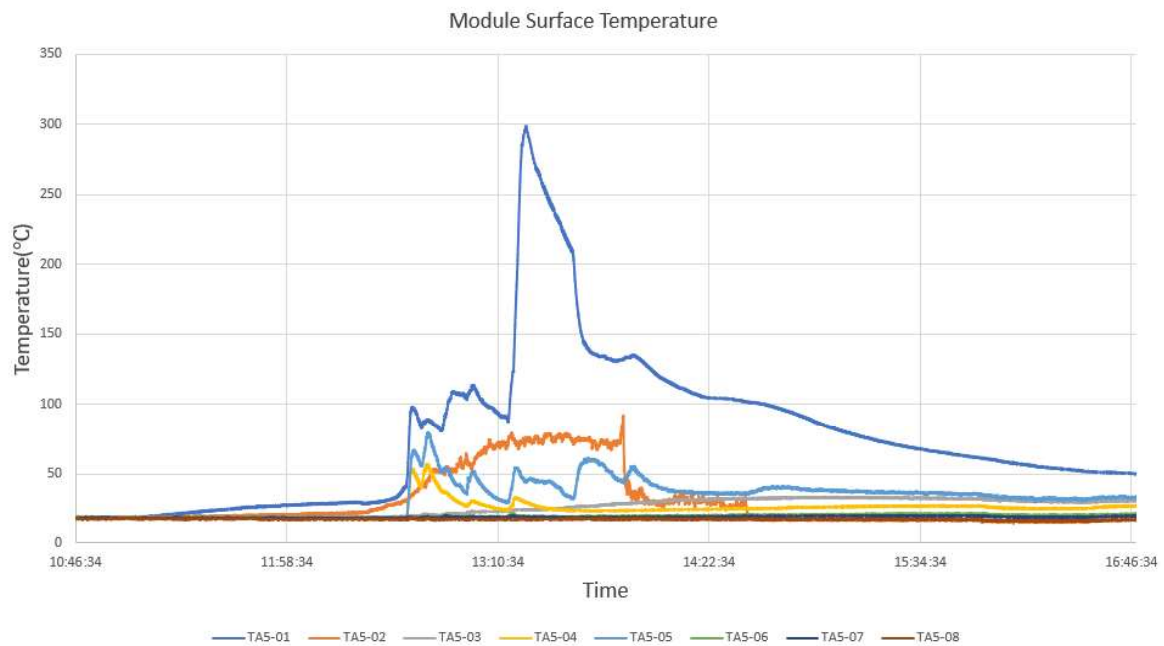


Figure 11. Temperatures of module surface



3.4 Chemical heat release rate measurement

3.4.1 Test method

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:

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

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:

$$\phi = \frac{X_{O_2}^o \times [1 - X_{CO_2} - X_{CO}] - X_{O_2} \times [1 - X_{CO_2}^o]}{X_{O_2}^o \times [1 - X_{O_2} - X_{CO_2} - X_{CO}]}$$

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

X_{CO_2} = Measured mole fraction of CO₂ in exhaust flow (non-dimensional)

$X_{CO_2}^o$ = Measured mole fraction of CO₂ in incoming air (non-dimensional)

$X_{H_2O}^o$ = Measured mole fraction of H₂O in incoming air (non-dimensional)

X_{O_2} = Measured mole fraction of O₂ in exhaust flow (non-dimensional)

$X_{O_2}^o$ = Measured mole fraction of O₂ 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

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

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

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)

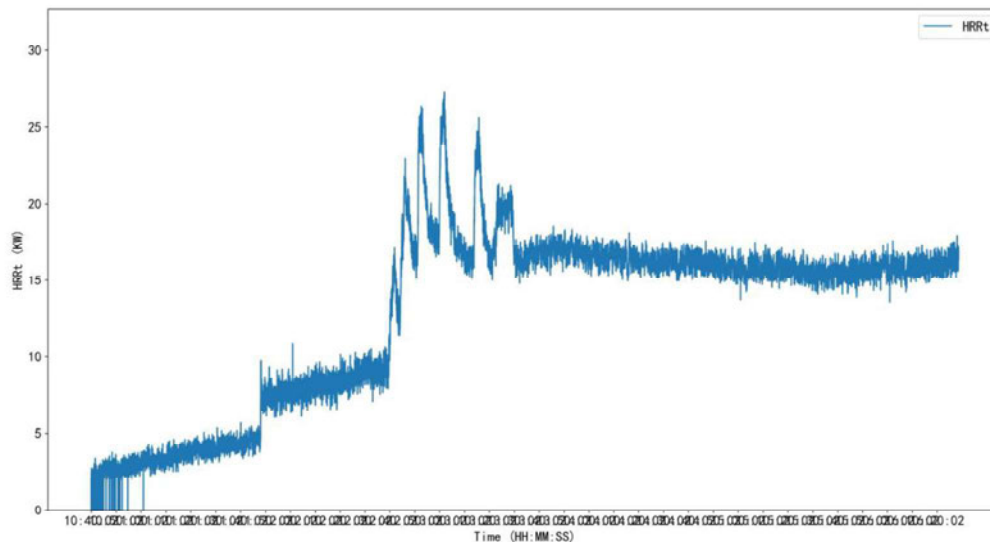
$f(Re)$ = Reynolds number correction (non-dimensional)

The whole heat release rate measurement system were calibrated using an atomized heptane diffusion burner before the test. The calibration were performed using flows of 1078mg/s and 1510mg/s of propane (corresponding to 50kW and 70kW heat release rate).

3.4.2 Test result

Peak chemical heat release rate HRR_t: 27.260 KW

Figure 12. HRR_t curve



3.5 Smoke release rate measurement

3.5.1 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:

$$SRR = 2.303 \left(\frac{V}{D} \right) \text{Log}_{10} \left(\frac{I_o}{I} \right)$$

Where:

SRR = Smoke release rate (m^2/s)

V = Volumetric exhaust duct flow rate (m^3/s)

D = duct diameter (m)

I_o = Light transmission signal of clear (pre-test) beam (V)

I = Light transmission signal during test (V)

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%, 16%, 10%, 1% and 0% light transmittance.

3.5.2 Test result

Peak smoke release rate SRR: $6.785 \text{ m}^2/\text{s}$

Total smoke release TSR: 1589.260 m^2

Figure 13. SRR curve

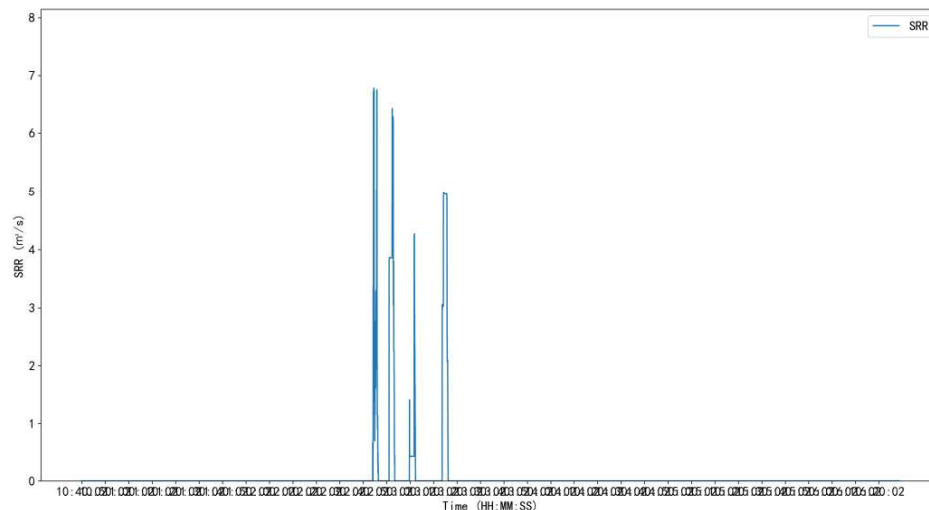
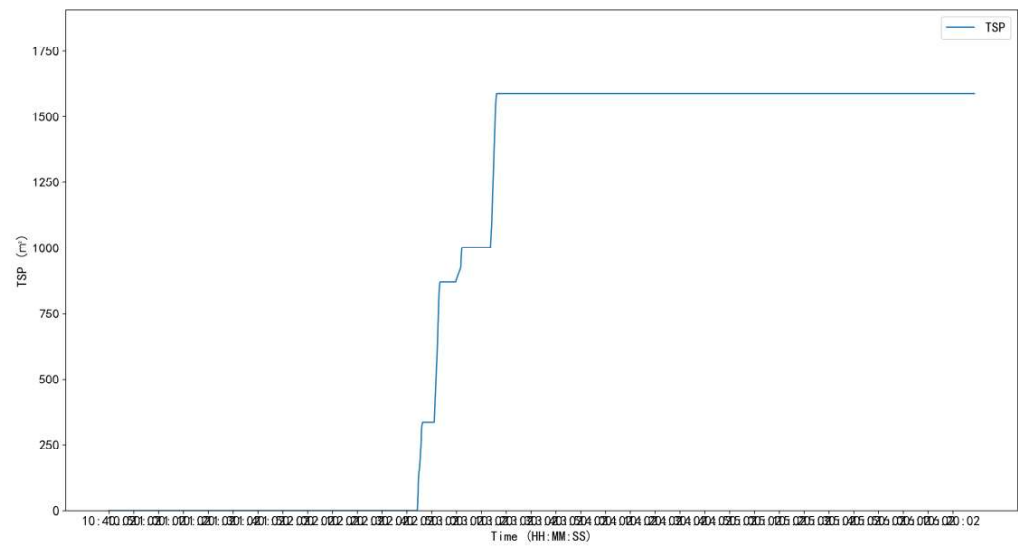


Figure 14. TSR curve



3.6 Gas generation measurement

3.6.1 Test method

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

Gas compositions 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.

3.6.2 Total gas release

The flow rates of various gases were integrated over the test duration and the total cumulative volume of gas calculated for the total test duration (10:47 ~ 14:10) were presented in below table.

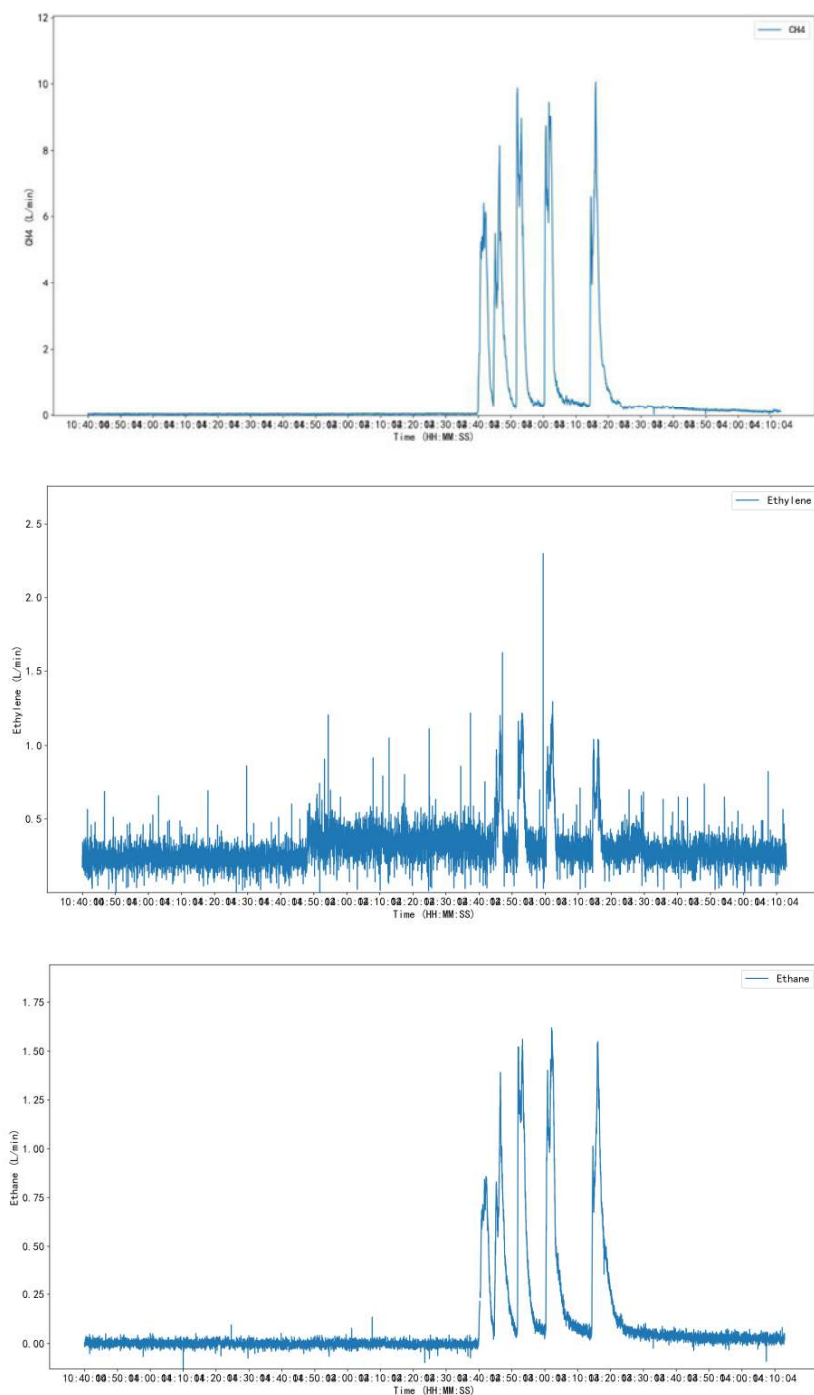
Total cumulative volume of gases before cell venting (10:47 ~ 12:39) were also presented in table for reference. Which may be considered as ambient gases background before test.

Gas type	Gas components		Total volume of gas (L)	
			Before cell venting	Throughout the test
Hydrocarbon species	Methane	CH ₄	0.00	86.10
	Ethylene	C ₂ H ₄	0.00	66.52
	Ethane	C ₂ H ₆	0.00	16.14
	Propylene	C ₃ H ₆	0.00	261.20
	Propane	C ₃ H ₈	0.00	47.45
Others	Carbon Monoxide	CO	0.00	170.20
	Carbon Dioxide	CO ₂	0.00	382.30
	Hydrogen ²⁾	H ₂	0.00	970.20
Total Hydrocarbons (equivalent to CH ₄ , measured by FID)				973.2
Note:				
1)The collection time is from 10:47 to 14:10				
2)The Hydrogen measured by Palladium nickel thin film solid state sensor.				

3.6.3 Gas components

Concentrations of the gases were scaled based on the measured flow rate of the exhaust system and were presented in standard volume flow rate of gas ventilated in Figures 15 to 19.

Figure 15. Hydrocarbon species



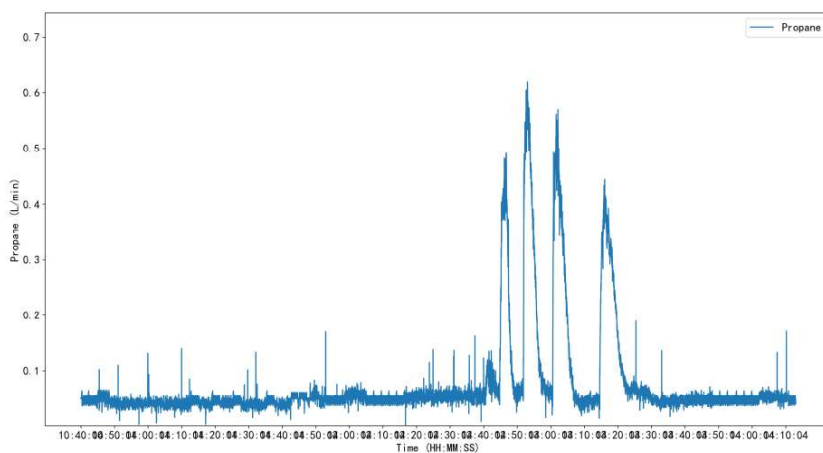
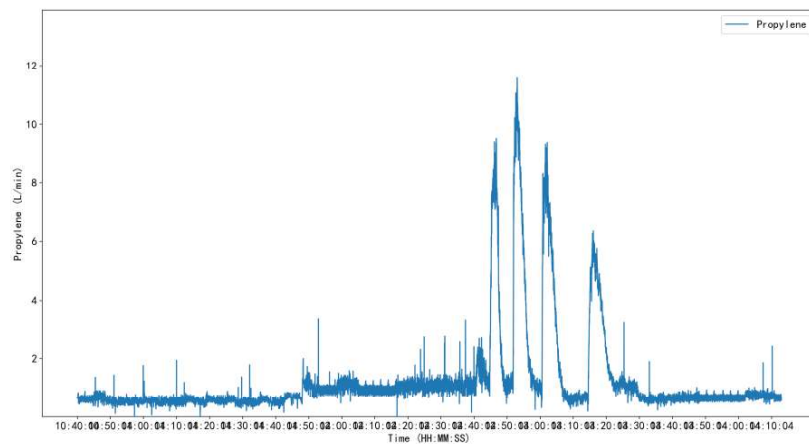
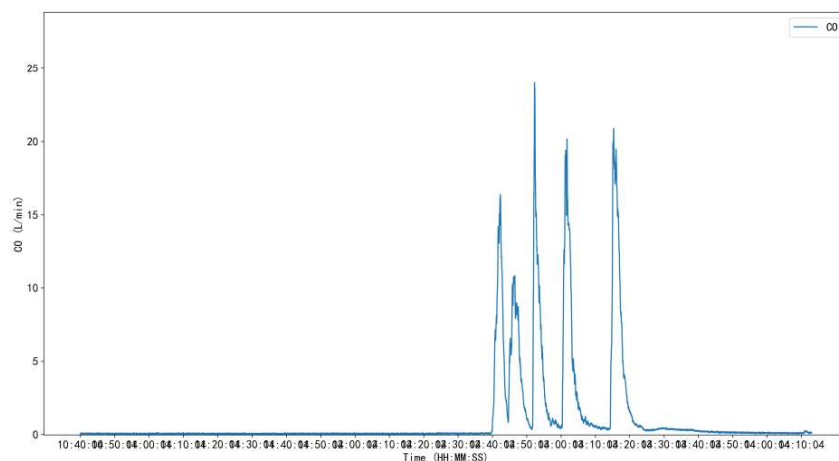


Figure 16. CO, CO₂ concentration



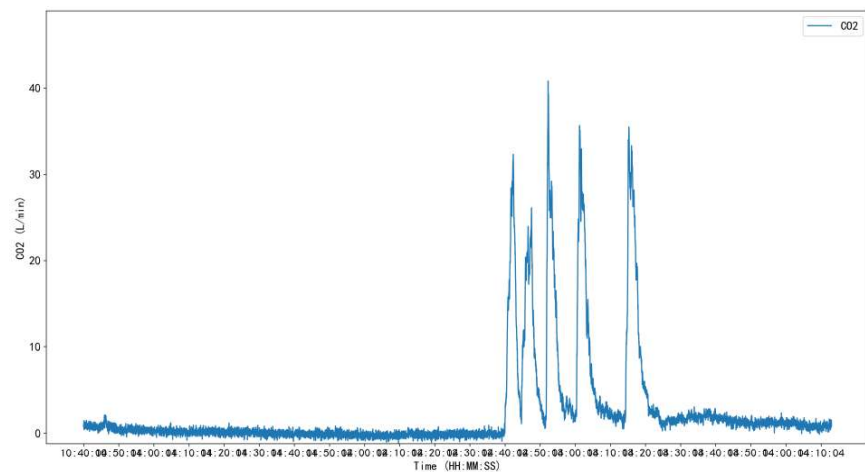
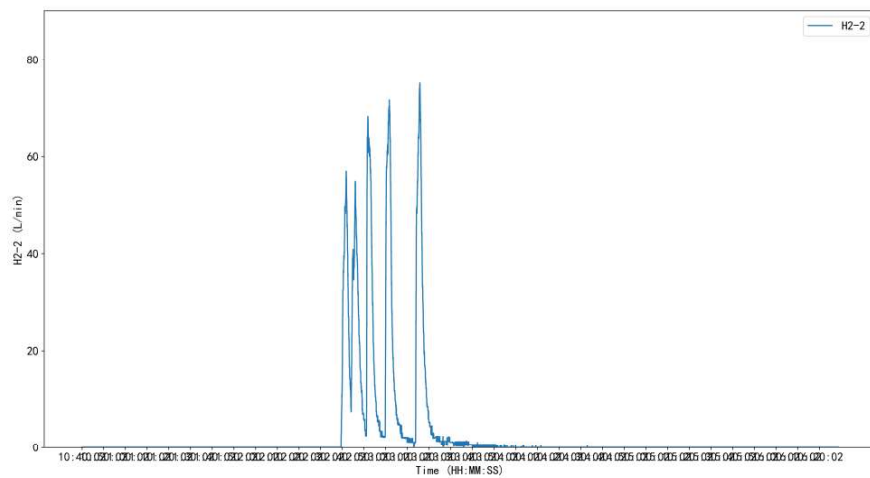
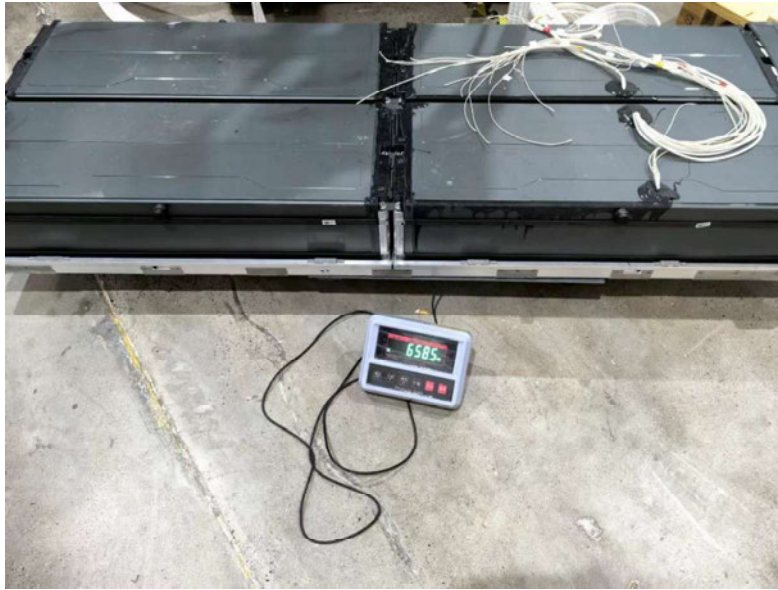


Figure 17. Hydrogen concentration



3.7 Photos

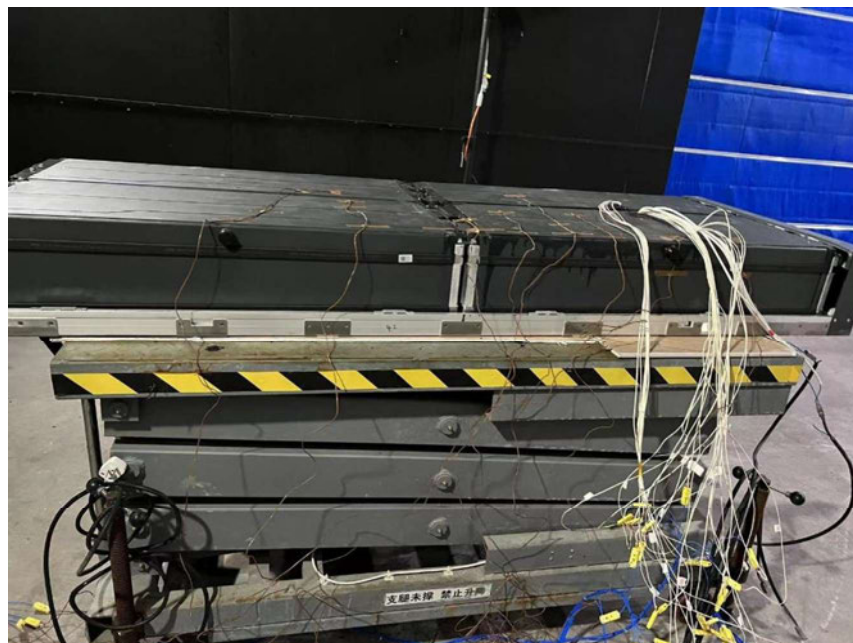
Sample before test



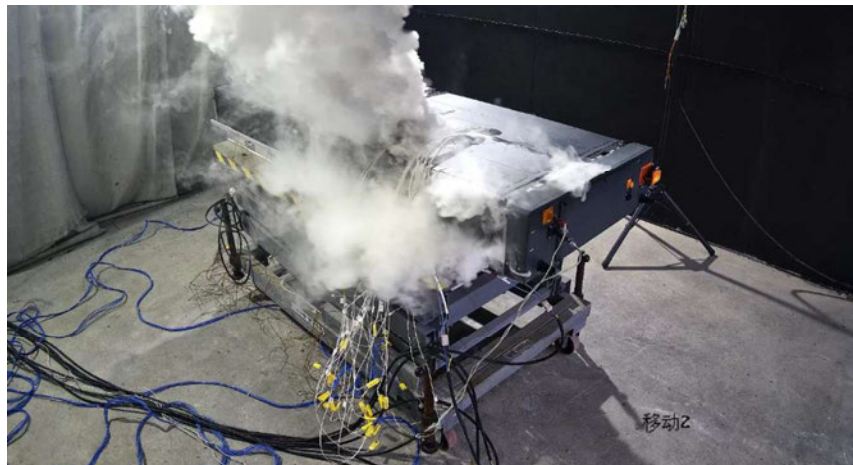
"Highly Confidential, Limited Use for Entity: [REDACTED]"

Customer Contact: [REDACTED] Date: 12 Jan 2024"

Test setup



Smoke release during test

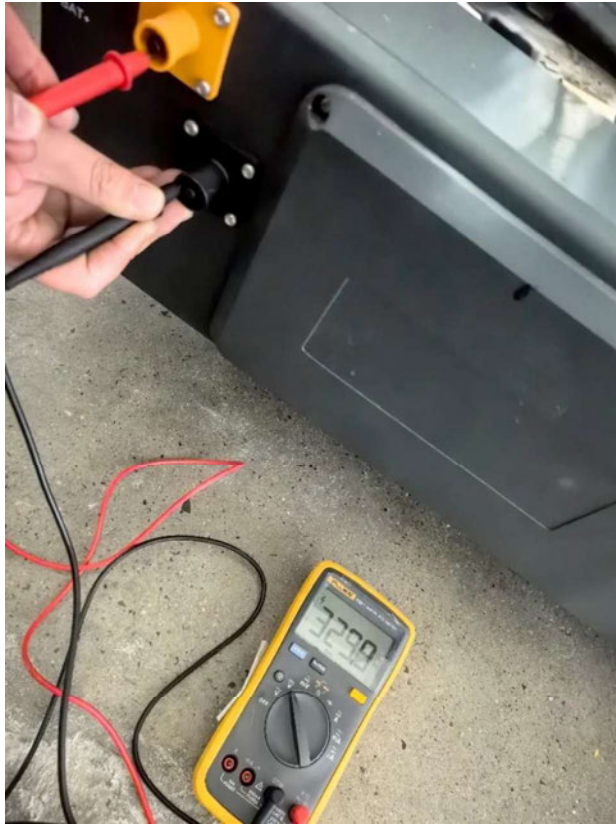


Sample after test



"Highly Confidential, Limited Use for Entity: [REDACTED]"

Customer Contact: [REDACTED] > Date: 12 Jan 2024"





4. List of Test and Measurement Instruments

No.	Equipment	Model	Rating	Inventory no.	Cal. Expire date
1	Ambient temperature and humidity	HWP01-10S	-30°C~50°C, 20%RH~100%RH	12005577	2024.2.2
2	Data acquisition equipment	DAQ970A	3-slot cardcage with 6½ digit (22 bit) internal DMM 0.004%, accuracy 0.06% Vac	TY2020000 138	2024.2.2
3	Electronic scale	CHAOOU C1	0-500KG	6596049416 9	2024.2.2
4	Paramagnetic oxygen analyser	SERVOME X4100	O2: paramagnetic sensor, range 0-25%, accuracy 0.02%, response time T90 < 7S	ZY2020000 018-1	2024.2.6
5	Velocity probe	2671-25L-D-11-G2-E-N	4-20mA output, range 0-250pa, accuracy ± 1% F.S	ZY2020000 018-2	2024.2.6
6	Photo detector	PDA36A2	Thorlabs optical receiver, wavelength range (350-1000) nm, gain adjustable, voltage output (0-10) V, instability < 0.1%	ZY2020000 018-3	2024.2.2
7	Fourier-Transform Infrared Spectrometer	atmosFIR	Spectral scanning range: 485 - 7500cm ⁻¹ ; Spectral repeatability: < 0.1cm ⁻¹	ZY2020000 018-5	2024.3.9
8	Non-dispersive infrared carbon dioxide and carbon monoxide sensor	SERVOME X4100	CO2: infrared sensor, measuring range 0-10%, accuracy 1% F.S, response time T90 < 7S Co: infrared sensor, measuring range 0-1%, accuracy 1% F.S, response time T90 < 8s	ZY2020000 018-4	2024.2.6
9	Palladium-nickel thin-film solid state sensor	MODEL 2000	Range: 0-2000ppm, temperature less than 100 C, -90~110kPa	ZY2021000 210	2024.2.2

10	Flame ionization detector	3010	Accuracy: 2.0%	19937	2024.3.9
11	Heat flux measurement equipment	MW88-JTC08C	0 ~ ± 99999 w / m2, - 250 ~ 980 °C, accuracy 5%, response time less than 0.1s,	ZY2020000010	2024.2.2
12	Thermopile	RS-WD-HW-1	0-200 °C, 4-20mA, response speed < 0.15s	28348141942	2024.2.2

End of Test Report

Prüfbericht-Nr.: <i>Test report no.:</i>	CN23JPBV 001	Auftrags-Nr.: <i>Order no.:</i>	244559560	Seite 1 von 59 Page 1 of 59	
Kunden-Referenz-Nr.: <i>Client reference no.:</i>	2003666	Auftragsdatum: <i>Order date:</i>	2023-11-20		
Auftraggeber: <i>Client:</i>	Sungrow Power Supply Co., Ltd. No.1699 Xiyou Rd., New & High Technology Industrial Development Zone, Hefei, 230088 Anhui, P.R. China				
Prüfgegenstand: <i>Test item:</i>	Battery Rack				
Bezeichnung / Typ-Nr.: <i>Identification / Type no.:</i>	R0417BL-AHAA, R0417BL-AHDA, R0835BL-AHCA, R0417BL-AHAS, R0417BL-AHCS, R0835BL-AHAS, R0835BL-AHCS, R0417BL-AHAT, R0417BL-AHCT				
Auftrags-Inhalt: <i>Order content:</i>	Test report				
Prüfgrundlage: <i>Test specification:</i>	UL 9540A: 2019 (Fourth Edition) Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems				
Wareneingangsdatum: <i>Date of sample receipt:</i>	2023-11-28				
Prüfmuster-Nr.: <i>Test sample no.:</i>	#2023112801				
Prüfzeitraum: <i>Testing period:</i>	2023-11-29 - 2023-12-11				
Ort der Prüfung: <i>Place of testing:</i>	See clause 1.1 of main report				
Prüflaboratorium: <i>Testing laboratory:</i>	TUV Rheinland (Shanghai) Co., Ltd.				
Prüfergebnis*: <i>Test result*:</i>	See main report				
geprüft von: <i>tested by:</i>	 Minhao Hu		genehmigt von: <i>authorized by:</i>		
Datum: <i>Date:</i>	2023.12.15	Simon Wang&Minhao Hu	Ausstellungsdatum: <i>Issue date:</i>	2023.12.16	
Stellung / Position:	Project Engineer/Trainee		Stellung / Position:	Reviewer	
Sonstiges / <i>Other:</i>					
Zustand des Prüfgegenstandes bei Anlieferung: <i>Condition of the test item at delivery:</i>	Prüfmuster vollständig und unbeschädigt <i>Test item complete and undamaged</i>				
* 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	
Dieser Prüfbericht bezieht sich nur auf das o.g. Prüfmuster und darf ohne Genehmigung der Prüfstelle nicht auszugsweise vervielfältigt werden. Dieser Bericht berechtigt nicht zur Verwendung eines Prüfzeichens. <i>This test report only relates to the above mentioned test sample as. Without permission of the test center this test report is not permitted to be duplicated in extracts. This test report does not entitle to carry any test mark.</i>					

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 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.

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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 TÜV Rheinland (Shanghai) Co., Ltd. and TÜV Rheinland's partner labs that were under supervision of TÜV Rheinland's engineer.

Testing period: Nov. 29, 2023 ~ Dec. 11, 2023

All tests were under supervision of TÜV Rheinland's engineer.

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 Summary of the test

Two external heater were placed in the module to initiating thermal. The initiating cells were heated at a rate of 4°C~7°C per minute until the cell thermal runaway.

White smoke was observed during test.

Cell thermal runaway was observed.

Cell to cell thermal runaway propagation was observed.

No module-to-module thermal runaway propagation.

No flying debris or explosive discharge of gases during the test.

No electrical arcs, or other electrical events during test.

No external flaming was observed.

The battery module weight measured was 662.6 kg (before test) and 654.5 kg (after test).

Measured peak chemical heat release rate HRR_t was 82.04 kW

Measured peak smoke release rate SRR was 2.63 m²/s

Total smoke release TSR was 943.42 m²

Total hydrocarbons was 989.9 L (equivalent to CH₄, measured by FID)

Detail information see relevant clause of this report.

1.5 List of attachments

Video records of the test from 3 direction were provided in .mp4 format. Complete records were provided in following document, file number listed as below:

202301129 Sungrow Unit UL9540A video ch01 (01-02).mp4

202301129 Sungrow Unit UL9540A video ch02 (01-02).mp4

202301129 Sungrow Unit UL9540A video ch03 (01-02).mp4

1.6 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 (Section 9).

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

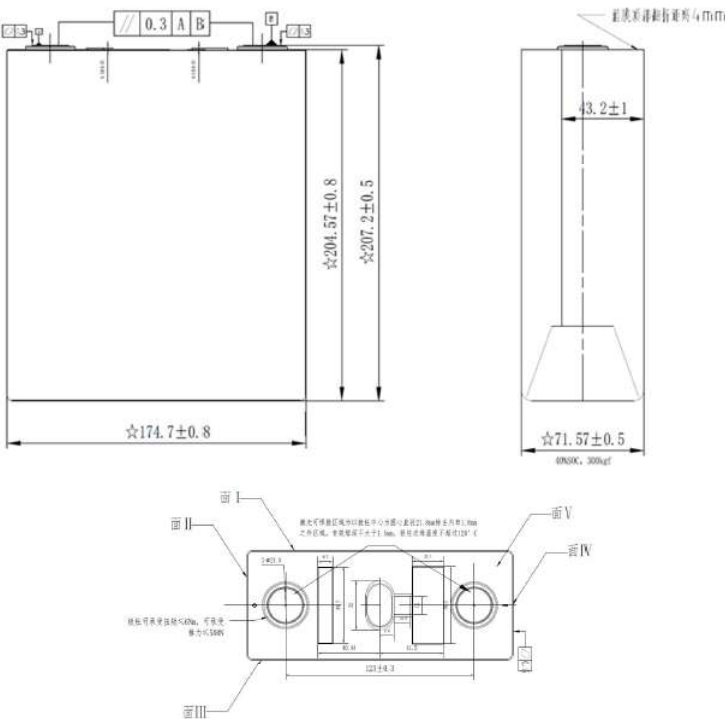
2.1 Cell

2.1.1 Product information and parameters

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

Manufacturer	CALB Group Co., Ltd.	
Model number.....	L173F314	
Chemistry	LiFePO4	
Physical configuration.....	Prismatic	
	Weight:	5.56±0.15 kg
Electrical rating	Rated capacity:	314 Ah
	Nominal voltage:	3.2 V
Standard charge method	Charge current:	157 A
	End of charge voltage:	3.65 V
Standard discharge method.....	Discharge current:	314 A
	End of discharge voltage:	2.5 V

Diagram with overall dimension



2.1.2 Cell level test information

Cell level thermal runaway test information is from UL cell level test report 4789764715 provided by the client.

Thermal Runaway Methodology	Two pieces 185 mm by 160 mm heater for each sample
Cell Surface Temperature at Gas Venting ..	140.5°C
Cell Surface Temperature at Thermal Runaway.....	210.6°C

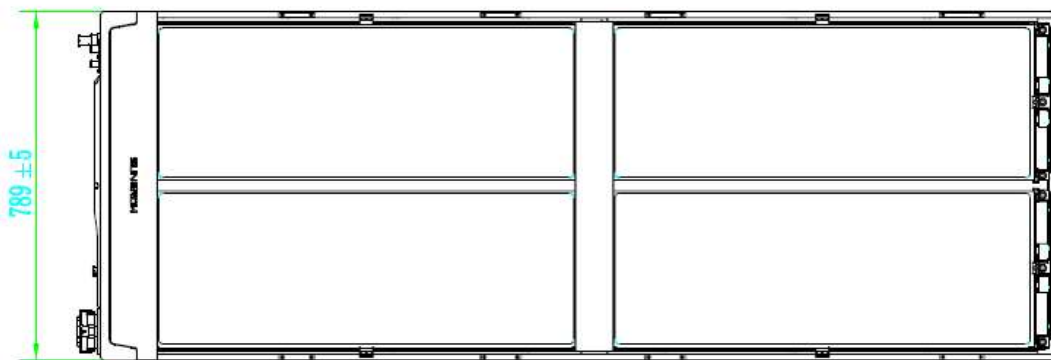
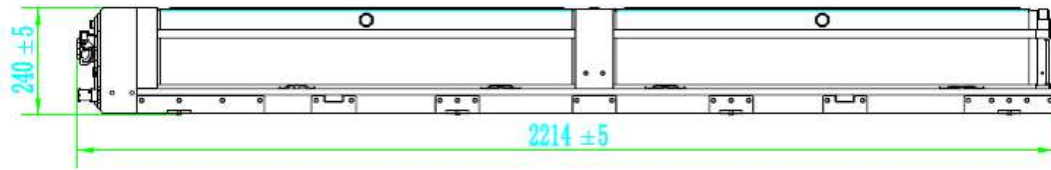
2.2 Module

2.2.1 Product information and parameters

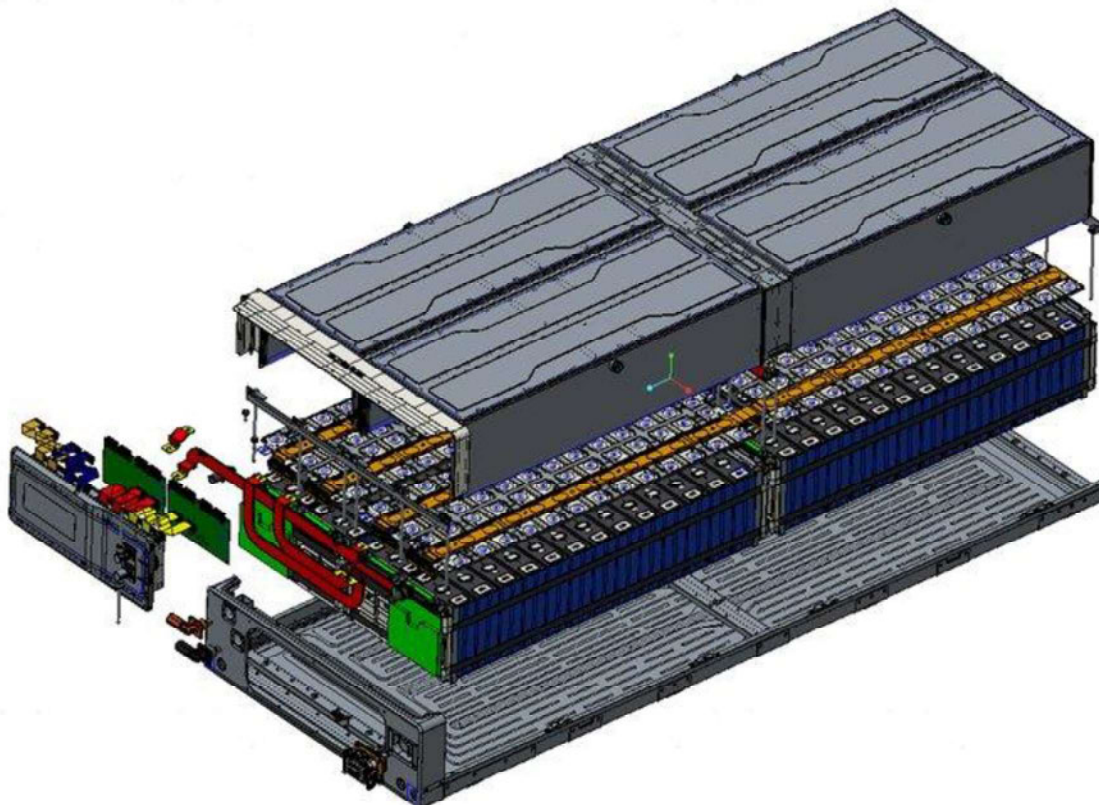
The product information and parameters are provided by the client as below.

Manufacturer name.....		Sungrow Power Supply Co., Ltd.
Model number.....		P1044AL-AHA
Physical configuration.....		Metal enclosure with plastic cover
		Weight: 660±9 kg
		Cells in series/parallel: 104S
Cooling method.....		Liquid cooling
Separation between cells.....		N/A
Electrical rating		Rated capacity: 314 Ah
		Nominal voltage: 332.8 V
Standard charge method.....	Charge current:	157 A
	End of charge voltage:	379.6 V
Standard discharge method.....	Discharge current:	157 A
	End of discharge voltage:	280.8 V
Compliance with UL 1973		Yes. Report No. : CN232YU5 001 Certificate No. : CU 72303382 0001

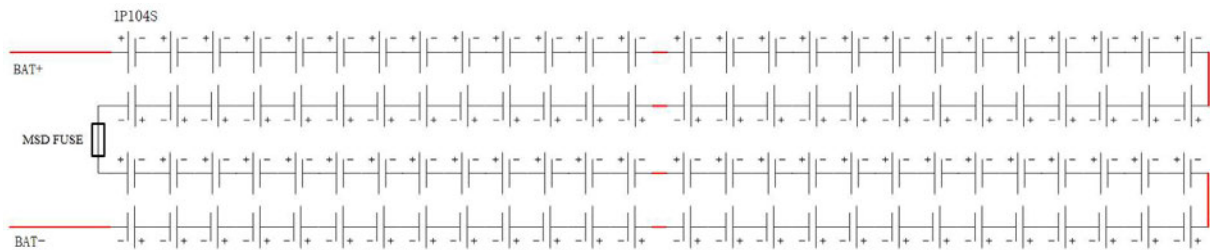
2.2.2 Diagram with overall dimension



2.2.3 Layout of the module contents



2.2.4 Configuration diagram of the module



2.3 Battery system (rack)

2.3.1 Manufacture information and model list

	Battery system	Battery system	Battery system
Product	LFP Lithium Ion Energy Storage System	LFP Lithium Ion Energy Storage System	LFP Lithium Ion Energy Storage System
Type/model	R0417BL-AHAA	R0417BL-AHDA	R0835BL-AHCA
Cell Capacity [Ah]	314	314	628
Cell Quantity	416	416	832
Battery structure	(104S)4S	(104S)4S	((104S)4S)2P
Nominal voltage [V]	1331.2V	1331.2V	1331.2V
Rated capacity [Wh]	417996.8	417996.8	835993.6
Upper limit charging voltage [V]	1497.6	1497.6	1497.6
Recommend charging current [A]	157	104.7	157
Maximum charging current [A]*	186.1	124.1	186.1
Maximum charging power	208.9kW	139.3kW	208.9kW
Recommend discharging current [A]	157	104.7	157
Maximum discharging current [A]	186.1	124.1	186.1
Maximum discharging power	208.9kW	139.3kW	208.9kW
Discharge cut-off voltage [V]	1123.2	1123.2	1123.2
Temperature range for charging [°C]	0 to 50	0 to 50	0 to 50
Temperature range for discharging [°C]	-30 to 50	-30 to 50	-30 to 50
Temperature threshold for protection	55	55	55
Overcharge protected voltage supply by battery system	≥3.75V /Cell	≥3.75V /Cell	≥3.75V /Cell
Recommend charging method by manufacturer	Charge at constant power 208.9kW until the voltage reaches 1497.6V or any one cell reaches 3.65V	Charge at constant power 138.3kW until the voltage reaches 1497.6V or any one cell reaches 3.65V	Charge at constant power 208.9kW until the voltage reaches 1497.6V or any one cell reaches 3.65V
Dimension [mm]	Rack: 790*2214*1000mm (W*D*H) PCS : 790*875* 230mm (W*D*H)	Rack: 790*2214*1000mm (W*D*H) PCS : 790*875* 230mm (W*D*H)	Rack: 790*2214*2000mm (W*D*H) PCS : 790*875* 230mm (W*D*H)

Weight [kg]	Rack: 2640±36kg PCS : 85±5kg	Rack: 2640±36kg PCS : 85±5kg	Rack: 5280±72kg PCS : 85±5kg
Ingress Protection (IP)	IP65	IP65	IP65
Protective Class	I	I	I
Cooling type	Liquid cooling	Liquid cooling	Liquid cooling
Altitude	4000m	4000m	4000m

	Battery system	Battery system	Battery system
Product	LFP Lithium Ion Energy Storage System	LFP Lithium Ion Energy Storage System	LFP Lithium Ion Energy Storage System
Type/model	R0417BL-AHAS	R0417BL-AHCS	R0835BL-AHAS
Cell Capacity [Ah]	314	314	628
Cell Quantity	416	416	832
Battery structure	(104S)4S	(104S)4S	((104S)4S)2P
Nominal voltage [V]	1331.2V	1331.2V	1331.2V
Rated capacity [Wh]	417996.8	417996.8	835993.6
Upper limit charging voltage [V]	1497.6	1497.6	1497.6
Recommend charging current [A]	157	78.5	314
Maximum charging current [A]	186.1	93.1	372.2
Recommend discharging current [A]	157	78.5	314
Maximum discharging current [A]	186.1	93.1	372.2
Discharge cut-off voltage [V]	1123.2	1123.2	1123.2
Temperature range for charging [°C]	0 to 50	0 to 50	0 to 50
Temperature range for discharging [°C]	-30 to 50	-30 to 50	-30 to 50
Temperature threshold for protection	55	55	55
Overcharge protected voltage supply by battery system	≥3.75V /Cell	≥3.75V /Cell	≥3.75V /Cell
Recommend charging method by manufacturer	Charge at constant power 208.9kW until the voltage reaches 1497.6V or any one cell reaches 3.65V	Charge at constant power 104.4kW until the voltage reaches 1497.6V or any one cell reaches 3.65V	Charge at constant power 417.9kW until the voltage reaches 1497.6V or any one cell reaches 3.65V
Dimension [mm]	Rack: 790*2214*1000mm (W*D*H) S/G : 790*1097.5*240mm	Rack: 790*2214*1000mm (W*D*H) S/G : 790*1097.5*240mm	Rack: 790*2214*2000mm (W*D*H) S/G : 790*1097.5*240mm

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Customer Contact: [REDACTED] Date: 12 Jan 2024"

	(W*D*H)	(W*D*H)	(W*D*H)
Weight [kg]	Rack: 2640±36kg S/G : 70±10kg	Rack: 2640±36kg S/G : 70±10kg	Rack: 5280±72kg S/G : 70±10kg
Ingress Protection (IP)	IP65	IP65	IP65
Protective Class	I	I	I
Cooling type	Liquid cooling	Liquid cooling	Liquid cooling
Altitude	5000m	5000m	5000m

	Battery system	Battery system	Battery system
Product	LFP Lithium Ion Energy Storage System	LFP Lithium Ion Energy Storage System	LFP Lithium Ion Energy Storage System
Type/model	R0835BL-AHCS	R0417BL-AHAT	R0417BL-AHCT
Cell Capacity [Ah]	628	314	314
Cell Quantity	832	416	416
Battery structure	((104S)4S)2P	(104S)4S	(104S)4S
Nominal voltage [V]	1331.2V	1331.2V	1331.2V
Rated capacity [Wh]	835993.6	417996.8	417996.8
Upper limit charging voltage [V]	1497.6	1497.6	1497.6
Recommend charging current [A]	157	157	78.5
Maximum charging current [A]	186.1	186.1	93.1
Recommend discharging current [A]	157	157	78.5
Maximum discharging current [A]	186.1	186.1	93.1
Discharge cut-off voltage [V]	1123.2	1123.2	1123.2
Temperature range for charging [°C]	0 to 50	0 to 50	0 to 50
Temperature range for discharging [°C]	-30 to 50	-30 to 50	-30 to 50
Temperature threshold for protection	55	55	55
Overcharge protected voltage supply by battery system	≥3.75V /Cell	≥3.75V /Cell	≥3.75V /Cell
Recommend charging method by manufacturer	Charge at constant power 208.9kW until the voltage reaches 1497.6V or any one cell reaches 3.65V	Charge at constant power 208.9kW until the voltage reaches 1497.6V or any one cell reaches 3.65V	Charge at constant power 104.4kW until the voltage reaches 1497.6V or any one cell reaches 3.65V
Dimension [mm]	Rack: 790*2214*2000mm (W*D*H) S/G : 790*1097.5*240mm	Rack: 790*2214*1000mm (W*D*H) S/G : 790*1097.5*240mm	Rack: 790*2214*1000mm (W*D*H) S/G : 790*1097.5*240mm

	(W*D*H)	(W*D*H)	(W*D*H)
Weight [kg]	Rack: 5280±72kg S/G : 70±10kg	Rack: 2640±36kg S/G : 75±10kg	Rack: 2640±36kg S/G : 75±10kg
Ingress Protection (IP)	IP65	IP65	IP65
Protective Class	I	I	I
Cooling type	Liquid cooling	Liquid cooling	Liquid cooling
Altitude	5000m	5000m	5000m

2.3.2 Product information

This product is used for Energy Storage System.

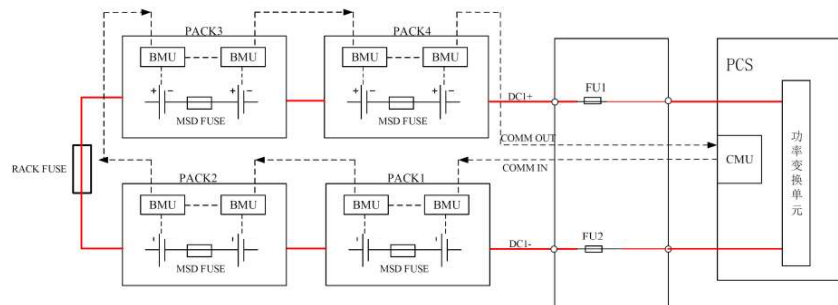
The EUTs described in this report are three models of LFP lithium ion battery energy storage systems which include one master control (or one control box) and several battery packs in series (parallel) connection. The master control function integrated in fuse box and PCS, the BMS master control board placed in PCS. The number of battery pack is 4 for model R0417BL-AHAA and R0417BL-AHDA, the difference between them is that the battery maximum power and current are different. The number of battery pack is 8 for model R0835BL-AHCA.

The battery pack contain 104 cells in structure 104S. And it contains one BMU board for measuring and collecting the cell parameters and uploading the information of cell voltage and temperature to CMU in PCS.

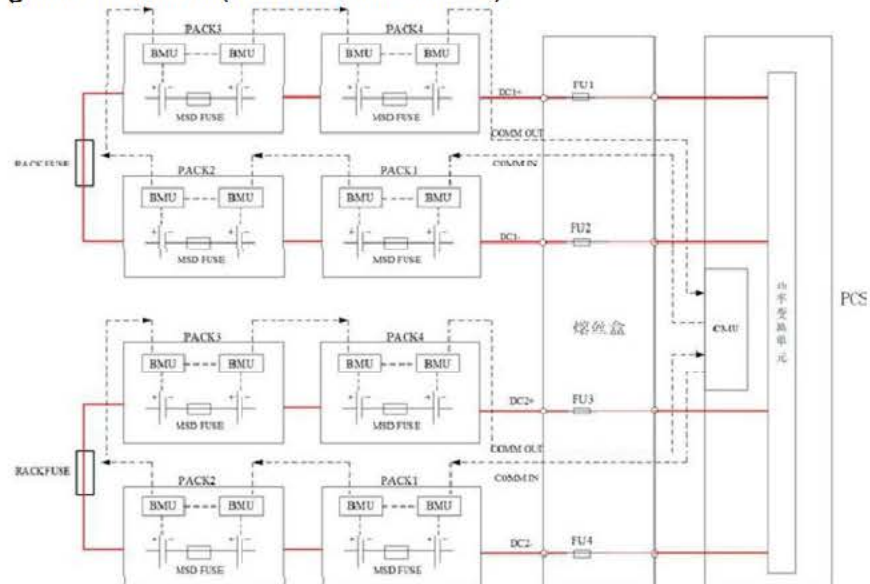
The EUTs are indoor type. The insulation between the DC circuit and the metal enclosure is basic insulation. And the insulation between the DC circuit and communication ports is reinforced insulation or double insulation. OVC II considered for the battery rack, it shall be isolated from an OVC III supply source (such as from an OVC III PCS) through an isolated transformer or protected in a manner that prevents transient overvoltage conditions in end use.

The PCS is certified individually. The BMS master control board is placed in PCS. The BMS functional safety was evaluated according to UL 60730-1 Annex H by TÜV Rheinland.

Block diagram as below (for R0417BL-AHAA and R0417BL-AHDA):
one fuse box shared by two racks:

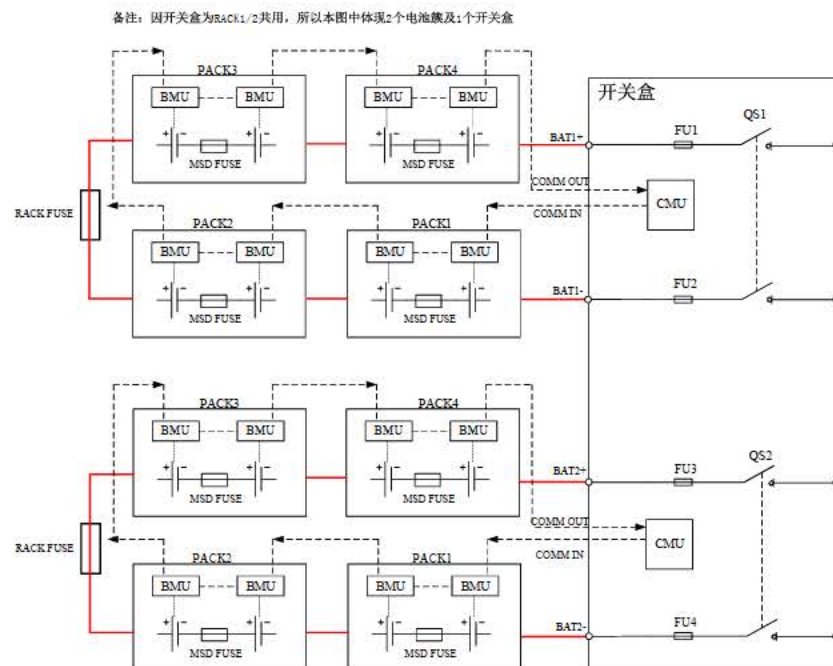


Block diagram as below (for R0835BL-AHCA):

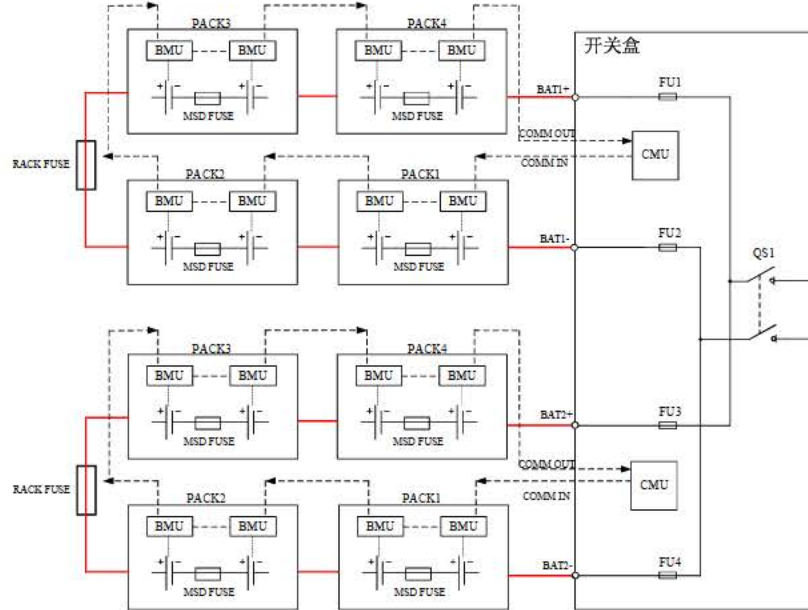


For models R0417BL-AHAS, R0417BL-AHCS, R0835BL-AHAS, R0835BL-AHCS, R0417BL-AHAT, R0417BL-AHCT, the EUTs described in this report are three models of LFP lithium ion battery energy storage systems which include one control box and several battery packs in series (parallel) connection.

Block diagram as below:



备注：因开关盒为RACK1/2共用，所以本图中体现2个电池簇及1个开关盒



Diagram



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Customer Contact: [REDACTED] > Date: 12 Jan 2024"

2.4 Photo

Module



Battery Rack



"Highly Confidential, Limited Use for Entity: [REDACTED]"

Customer Contact: [REDACTED] Date: 12 Jan 2024"

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

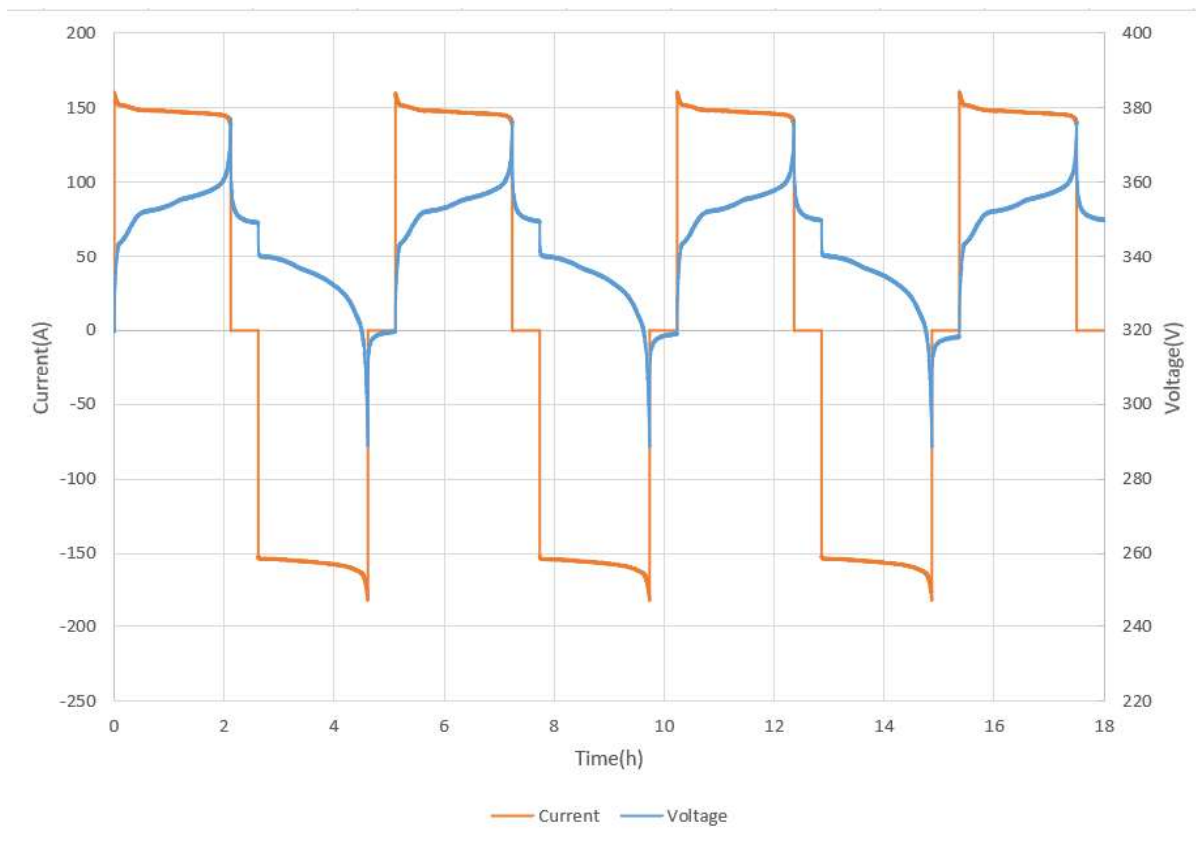
The battery system is constructed with open rack without enclosure. Eight rows and one column of the module and one switch gear were considered as a unit for purposes of the test.

Module sample was conditioned, prior to testing, through charge and discharge cycles of 3 cycles to verify that the module was functional.

Each cycle was defined as a charge to 100% SOC and allowed to rest several minutes and then discharged to an end of discharge voltage (EODV) determined by the manufacturer. Refer to 2.1 for charge and discharge profile.

The module sample was put in a climate chamber during charge and discharge. The ambient is kept at $25^{\circ}\text{C} \pm 2^{\circ}\text{C}$ and $50\% \pm 5\%$ R.H.

Figure 1. Module charge and discharge voltage/current profiles



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

Three instrumented walls with 3.8 m height and 3.55 m width form a right angle. Walls were constructed of 5/8 in gypsum painted flat black.

Two racks were used for the purpose of the test. As specified the manufacture, the target racks will be installed beside the initial unit. All racks were positioned facing instrumented wall C. See Figure 2 and photos in page 41.

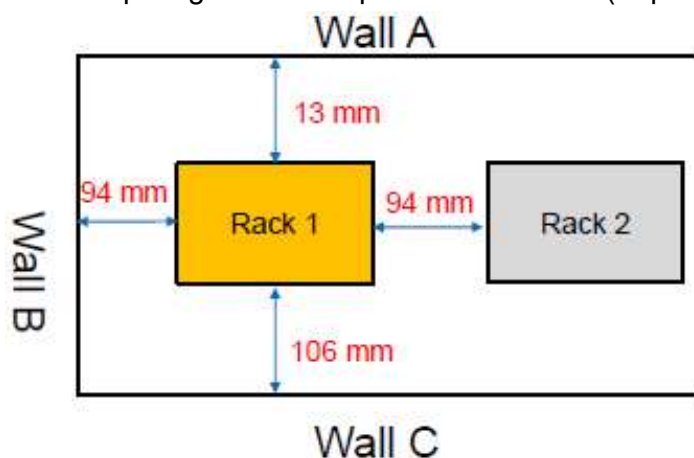
The initiating unit (unit 1) was positioned at the corner, adjacent to the two instrumented wall sections.

Minimum separation distance from the rack to wall and between racks were defined by the client. It is difficult to move the heavy rack to the position just conform to the separation distance provided by the client. There were 1 cm tolerance in actual setup.

Figure 2 was the test site setup diagram with separation distance.

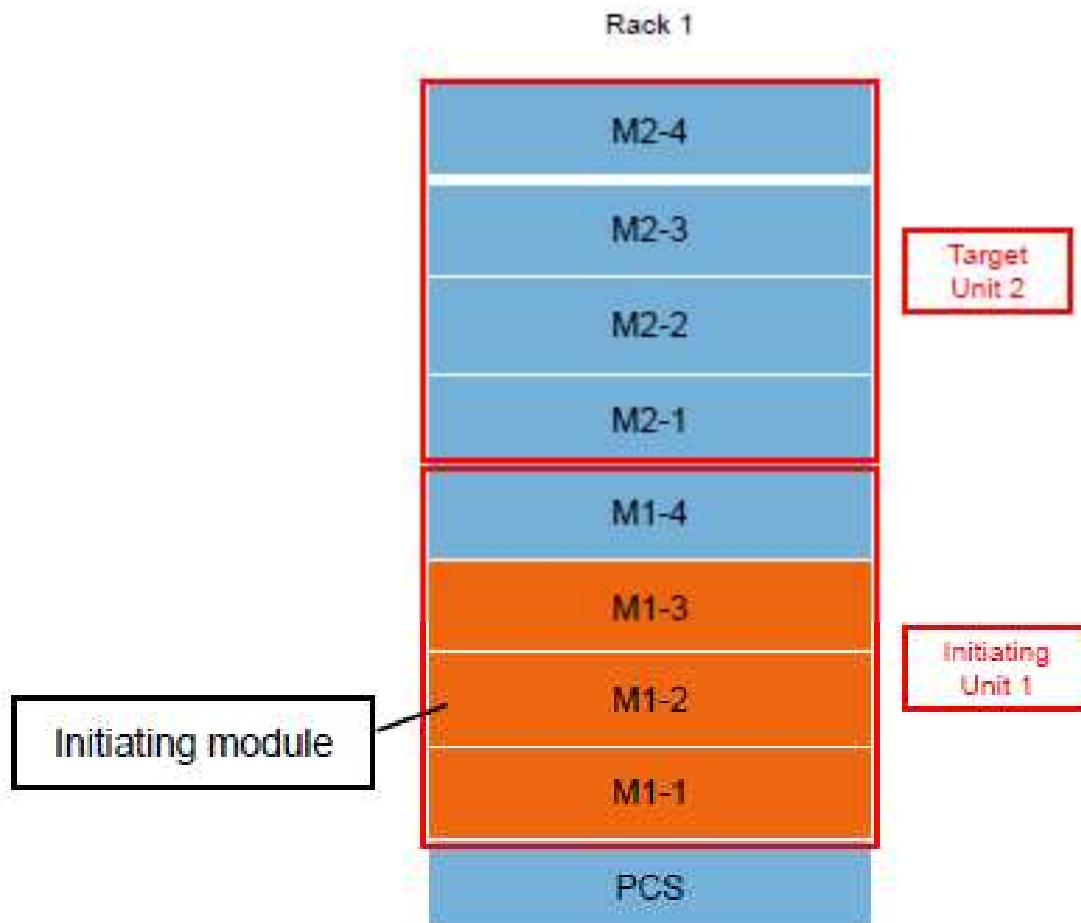
The whole setup was located under the smoke collection hood of the calorimeter measurement system.

Figure 2. Test site setup diagram with separation distance. (Top view)



For this test, the modules were numbered according to the electrical continuity.
In initial unit, modules numbers from M1 to M4.
In target units, modules numbers from M1 to M4 which was the target unit setting next to the initial module. See Figure 3.

Figure 3. Module numbering in units



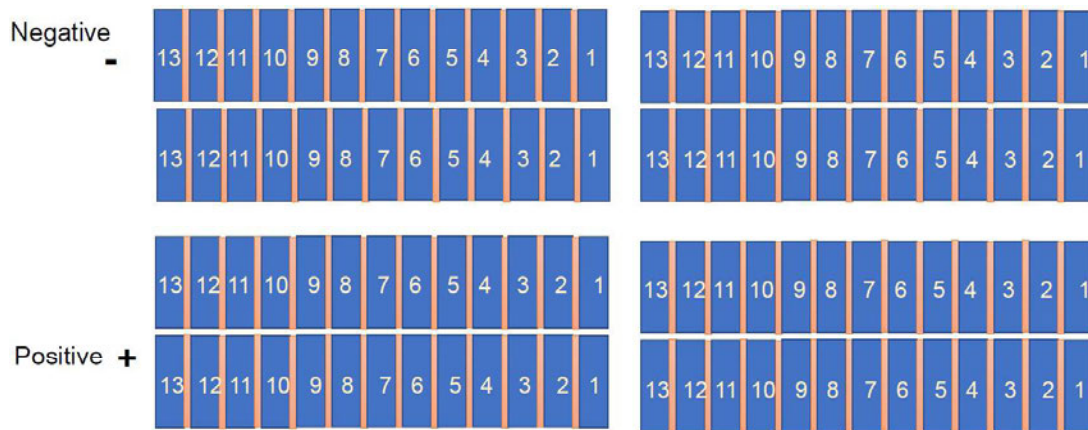
3.3.3 Thermal runaway setup

The module to be tested were 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.

The external heating method used for initiating thermal runaway in cell level test was used to initiate thermal runaway within the module.

Consider the unit level installation in the module. #2 ~ #4 cells located in the middle of the module was chose as target cell to be forced into thermal runaway.

Figure 4. Cell numbering, initiating cell selecting



The cells were heated by two external heaters rated 220VAC/800 W (size 200*165*1mm).

2 glass fiber thermocouples Type K, 24 AWG were attached on the center of two wide surface of #3 cell. (See 3.3.2 figure 3)

10 glass fiber thermocouples Type K, 24 AWG were attached on the center of each wide surface of #1 to #7 cells and 3 glass fiber thermocouples were attached on the vent of #2 to #4 cells, used for record cell temperature. (See 3.3.2 figure 4)

7 glass fiber thermocouples Type K, 24 AWG were attached on the center of each wide surface of #1 to #7 cells which were beside initiating cell #3 and another 7 glass fiber thermocouples Type K, 24 AWG were attached on the center of each narrow surface of #1 to #7 cells which were opposite initiating cell #3, used for record cell surface temperature. (See 3.3.2 figure 4)

8 glass fiber thermocouples Type K, 24 AWG were attached on the surface of module used for record module external temperature. (See 3.3.2 figure 5)

Manual control the voltage supply to the heater and maintain a 4°C/min to 7°C/min heating rate.

Once thermal runaway was observed, the heaters were immediately de-energized. Voltage of the modules are monitored during test.

The module was placed on top of a lift with the module orientation representative of its intended final installation.

The module was located under the smoke collection hood of the calorimeter measurement system.

Ambient conditions were within 25±5°C and 50±25% RH at the initiation of the test.

Figure 5. Thermocouples (no. xx) locations of initiating cell

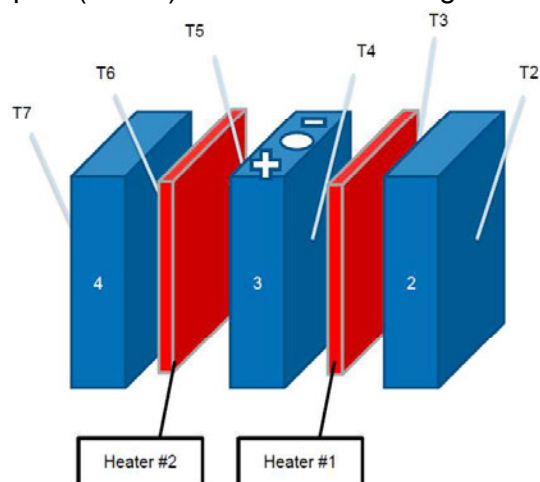


Figure 6. Thermocouples (no. xx) locations of initiating module

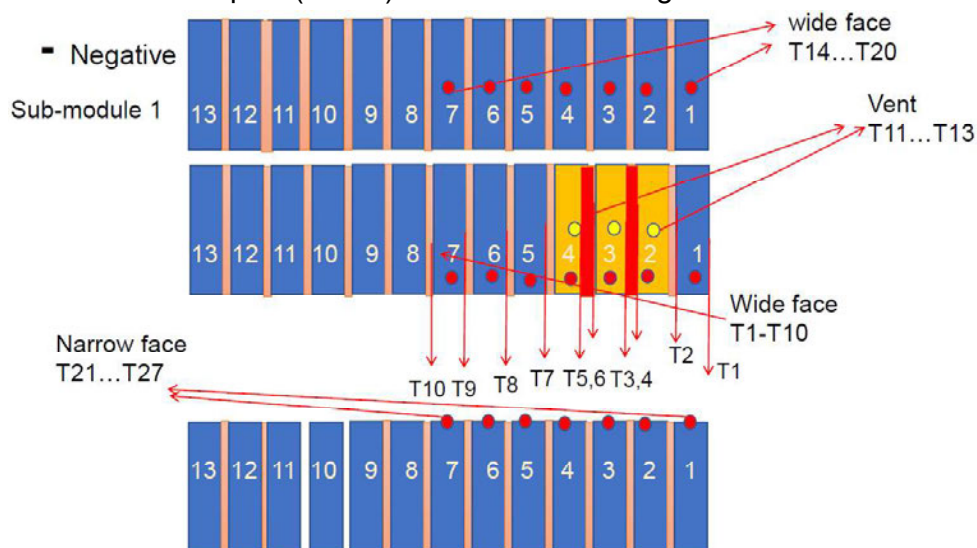
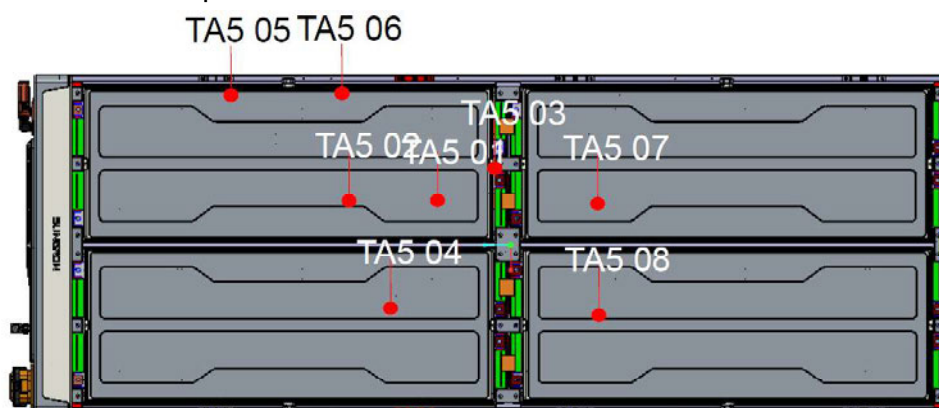


Figure 7. Thermocouple's locations outside module



3.4 Observations and records

Ambient conditions at the initiation of the test.....	21.0°C, 62.1% R.H.
Sample number	#2023112901
Open circuit voltage before test (V)	348.5
Weight before test (kg)	662.6 (with thermocouples)
Time initiating the test.....	12:48 start to heat the cells
Observations during test.....	Audible pops were heard at 14:25 (the pressure relief valve burst). Large amount of white smoke was observed on 14:41. After first thermal Runaway, Large amount of white smoke was observed on 14:46, 14:53, 14:57 and 15:42. No flying debris or explosive discharge of gases during test. No sparks, electrical arcs, or other electrical events during test. No flaming observed.
Posttest evaluation	Posttest evaluations were performed after 12 hours of test. Total 5 cells were damage after test. 3 of them were initiating cells and another two were cell-to-cell thermal propagation. Photos "sample after test" in page 54 show the damage of the module enclosure, electrolyte outside and damage of the components inside enclosure. 329.5 V was measured on the module output terminal.
Weight after test (kg)	654.5 (with thermocouples)
Weight loss (kg).....	8.1

3.5 Temperature measurements

3.5.1 Temperature measurement of initiating cells

Cell to cell propagation was observed during the test.

Cell thermal runaway occurred on #3 at around 13:56, #2 and #4 cell thermal runaway occurred at around 14:05 and 14:13. Maximum temperature 864.1°C (T6) were measured on the #2 cells wide surface. See figure 8 for the temperature vs time curve. Maximum temperature please see table 1 for detail.

Cell to cell propagation was observed on #1 and #5 in initial module during the test.

Figure 8. Temperatures of cell #2~#4

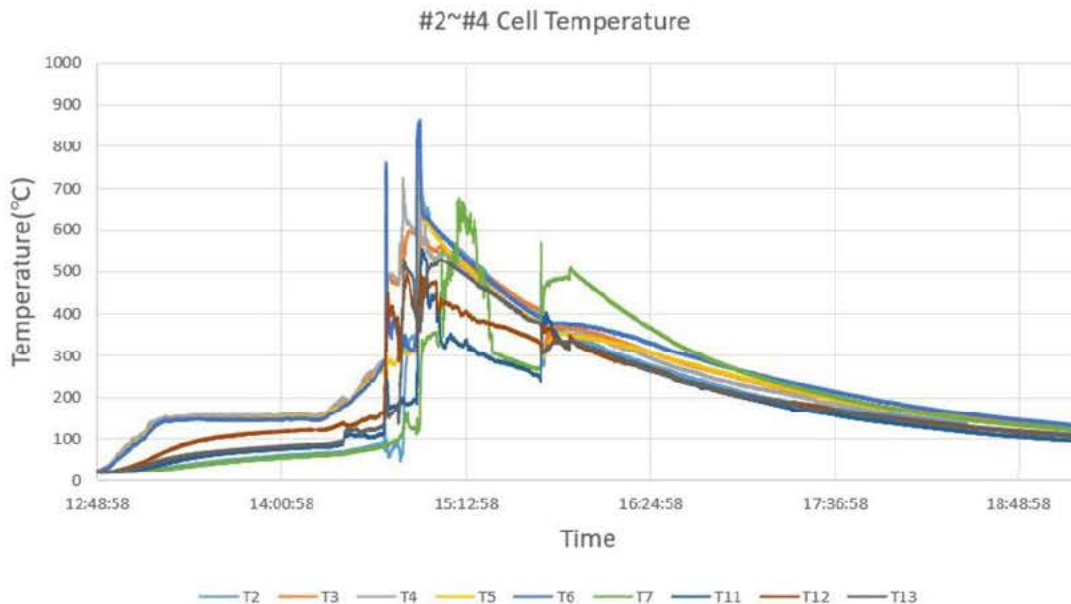


Table 1. Maximum temperature of cell #10~#11

Thermocouple no.	Location	Maximum temp.(°C)
T2	Surface of cell_2(right)	840.1
T3	Surface of cell_2(left)	742.5
T4	Surface of cell_3(right)	828.3
T5	Surface of cell_3(left)	709.2
T6	Surface of cell_4(right)	864.1
T7	Surface of cell_4(left)	676.0
T11	Vent of cell_2	555.9
T12	Vent of cell_3	493.0
T13	Vent of cell_4	530.6

Figure 9. Temperatures of cell #1 and #5~#7

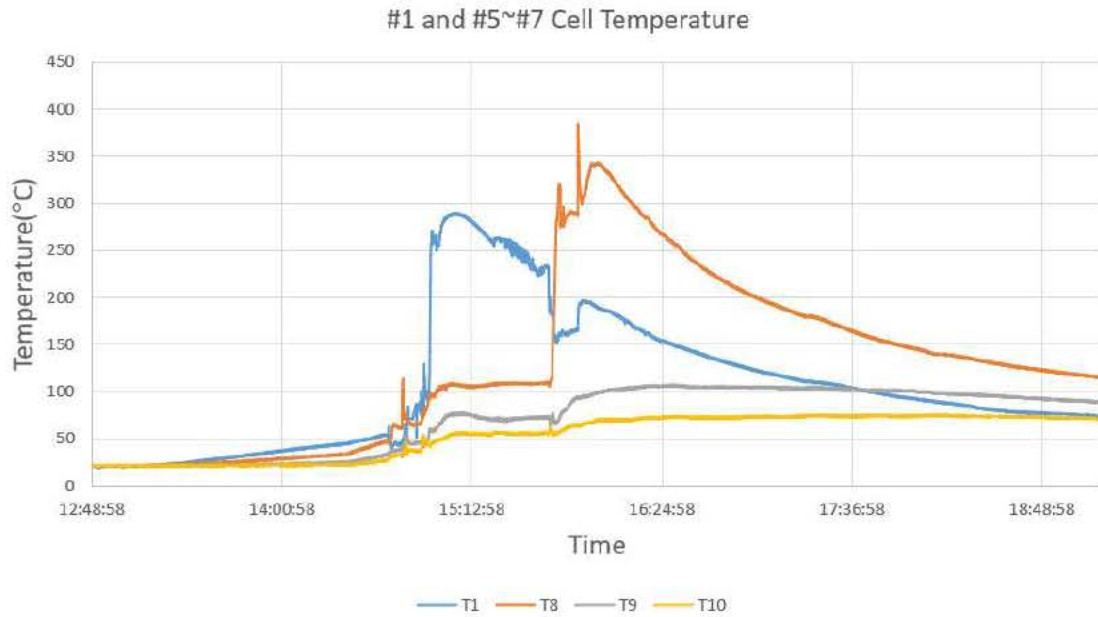


Table 2. Maximum temperature of cell #1 and #5~#7

Thermocouple no.	Location	Maximum temp.(°C)
T1	Surface of cell_1	290.1
T8	Surface of cell_5	383.4
T9	Surface of cell_6	107.1
T10	Surface of cell_7	75.3

Figure 10. Temperatures of cell #1~#7(beside initiating cell)

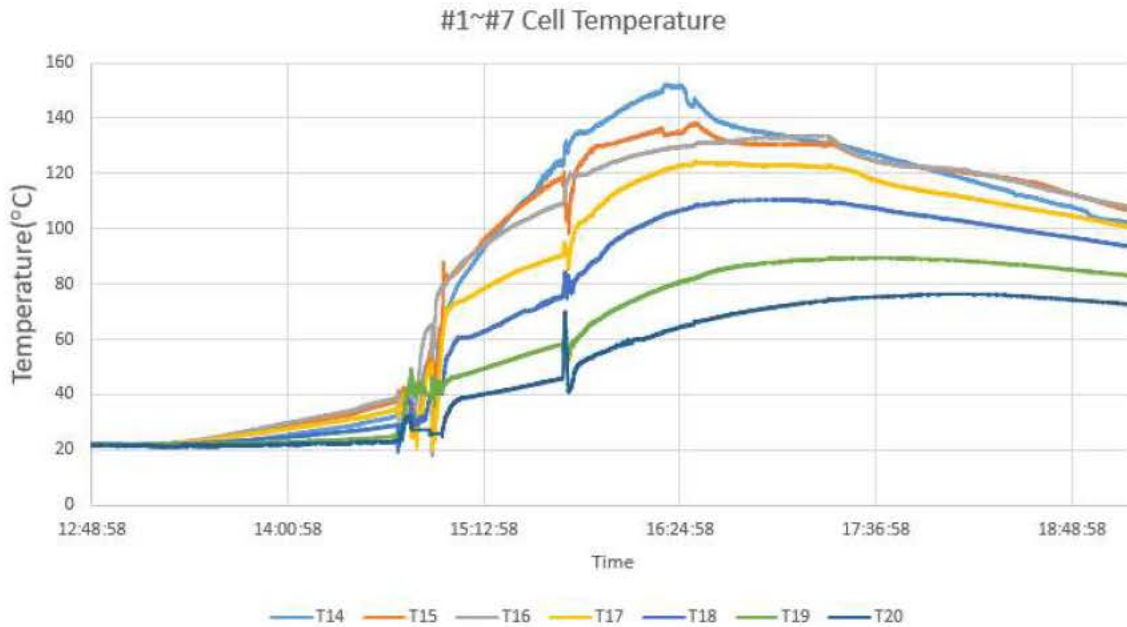


Table 3. Maximum temperature of cell #1~#7(beside initiating cell)

Thermocouple no.	Location	Maximum temp.(°C)
T14	Surface of cell_1	152.1
T15	Surface of cell_2	138.3
T16	Surface of cell_3	133.8
T17	Surface of cell_4	124.6
T18	Surface of cell_5	110.7
T19	Surface of cell_6	89.6
T20	Surface of cell_7	76.4

Figure 11. Temperatures of cell #1~#7(opposite initiating cell)

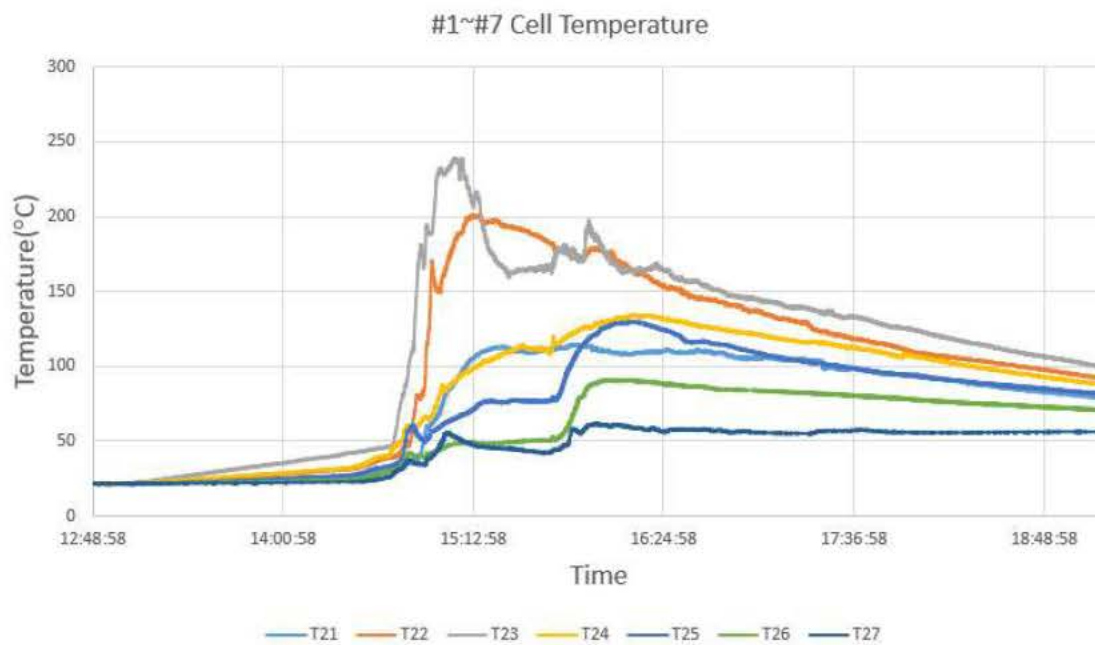


Table 4. Maximum temperature of cell #1~#7(beside initiating cell)

Thermocouple no.	Location	Maximum temp.(°C)
T21	Surface of cell_1	114.7
T22	Surface of cell_2	201.1
T23	Surface of cell_3	239.0
T24	Surface of cell_4	134.8
T25	Surface of cell_5	129.8
T26	Surface of cell_6	91.2
T27	Surface of cell_7	61.9

Figure 12. Module voltage

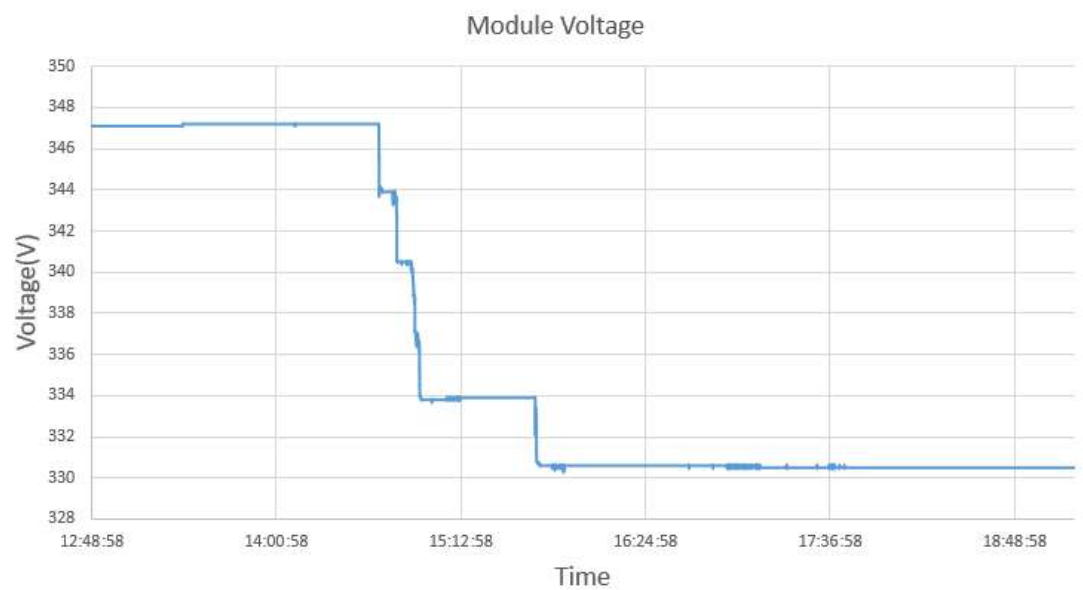
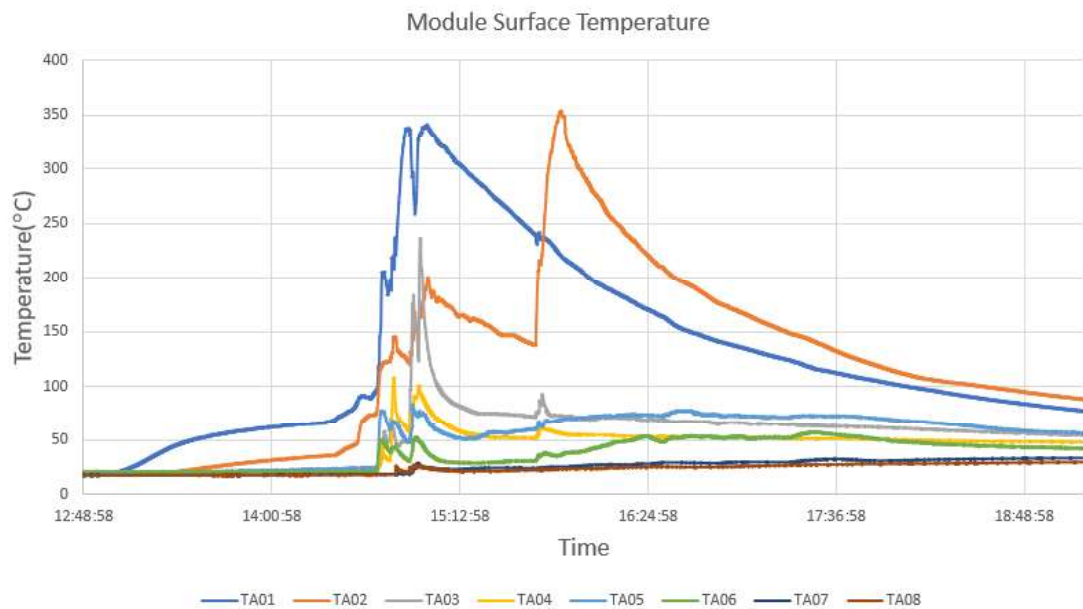


Figure 13. Temperatures of module surface



3.5.2 Temperature measurement of units

3 glass fiber insulated thermocouples, Type K, 24 AWG were attached on the center of the top, bottom, or side surface of modules M1 to M4 in initiating unit 1.

4 glass fiber insulated thermocouples, Type K, 24 AWG were attached on the center of side or front surface of modules in target unit 2.

4 glass fiber insulated thermocouples, Type K, 24 AWG were attached on the center of side or front surface of modules in each target unit 3 and 4.

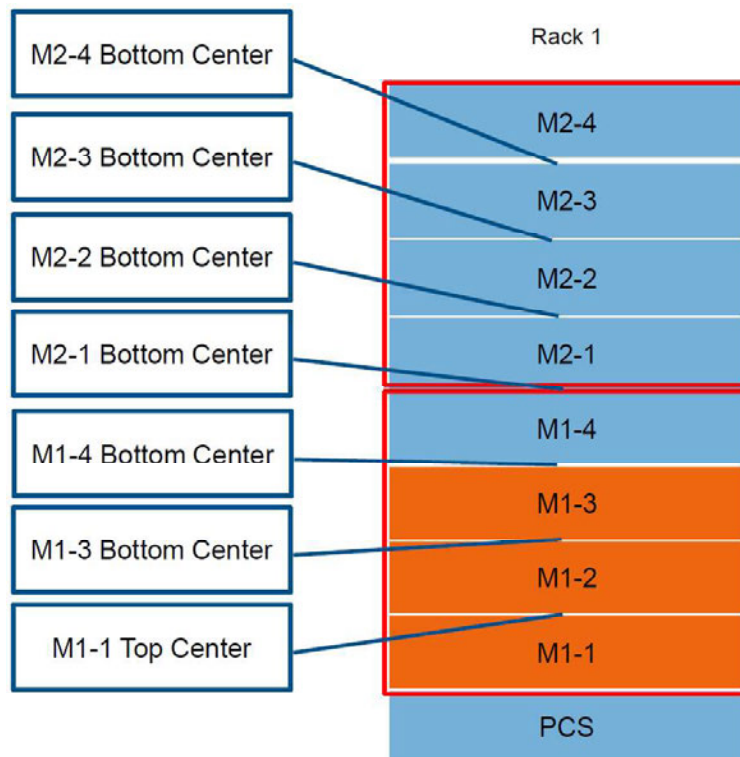
In initial unit 1, the maximum temperature 223.9°C was measured on the bottom surface of the module M1-3.

In target unit 2, the maximum temperature 35.9°C was measured on the bottom surface of the module M2-3.

In target unit 3, the maximum temperature 23.5°C was measured on the back surface of the module M3-4.

In target unit 4, the maximum temperature 29.1°C was measured on the back surface of the module M4-2.

Figure 14. Thermocouple location on modules in initiating unit 1 and target unit 2



View direction: towards instrument wall A with reference to Figure 2

Figure 15. Surface temperatures of modules in initial unit 1

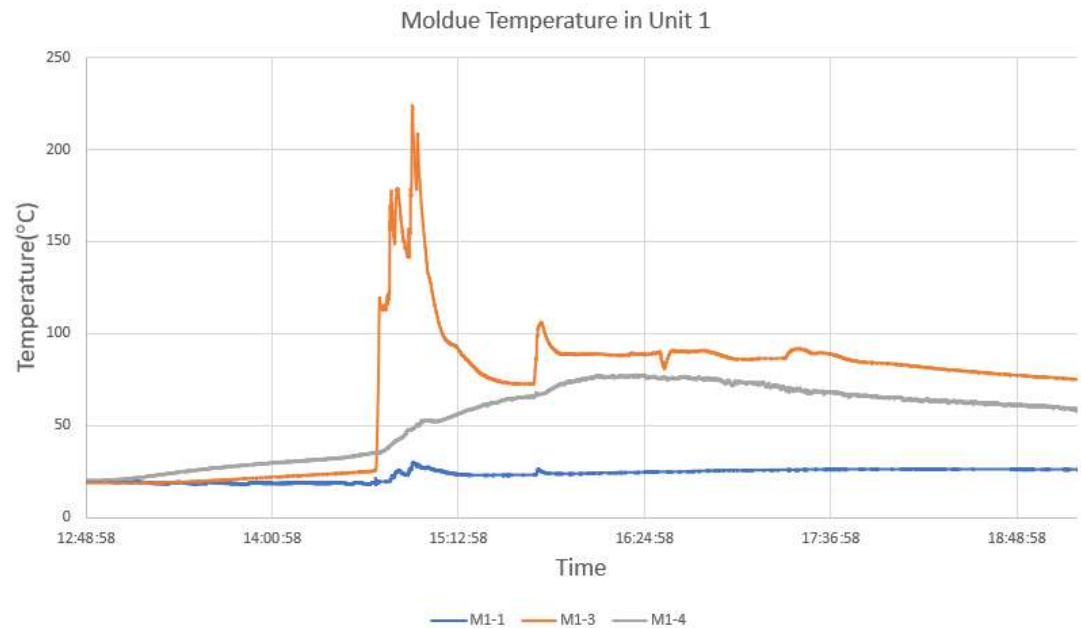


Figure 16. Surface temperatures of modules in target unit 2

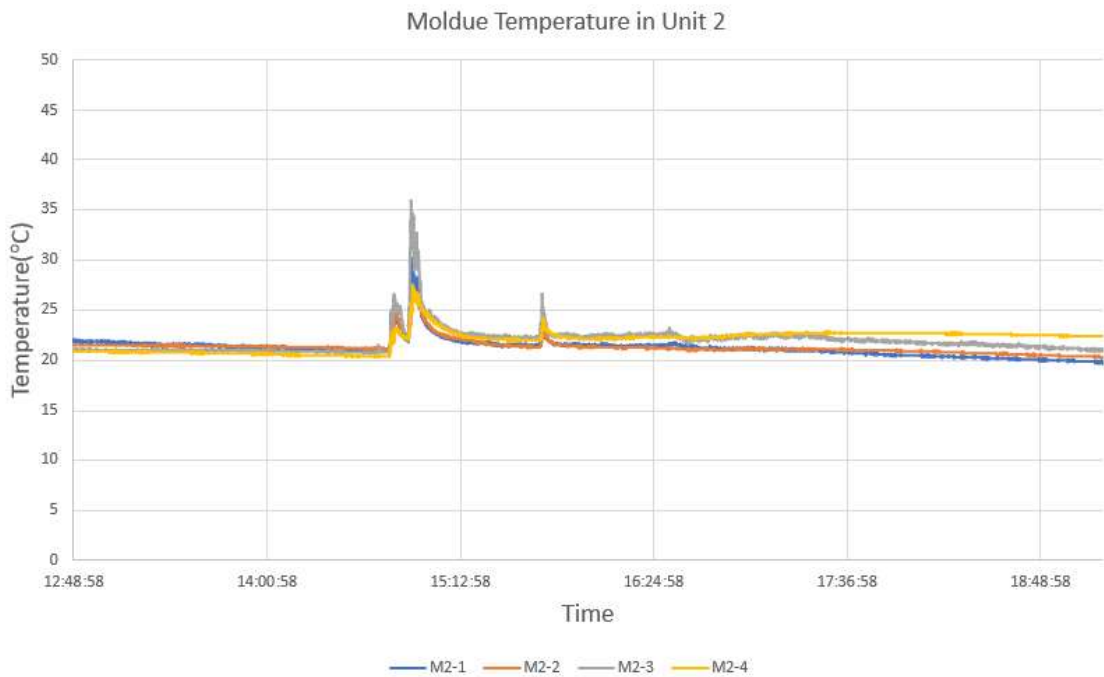
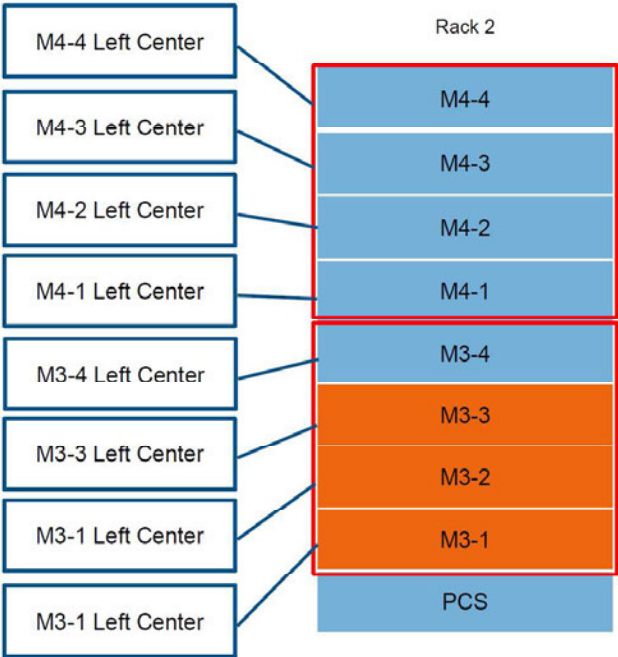


Figure 17. Thermocouple location on modules in target unit 3 and unit 4



View direction: towards instrument wall A with reference to Figure 2

Figure 18. Surface temperatures of modules in target unit 3

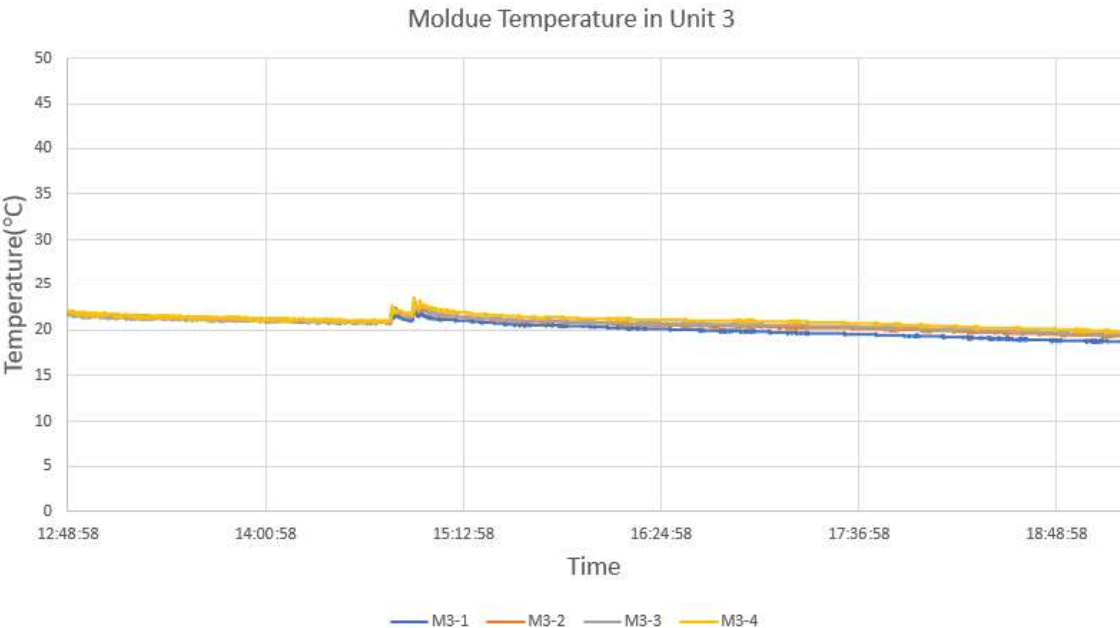
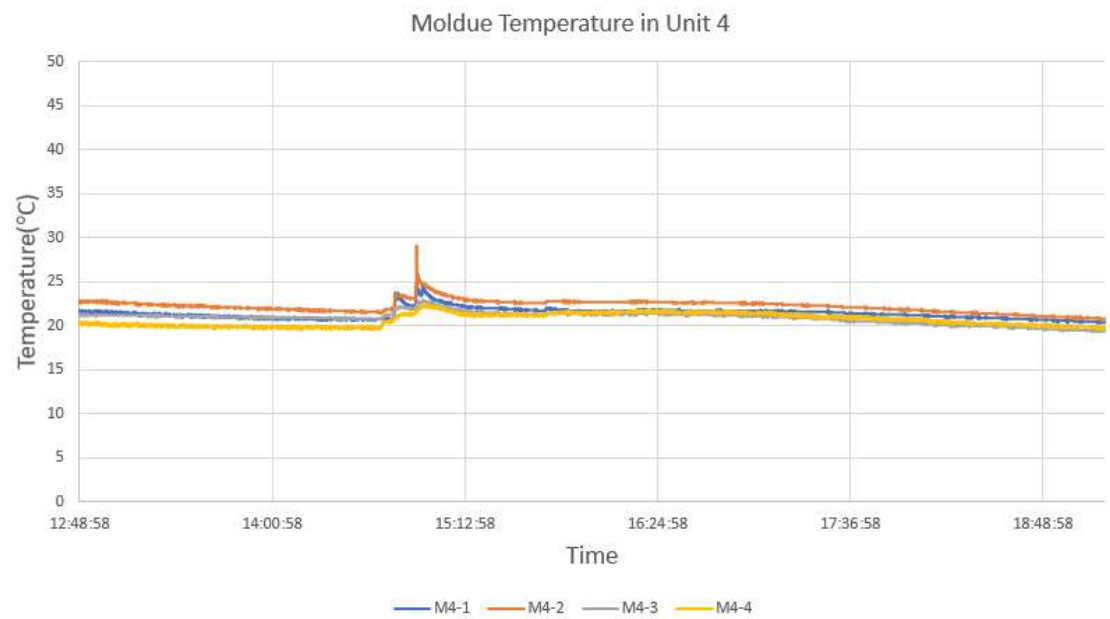


Figure 19. Surface temperatures of modules in target unit 4



3.5.3 Temperature measurement of instrumented walls

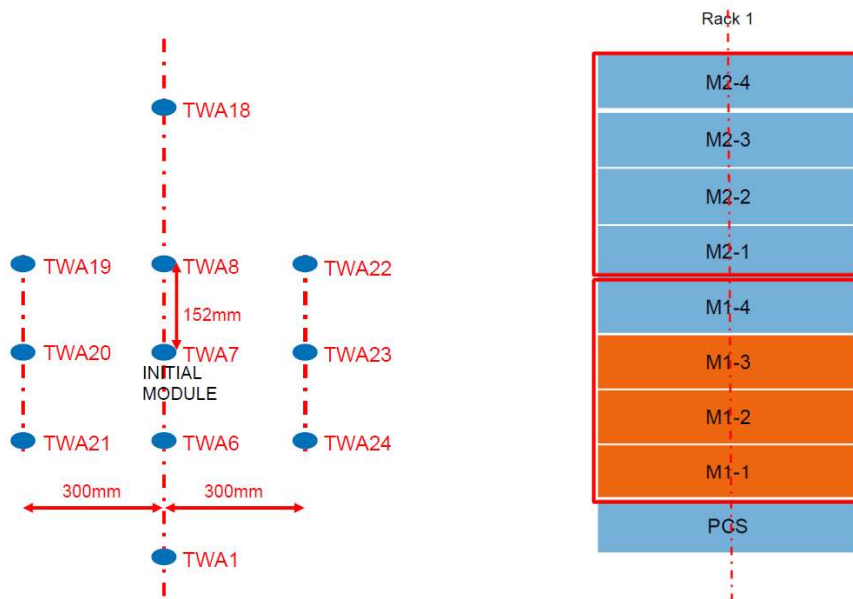
Wall surface temperatures were measured in vertical array at 152 mm intervals for the full height of the instrumented wall sections. The thermocouples array was collinear with the centre line of unit A. The red line shows the thermocouple array on the wall.

The first thermocouple starts from 152 mm from ground. Total 18 thermocouples were used for each array. The thermocouples were numbered from low to high as TWA1 to TWA18 for wall A.

Total 18 thermocouples were used for each array. The thermocouples were numbered from low to high as TWB1 to TWB18 for wall B.

Additional 6 thermocouples were positioned horizontally near the initial module M1-2 300 mm away from the vertical array each side, on instrumented wall A and wall B.

Figure 20. Vertical position of the thermocouples on the wall A



View direction: towards instrument wall A with reference to Figure 2

Maximum temperature measured on instrument wall A was 27.8°C at TWA23, temperature curve see figure 21 for detail.

Figure 21. Temperatures on instrument wall A.

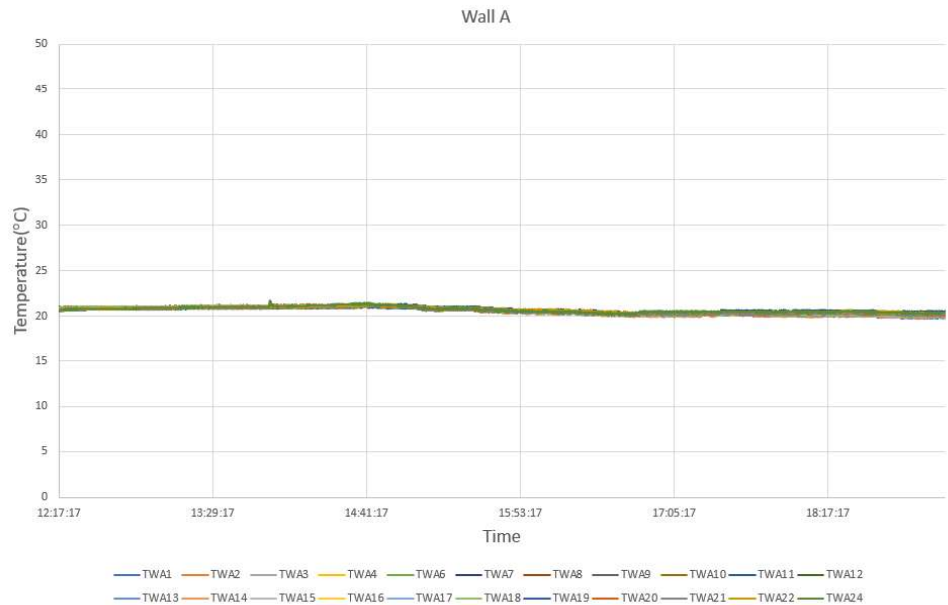
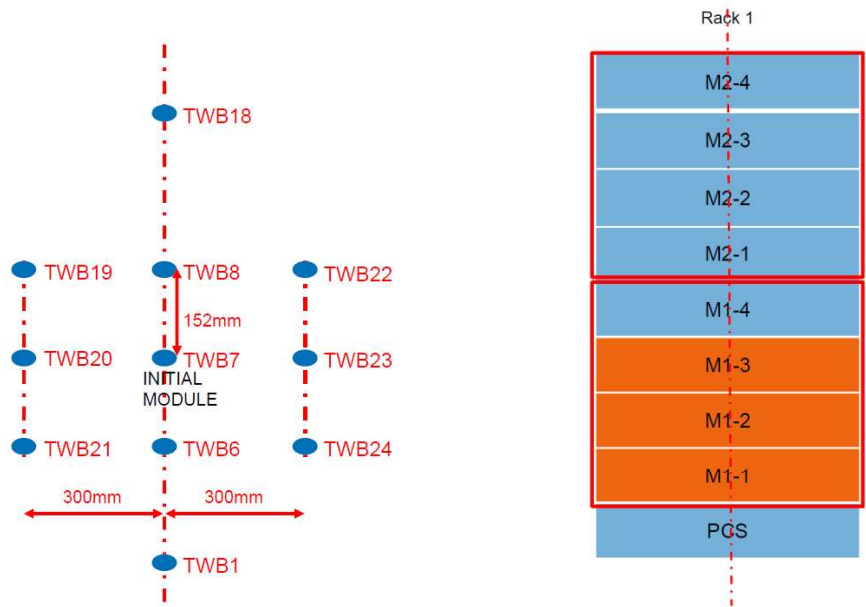


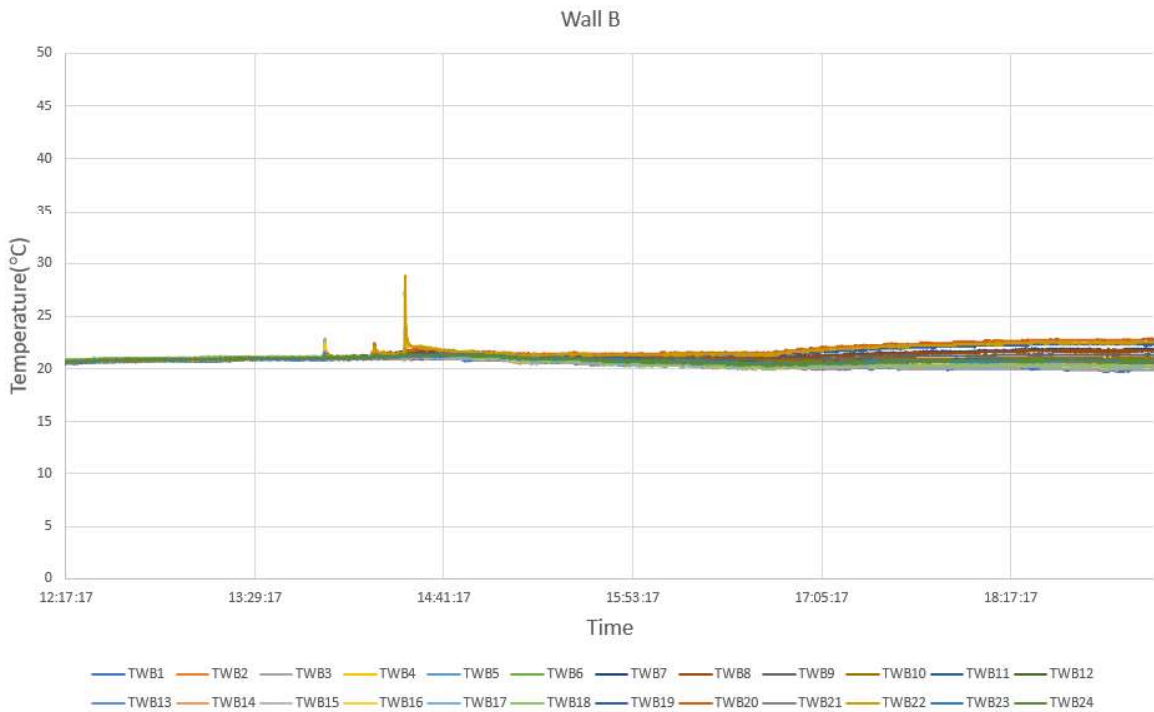
Figure 22. Vertical position of the thermocouples on the wall B



View direction: towards instrument wall A with reference to Figure 2

Maximum temperature measured on instrument wall B was 33.7°C at TWB24, temperature curve see figure 23 for detail.

Figure 23. Temperatures on instrument wall B.



3.6 Heat flux measurement

8 sensors were placed on the surface of unit, instrumented wall A, wall B and wall C. Two sensors were placed on the surface of each instrumented wall and adjacent unit 2 that faces the initiating unit.

The sensors were collinear with the vertical thermocouple array. One was positioned at the height equivalent to module M1-2 top edge, which was estimated to receive the greatest heat flux due to the thermal runaway of the initiating module within the initiating unit. Another was positioned at the height equivalent to module M4-3 top edge, which was estimated to receive the greatest surface heat flux due to the thermal runaway of the initiating unit.

Figure 24. Heat flux sensor locations on instrument wall

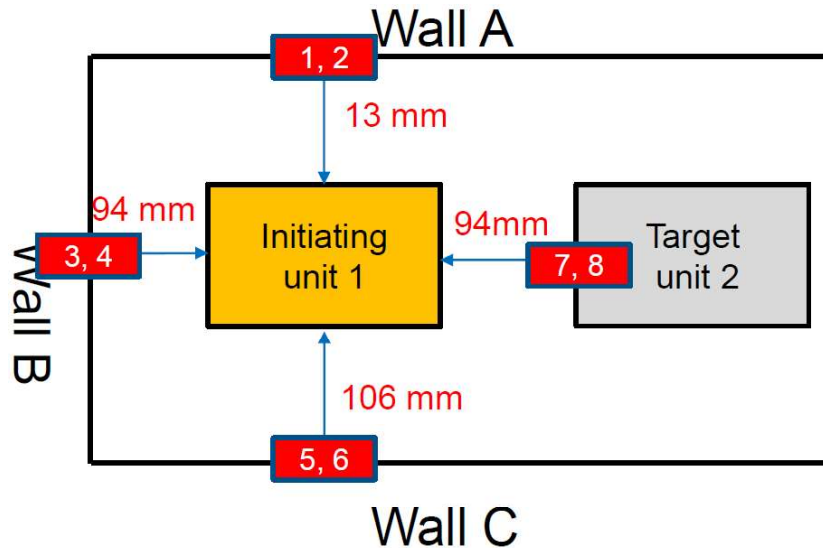
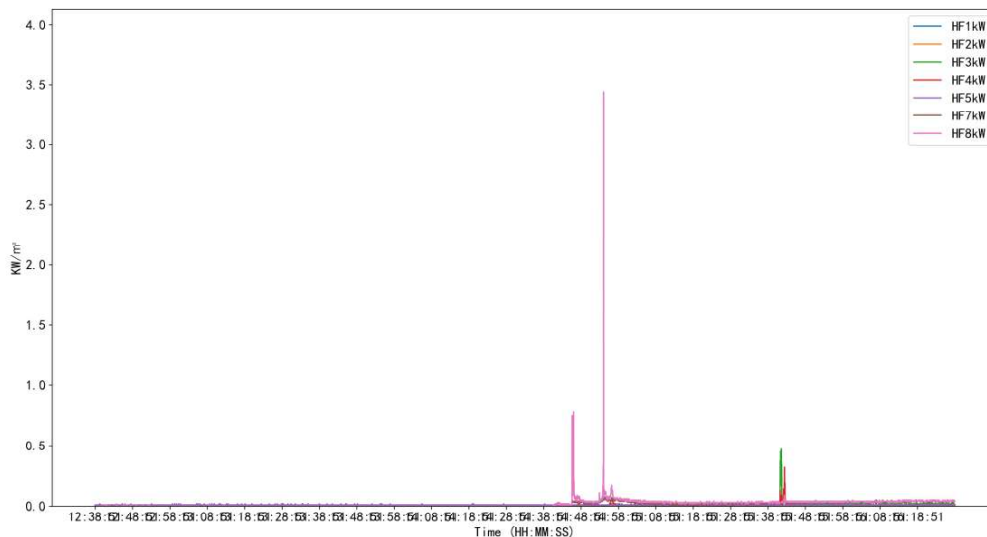


Figure 25. Measured heat flux of target wall and units



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:

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

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:

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

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

X_{CO_2} = Measured mole fraction of CO₂ in exhaust flow (non-dimensional)

$X_{CO_2}^o$ = Measured mole fraction of CO₂ in incoming air (non-dimensional)

$X_{H_2O}^o$ = Measured mole fraction of H₂O in incoming air (non-dimensional)

X_{O_2} = Measured mole fraction of O₂ in exhaust flow (non-dimensional)

$X_{O_2}^o$ = Measured mole fraction of O₂ 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

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

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

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)

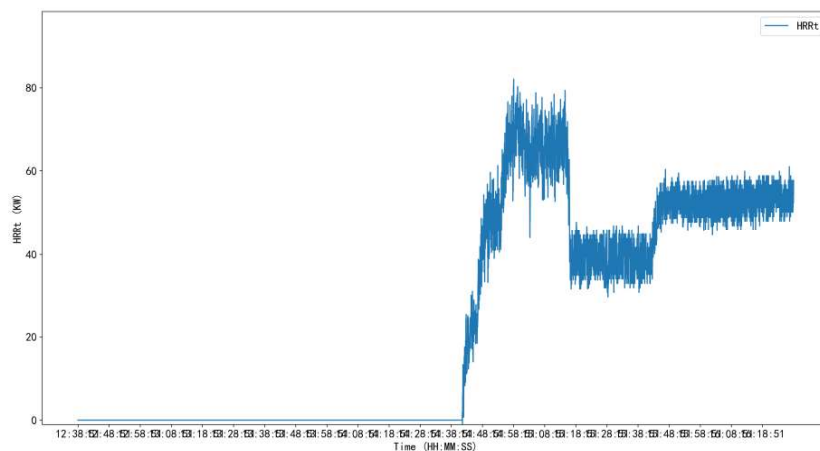
k_c = Velocity profile shape factor (non-dimensional)

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

The whole heat release rate measurement system was calibrated at 50kW and 70kW heat release rate using a standard propane burner before the test. The calibrations were performed using flows of 1078mg/s and 1510mg/s of propane.

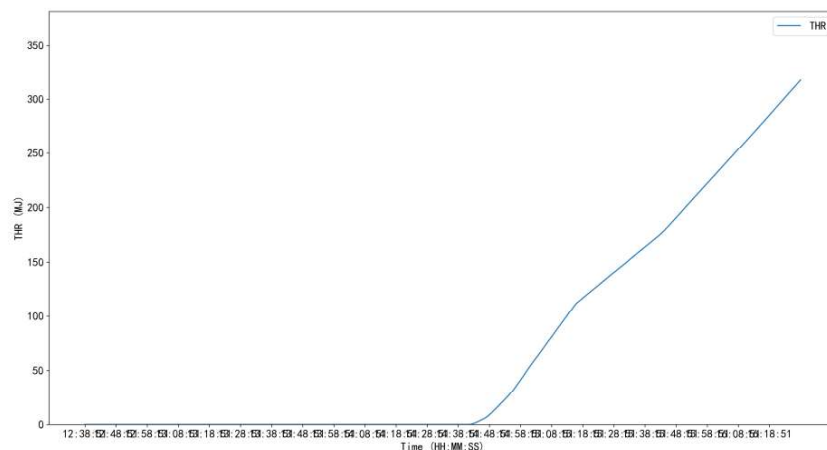
Measured peak chemical heat release rate HRR_t was 82.04 kW

Figure 26. HRR_t curve



Measured total heat release THR through the test was 317.55 MJ

Figure 27. 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)

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

C_p = 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:

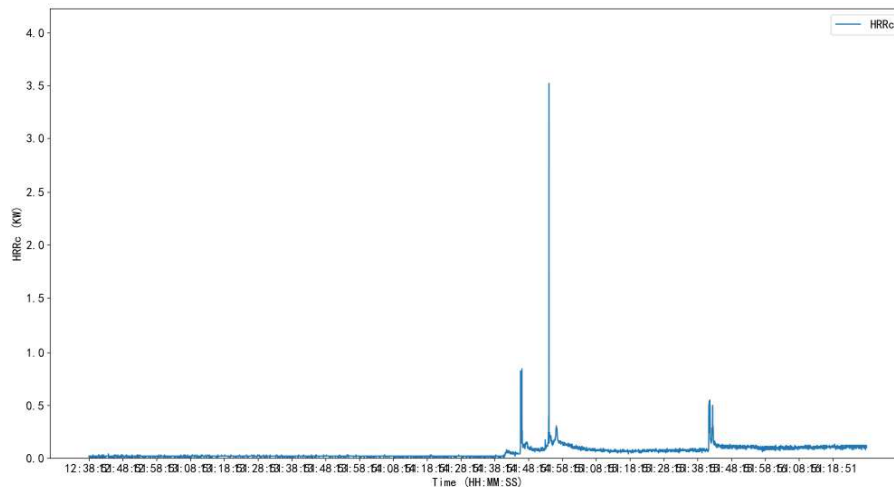
$$A_0 = 0.9950$$

$$A_1 = -5.29933E-05$$

$$A_2 = 3.21022E-07$$

$$A_3 = -1.22004E-10$$

Figure 28. HRR_c curve



3.9 Smoke release rate measurement

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:

$$SRR = 2.303 \left(\frac{V}{D} \right) \log_{10} \left(\frac{I_o}{I} \right)$$

Where:

SRR = Smoke release rate (m^2/s)

V = Volumetric exhaust duct flow rate (m^3/s)

D = duct diameter (m)

I_o = Light transmission signal of clear (pre-test) beam (V)

I = Light transmission signal during test (V)

The whole smoke release rate measurement system was self-checked using calibrated light filter before the test. The self-check was performed at 100%, 79%, 50%, 32%, 16%, 10%, 1% and 0% light transmittance.

Figure 29. Peak smoke release rate SRR: 2.63 m^2/s

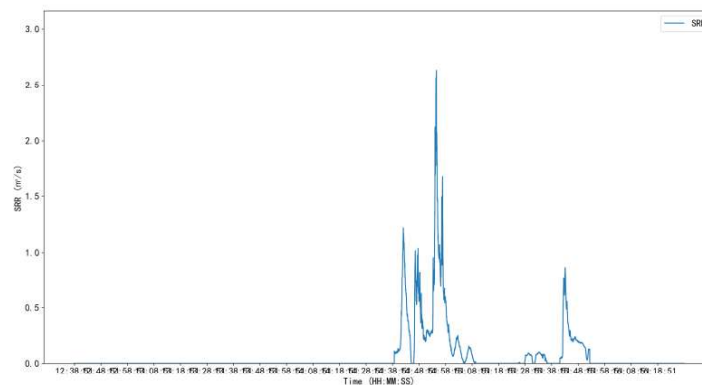
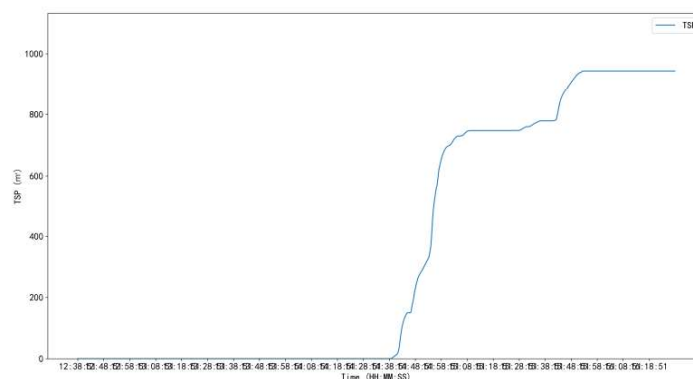


Figure 30. Total smoke release TSR: 943.42 m^2



3.10 Gas generation measurement

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

Gas compositions 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 total hydrocarbon content of the vent gas was measured using flame ionization detection.

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

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

3.10.1 Total gas release

The flow rates of various gases were integrated over the test duration and the total cumulative volume of gas calculated for the total test duration (12:48 ~ 16:20) were presented in below table.

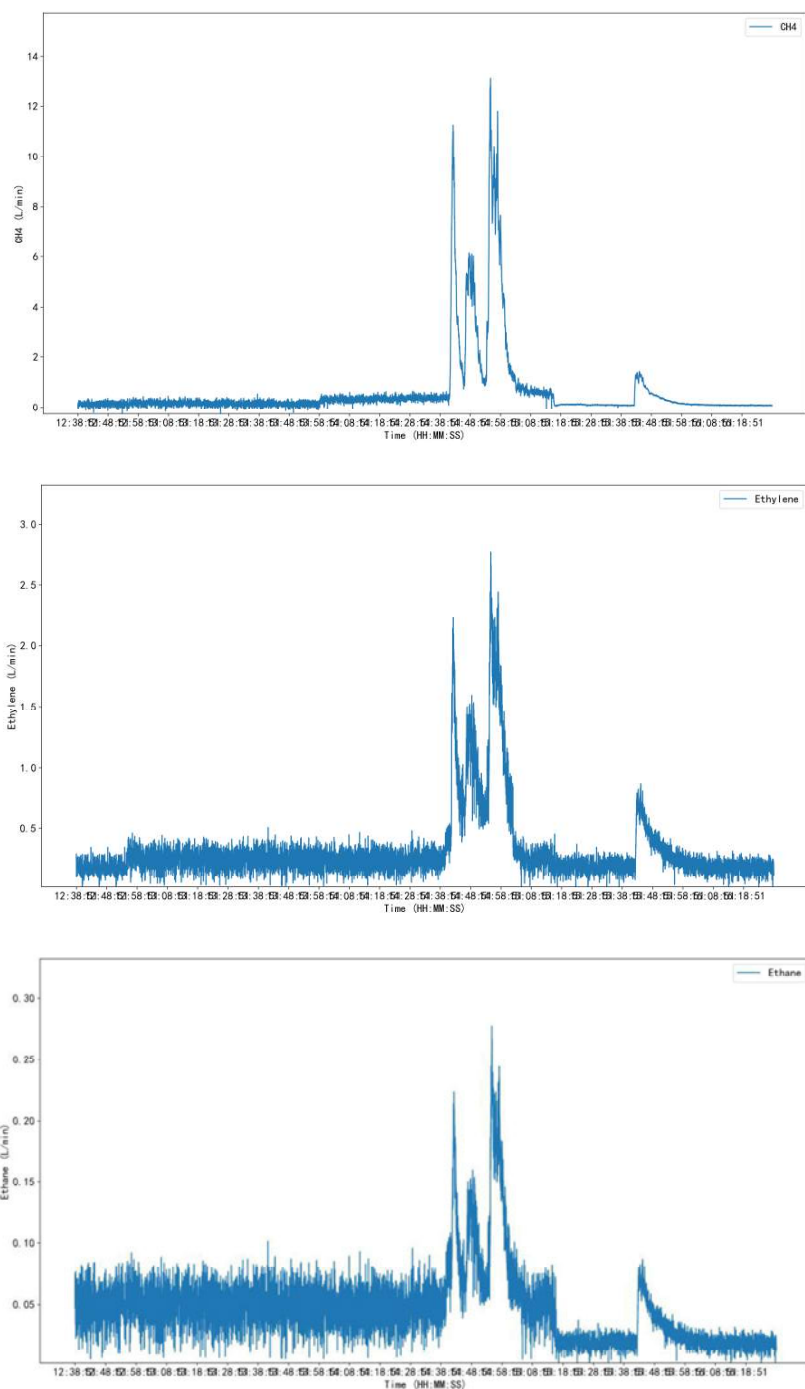
Total cumulative volume of gases before cell venting (12:48 ~ 14:25) were also presented in table for reference. Which may be considered as ambient gases background before test.

Gas type	Gas components		Total volume of gas (L)	
			Before cell venting	Through out the test
Hydrocarbon species	Methane	CH ₄	0.0	143.10
	Ethylene	C ₂ H ₄	0.0	73.26
	Ethane	C ₂ H ₆	0.0	13.61
	Propylene	C ₃ H ₆	0.0	278.2
	Propane	C ₃ H ₈	0.0	55.63
Others	Carbon Monoxide	CO	0.0	176.2
	Carbon Dioxide	CO ₂	0.0	383.7
	Hydrogen ²⁾	H ₂	0.0	939.9
Total Hydrocarbons (equivalent to CH ₄ , measured by FID)				989.9
Note:				
1)The collection time is from 12:48 to 16:20				
2)The Hydrogen measured by Palladium nickel thin film solid state sensor.				

3.10.2 Gas components

Concentrations of the gases were scaled based on the measured flow rate of the exhaust system and were presented in standard volume flow rate of gas ventilated in below figures.

Figure 31. Hydrocarbon species



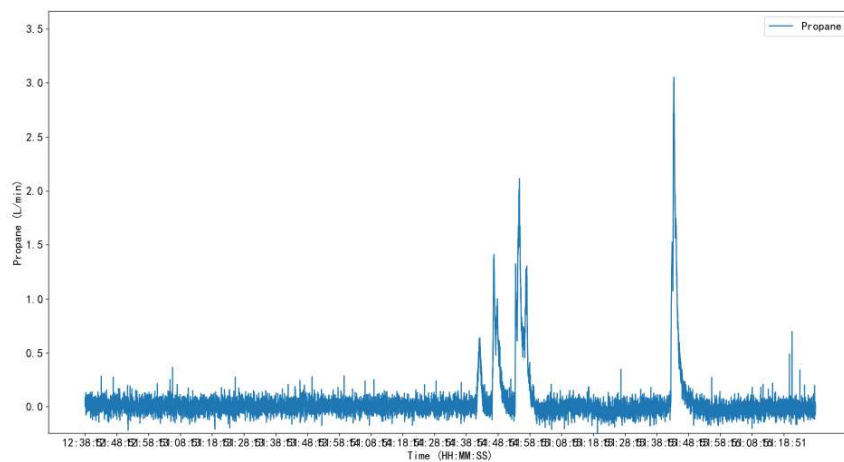
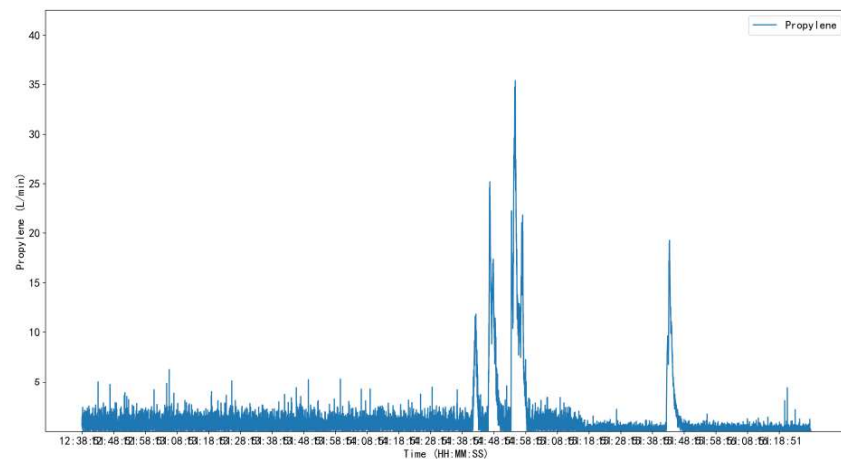
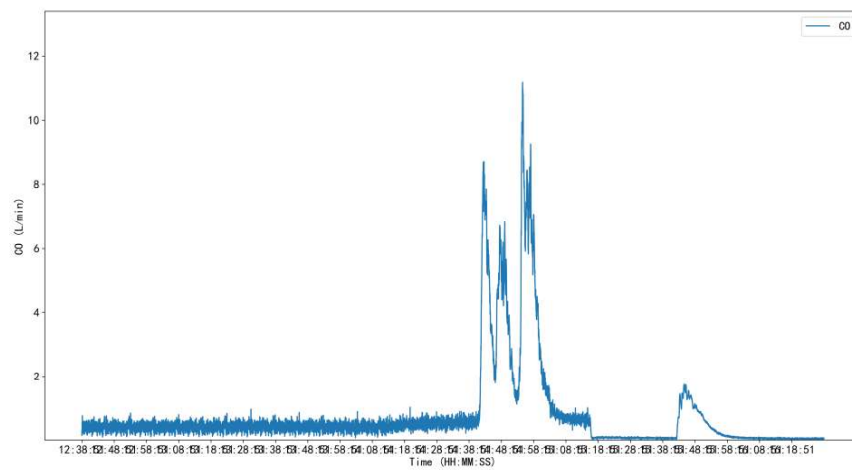


Figure 32. CO, CO₂ containing species



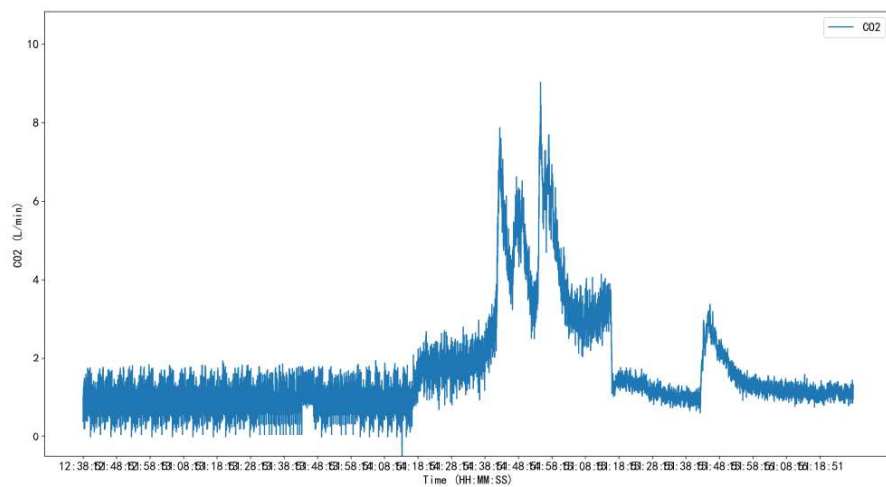
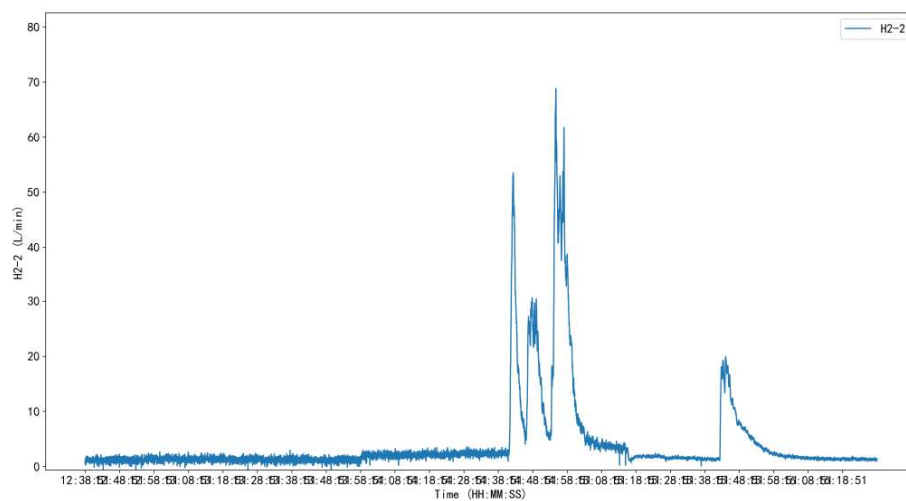


Figure 33. H₂ containing species



3.11 Photos

Initiating module





"Highly Confidential, Limited Use for Entity: [REDACTED]"

Customer Contact: [REDACTED] Date: 12 Jan 2024"

Test setup





Smoke release during test



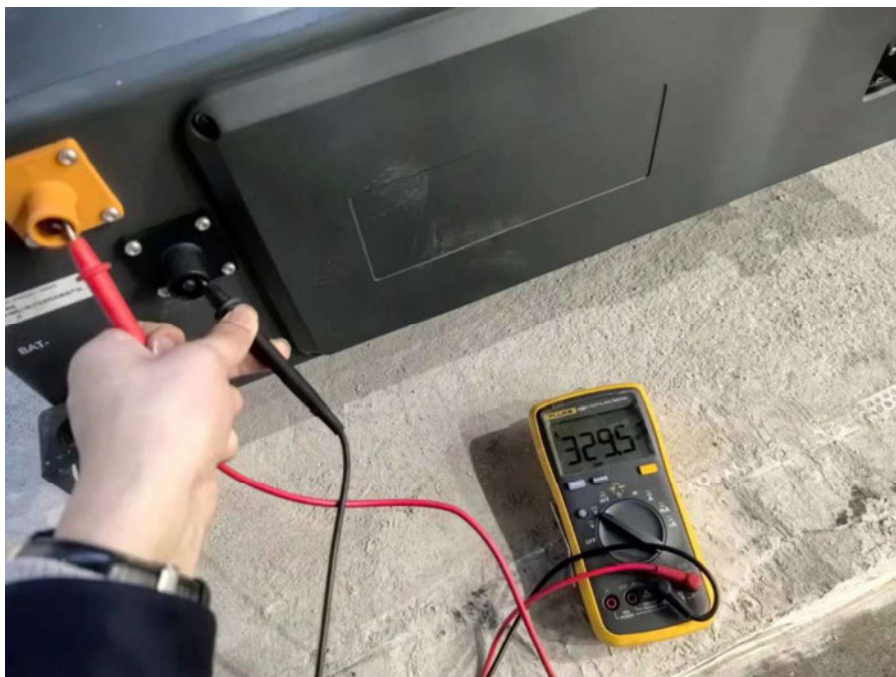
Photos after test



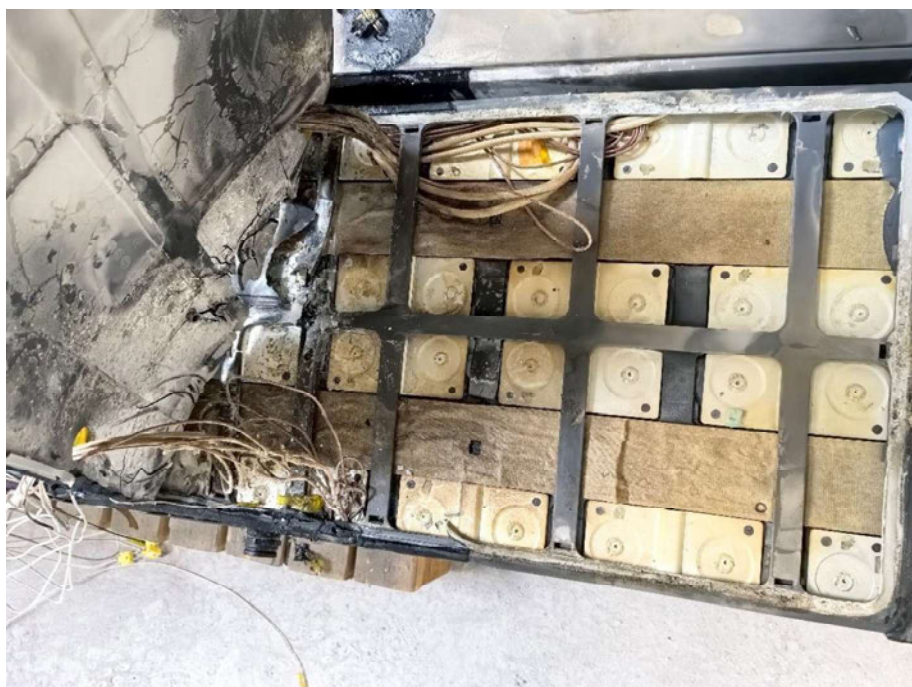
"Highly Confidential, Limited Use for Entity: [REDACTED]"

Customer Contact: [REDACTED] > Date: 12 Jan 2024"

Initiating module after test







"Highly Confidential, Limited Use for Entity: [REDACTED]"

Customer Contact: [REDACTED] > Date: 12 Jan 2024"

4 List of Test and Measurement Instruments

No.	Equipment	Model	Rating	Inventory no.	Cal. Expire date
1	Ambient temperature and humidity	HWP01-10S	-30°C~50°C, 20%RH~100%RH	12005577	2024.2.2
2	Data acquisition equipment	DAQ970A	3-slot cardcage with 6½ digit (22 bit) internal DMM 0.004%, accuracy 0.06% Vac	TY2020000138	2024.2.2
3	Data acquisition equipment	TP700	Measuring range-60 °C to 1372 °C Measurement accuracy ± (0.05% rdg.+0.5°C) Display resolution0.01°C	TY2211000716-2	2024.2.2
4	Data acquisition equipment	TP700	Measuring range-60 °C to 1372 °C Measurement accuracy ± (0.05% rdg.+0.5°C) Display resolution0.01°C	TY2020000217	2024.2.2
5	Electronic scale	CHAOOUC1	0-500KG	65960494169	2024.2.2
6	Paramagnetic oxygen analyser	SERVOME X4100	O2: paramagnetic sensor, range 0-25%, accuracy 0.02%, response time T90 < 7S	ZY2020000018-1	2024.2.6
7	Velocity probe	2671-25L-D-11-G2-E-N	4-20mA output, range 0-250pa, accuracy ± 1% F.S	ZY2020000018-2	2024.2.6
8	Photo detector	PDA36A2	Thorlabs optical receiver, wavelength range (350-1000) nm, gain adjustable, voltage output (0-10) V, instability < 0.1%	ZY2020000018-3	2024.2.2
9	Fourier-Transform Infrared Spectrometer	atmosFIR	Spectral scanning range: 485 - 7500cm ⁻¹ ; Spectral repeatability: < 0.1cm ⁻¹	ZY2020000018-5	2024.3.9

10	Non-dispersive infrared carbon dioxide and carbon monoxide sensor	SERVOME X4100	CO2: infrared sensor, measuring range 0-10%, accuracy 1% F.S, response time T90 < 7S Co: infrared sensor, measuring range 0-1%, accuracy 1% F.S, response time T90 < 8s	ZY20200000 18-4	2024.2.6
11	Palladium-nickel thin-film solid state sensor	MODEL 2000	Range: 0-2000ppm, temperature less than 100 C, -90~110kPa	ZY20210002 10	2024.2.2
12	Flame ionization detector	3010	Accuracy: 2.0%	19937	2024.3.9
13	Heat flux measurement equipment	MW88-JTC08C	0 ~ ± 99999 w / m2, - 250 ~ 980 °C, accuracy 5%, response time less than 0.1s,	ZY20200000 10	2024.2.2
14	Thermopile	RS-WD-HW-1	0-200 °C, 4-20mA, response speed < 0.15s	2834814194 2	2024.2.2

End of Test Report