Test Report

For

ANSI/CAN/UL9540A

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

[Module Level]

Report Number:	**CQES231000049001**
Date of issue:	**2024-03-18**
Total number of pages:	**26**
Test object / Model:	**Pi LV1 BMU**
Applicant's name:	**Shanghai PYTES Energy Co., Ltd.**
Address:	**No. 3492 Jinqian Road, Qingcun Town, Fengxian District, Shanghai, China**

Report Number:	CQES231000049001
Manufacturer:	Shanghai PYTES Energy Co., Ltd.
Address:	No. 3492 Jinqian Road, Qingcun Town, Fengxian District, Shanghai, China
Factory：	Shanghai PYTES Energy Co., Ltd.
Address:	No. 3492 Jinqian Road, Qingcun Town, Fengxian District, Shanghai, China
Test object / Model:	Pi LV1 BMU
Test specifications:	ANSI/CAN/UL9540A:2019 Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems Fourth Edition, Dated November 12, 2019
Date of receipt:	2023-09-25
Sample No.:	M1
Test Period:	2023-10-09 to 2023-10-14
Issuing Laboratory:	SGS-CEC New Energy Technology (Chongqing) Co., Ltd.
Address:	Building 13 & 14, No. 1839, Ranjun Road, Shuangfu Street, Jiangjin District, Chongqing, China
Testing location:	SGS-CEC New Energy Technology (Chongqing) Co., Ltd. Building 13 & 14, No. 1839, Ranjun Road, Shuangfu Street, Jiangjin District, Chongqing, China
Test Result:	Refer to summary of test results page for details.
Remark:	Test results reported relate only to the items being tested.

Confidential level:

☒ Strictly Confidential

☐ Private and Confidential

☐ Public

Tested by / Witness by

Kyle Tian
Project Engineer

Reviewed by

Ryan Hu
Project Manager

[Summary of Test results]

Cell Level Test
Cell model:

Report No.:
CN21GRDU 001

Cell Design:	
Thermal Runaway Methodology:	External heating
Cell Surface Temperature at Gas venting:	209.4°C
Cell Surface Temperature at Thermal Runaway:	270.7°C
Gas Composition:	Hydrocarbon, H_2, CO_2, CO
Lower Flammability Limit:	5.6 Vol% at ambient temperature 4.5 Vol% at 200°C
Burning Velocity:	83.6 cm/s
Pmax:	1.015 MPa
Thermal Runaway was Induced in the Cell or not:	Induced
Cell Vent Gas is Flammable or not in Air:	Flammable

Remark: Information was cited from TÜV Rheinland test report CN21GRDU 001.

Module Level Test
Module model: Pi LV1 BMU,
Report No:
CQES231000049001

Module Design:	Pi LV1 BMU
Thermal Runaway Methodology:	External heating using film heater
External Flaming:	No external flaming observed
Locations of Flame Venting:	No flame extension observed
Flying Debris:	No flying debris observed
Peak Smoke Release Rate :	5.745m^2/s
Gas Generation and Composition:	Mainly Hydrocarbon, H_2, CO_2, CO_2
Thermal Runaway are Contained by the Module Design or not:	Contained by the Module Design
Cell Vent Gas is Flammable or not:	Flammable
Other Description:	N/A
Test Video file:	Archived by Applicant

Remark:
This report only evaluated module level test which is listed inside the dotted box.

[Test object Description]

Table 1: Description of component cell

Model:		
Manufacturer:		
Nominal capacity:	100 Ah	
Nominal voltage:	3.2 Vd.c.	
Chemistry:	Lithium ion, $LiFePO_4$	
Maximum charge current:	100 A	
Discharge current:	100 A	
Maximum charge voltage:	3.65 Vd.c.	
Cut-off Voltage:	2.5 Vd.c.	
External dimensions:	207.01±0.6mm *174.7mm±0.6mm * 27.5mm±1.0mm	
Weight:	2.1±0.1kg	
UL 1973 compliant:	☒ Yes / ☐ No	Reference: TÜV Rheinland Report No.: CN212RU5 001
UL 9540A report provide:	☒ Yes / ☐ No	Reference: TÜV Rheinland Test report: CN21GRDU 001

Figure 1. View of component cell

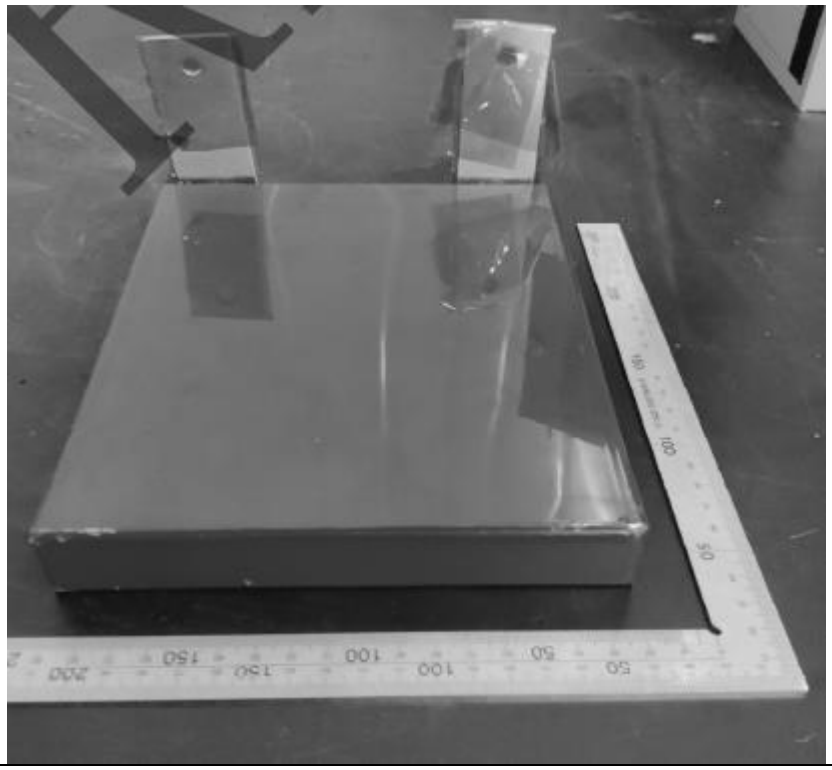

Table 2: Description of battery module

Model:	Pi LV1 BMU	
Manufacturer:	Shanghai PYTES Energy Co., Ltd.	
Nominal capacity:	100 Ah	
Nominal voltage:	51.2 Vd.c.	
Standard Charge current:	50 A	
Standard Discharge current:	50 A	
Maximum charge voltage:	58.0 Vd.c.	
Cut-off Voltage:	45.5 Vd.c.	
Charge temperature range:	0 to 57 °C	
Discharge temperature range:	-22 to 57°C	
Module configuration:	1P16S	
External dimensions:	L681mm * W242mm * H260mm	
Enclosure material:	Iron	
Weight:	57 kg	
UL 1973 compliant:	☐ Yes / ☐ No	Reference: N/A

Supplementary information:
1. Two different constructures for battery module (Pi LV1 BMU), which was that there were brackets on top-cover or not.
2. Battery module with screw brackets was picked up samples in this report. And no further testing is considered as necessary for battery module without brackets.

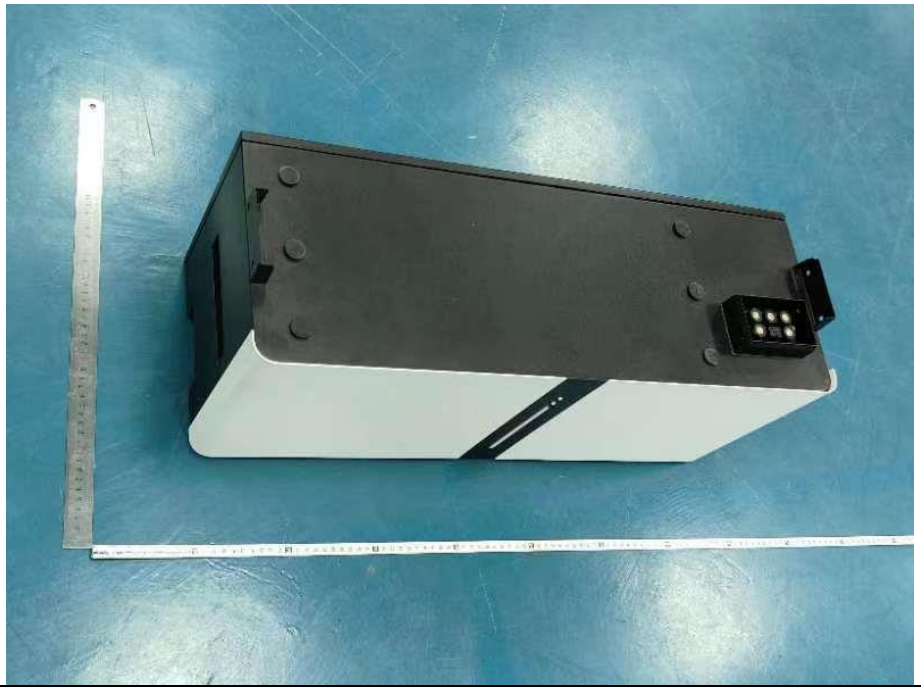

Figure 2. View of battery module

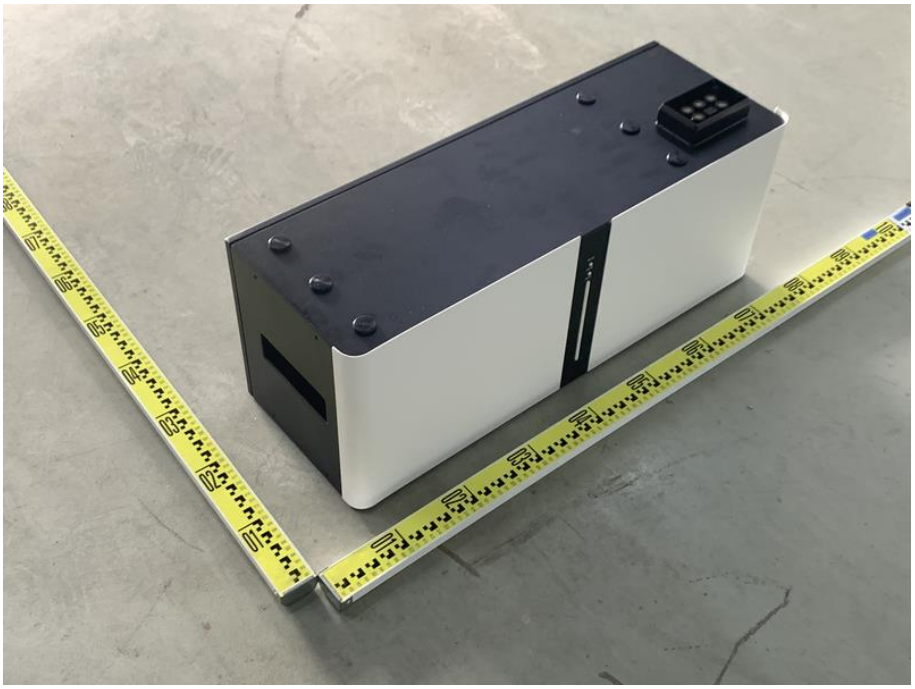

Figure 2a. View of battery module (Alternative)

Figure 3. Interview of battery module

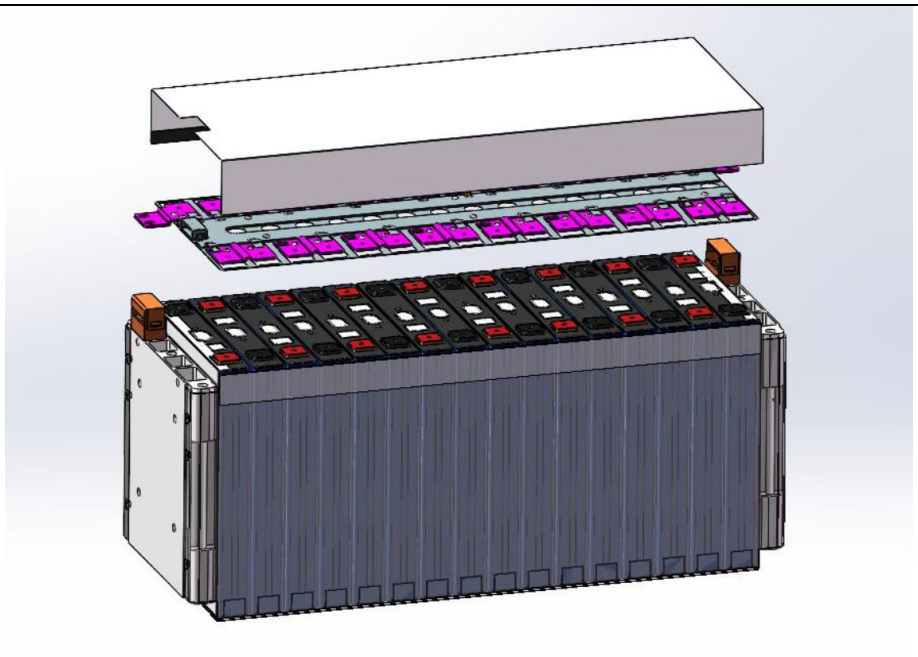

Figure 4. Structural diagram

[Description of thermal runaway methodology]

Pre-condition of test sample

Module samples shall be conditioned, prior to testing, through charge and discharge cycles for a minimum of 2 cycles, using a manufacturer specified methodology to verify that the module is functional. Each cycle shall be defined as a charge to 100% SOC and allowed to rest a maximum of 8 h and then discharged to an end of discharge voltage (EODV) specified by the module manufacturer.

The module to be tested shall be charged to 100% SOC and allowed to rest a maximum of 8 h before the start of the test. The module voltage shall be determined by measuring at the module terminals after charging up to the fully charged condition and before beginning testing. The sample module shall stabilize for a minimum of one hour prior to testing.

Table 3: Charge and discharge parameters (provided by manufacturer)

Charge		Discharge	
Charge current (A)	50	Discharge current (A)	50
Max. charge voltage (V)	58.0	Cut-off voltage (V)	45.5
Cut-off charge current (A)	--		

Module level Test method description

Ambient indoor laboratory conditions shall be 25 ±5°C (77 ±9°F) and 50 ±25% RH at the initiation of the test.

The test shall be conducted under a smoke collection hood that is sized appropriately to collect the gasses generated from the module.

The methodology used for initiating thermal runaway pursuant to cell level test shall be used to initiate thermal runaway within the module.

Thermal runaway methodology for module level test: The propensity of the module to exhibit thermal runaway was demonstrated by heating the cell with externally applied heaters. With a surface heating rate of 4ºC (7.2ºF) to 7ºC (12.6ºF) per minute until cell thermal runaway occurs within the test module.

The number of cells within the module that are forced into thermal runaway can be one or multiple cells, and is dependent upon the energy contained within the individual cells. A sufficient number of cells shall be forced into thermal runaway to create a condition of cell to cell propagation within the module. For example, it may be necessary to force nine, 3-Ah cells into thermal runaway as opposed to one, 30-Ah cell in order to get cell to cell propagation. The location of the cell (s) forced into thermal runaway shall be selected to present the greatest thermal exposure to adjacent cells that are not forced into thermal runaway. Factors to be taken into consideration shall include selecting locations within the module where heat transfer is maximized to other cells, cooling by ventilation is restricted or limited, and thermal sensors, detection and suppression discharge points are remote.

The module shall be placed on top of a noncombustible horizontal surface with the module orientation representative of its intended final installation.

The chemical heat release rate of the module in thermal runaway shall be measured with oxygen consumption calorimetry.
The chemical heat release rate shall be measured for the duration of the test.

Occurrence of thermal runaway shall be verified by sustained temperature above the cell surface temperature at the onset of thermal runaway, as determined in cell level test.

The chemical heat release rate shall be measured by a 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 instrumentation shall be located in the exhaust duct of the heat release rate calorimeter at a location that minimizes the influence of bends or exhaust devices.

Calculate the chemical heat release rate at each of the flows as follows:

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

Vent gas composition shall be measured using a Fourier-Transform Infrared Spectrometer with a minimum resolution of 1 cm^{-1} and a path length of at least 2 m (6.6 ft), or equivalent gas analyzer, and velocity and temperature measurements respectively shall be obtained in the exhaust duct of the heat release rate calorimeter using equipment.

The hydrocarbon content of the vent gas shall be measure using flame ionization detection.
Hydrogen gas shall be measured with a palladium-nickel thin-film solid state sensor.

The light transmission in the exhaust duct of the heat release rate calorimeter shall be measured using a white light source and photo detector for the duration of the test, and the smoke release rate shall be calculated.

Smoke release rate shall be calculated as follows:

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

Test configuration description

Thermal runaway initiation method used including number and locations of cells for initiating thermal runaway
Initiation method: External heating method was used for initiating thermal runaway. By controlling the input power of the heaters, a surface heating rate of 4°C (9°F) to 7°C (12.6°F) per minute was achieved. Max. power of the film heater 1 was 300 W, and Max. power of the film heater 2 was 300 W.
Number of cells for initiating thermal runaway: ☒ Single cell 100 Ah (total capacity)
Locations of cells for initiating thermal runaway: The battery module consists of 16 cells, which are connected in series. Cell 8 (as shown in Figure 5b within blue box) is selected as the initiating cell. Two film heaters were placed on large surfaces of cell 8.
Other description : N/A

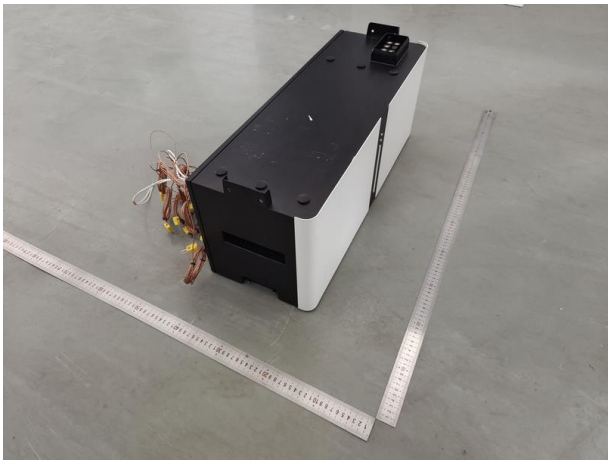

Figure 5a. External view of DUT.

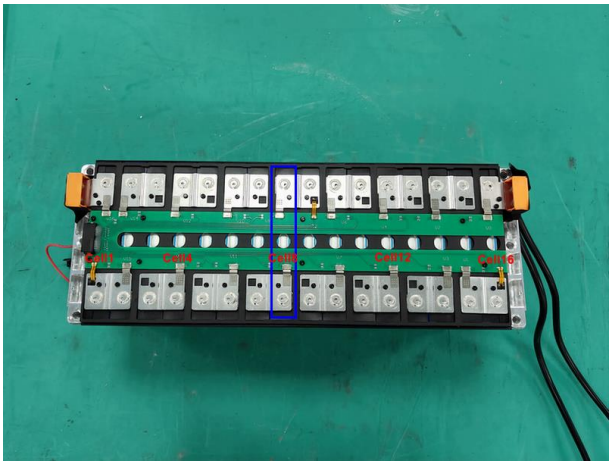

Figure 5b. Internal view of DUT.

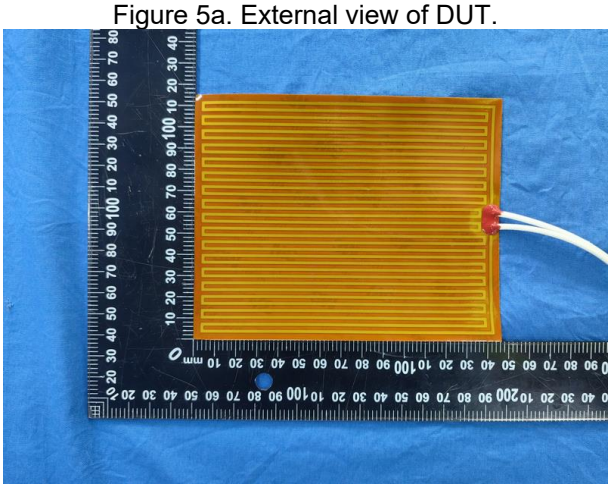

Figure 5c. View of film heater.

Illustration of external heater and thermocouple location
Description: N/A

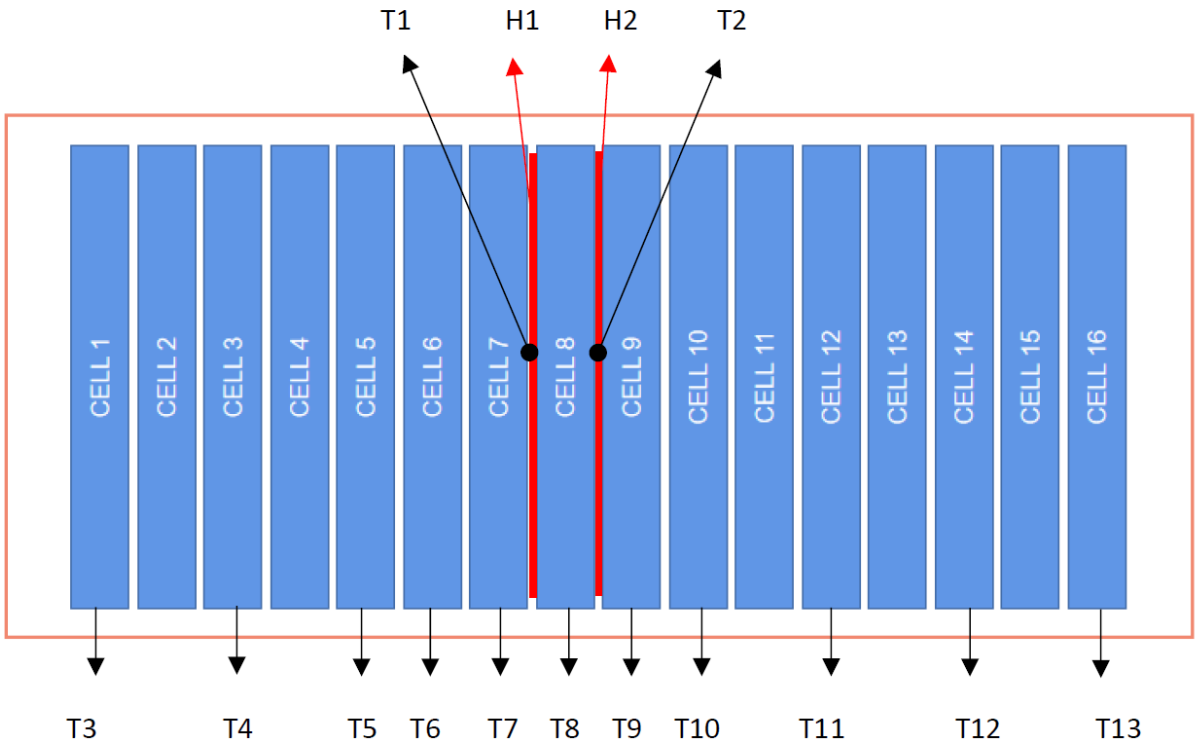

Figure 6. Schematic Illustration of film heaters and thermocouple locations in DUT (T1 to T13 means thermocouples T1 to T13. H1 and H2 means Film heater 1 and Film heater 2. View from top.).

Positioning of module within testing room
Test Start Time: 2023-10-13 10:42:28
Initial Ambient Test Temperature: 21.3 °C
Initial Relative Humidity: 59.4% RH
Description: N/A

Figure 7. View of positioning of module within testing room.

Table 4: Thermocouple placement

Thermocouple ID	Description of location	Remark
CH2107	Ambient Temperature	--
CH2001	Center of face between Cell 8 and Heater 1	T1
CH2002	Center of face between Cell 8 and Heater 2	T2
CH2003	Side surface of Cell 1	T3
CH2004	Side surface of Cell 3	T4
CH2005	Side surface of Cell 5	T5
CH2006	Side surface of Cell 6	T6
CH2007	Side surface of Cell 7	T7
CH2008	Side surface of Cell 8	T8
CH2009	Side surface of Cell 9	T9
CH2010	Side surface of Cell 10	T10
CH2101	Side surface of Cell 12	T11
CH2102	Side surface of Cell 14	T12
CH2103	Side surface of Cell 16	T13
CH2104	Top Surface of battery module	T14
CH2106	Side Surface of battery module	T15
Thermocouple information: Type K 24 AWG		

[Description of test results]

Table 5: Overview of test timeline and key events

Time (HH: MM: SS)	Relative Time (HH: MM: SS)	Event ID	Event	Description	Photo Reference
10:42:28	00:00:00	E1	Test Start	--	Figure 11
10:45:03	00:02:35	E2	Heaters Energized	--	Figure 12
11:42:59	01:00:31	E3	Initiating Cell Venting	--	Figure 13
11:44:17	01:01:49	E4	Thermal Runaway onset	Smoke venting observed from module enclosure. All Heaters de-energized.	Figure 14
11:48:57	01:06:29	E5	Second Release	Smoke venting observed from module enclosure	Figure 15
11:54:07	01:11:39	E6	Third Release	Smoke venting observed from module enclosure	Figure 16
12:01:40	01:19:12	E7	Fourth Release	Smoke venting observed from module enclosure	Figure 17
12:08:15	01:25:47	E8	Fifth Release	Smoke venting observed from module enclosure	Figure 18
12:16:59	01:34:31	E9	Sixth Release	Smoke venting observed from module enclosure	Figure 19
16:10:03	05:27:35	E10	Test Termination	--	Figure 20
Test Start Time : 2023-10-13 10:42:28					

Heat release rate versus time
Description: No flaming combustion observed outside test module.
N/A

Flammable gas generation and composition
Flammable gas generation: ☒ YES ☐ NO
Description :N/A

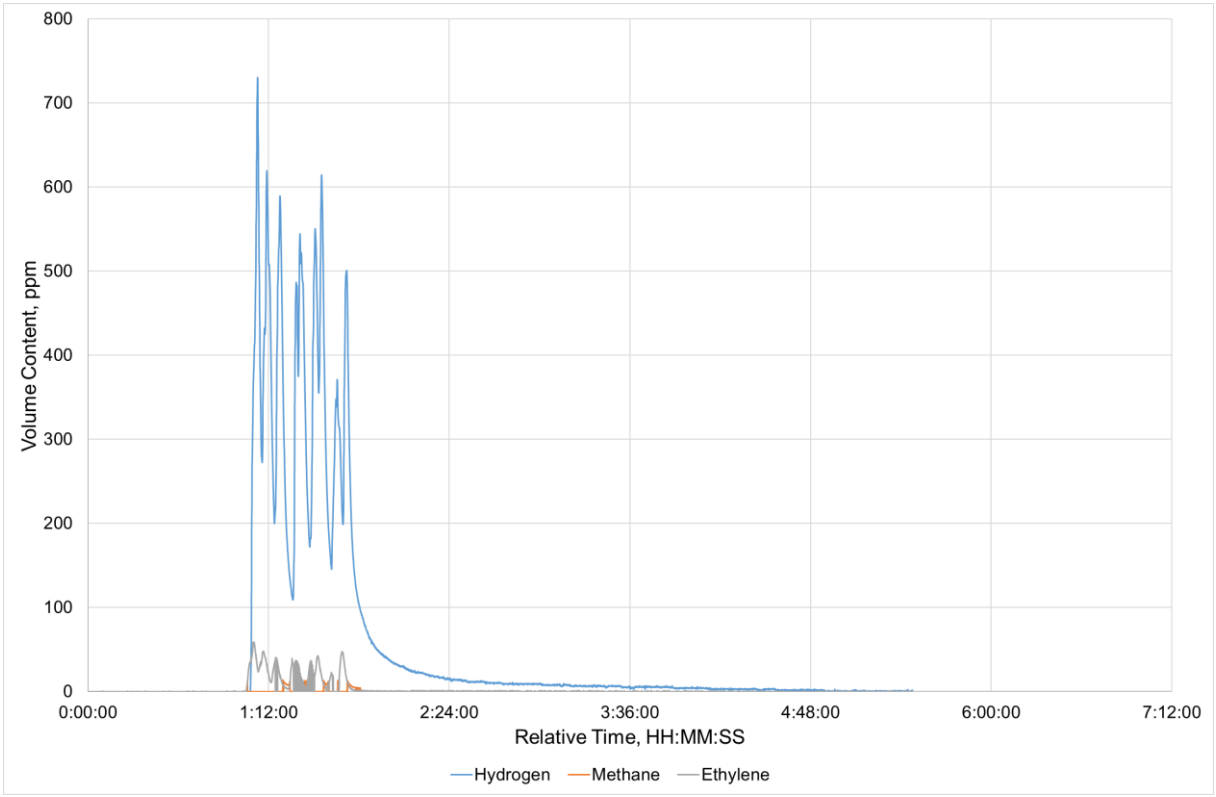

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Figure 8. Online flammable gas content measurements during test. (Remark: The content of other hydrocarbons is below the detection limit of the test equipment.)

Peak smoke release rate and total smoke release
Description: 1. Peak smoke release rate is 5.754m^2/s during test. 2. Total smoke release is 2786.95 m^2 during test.

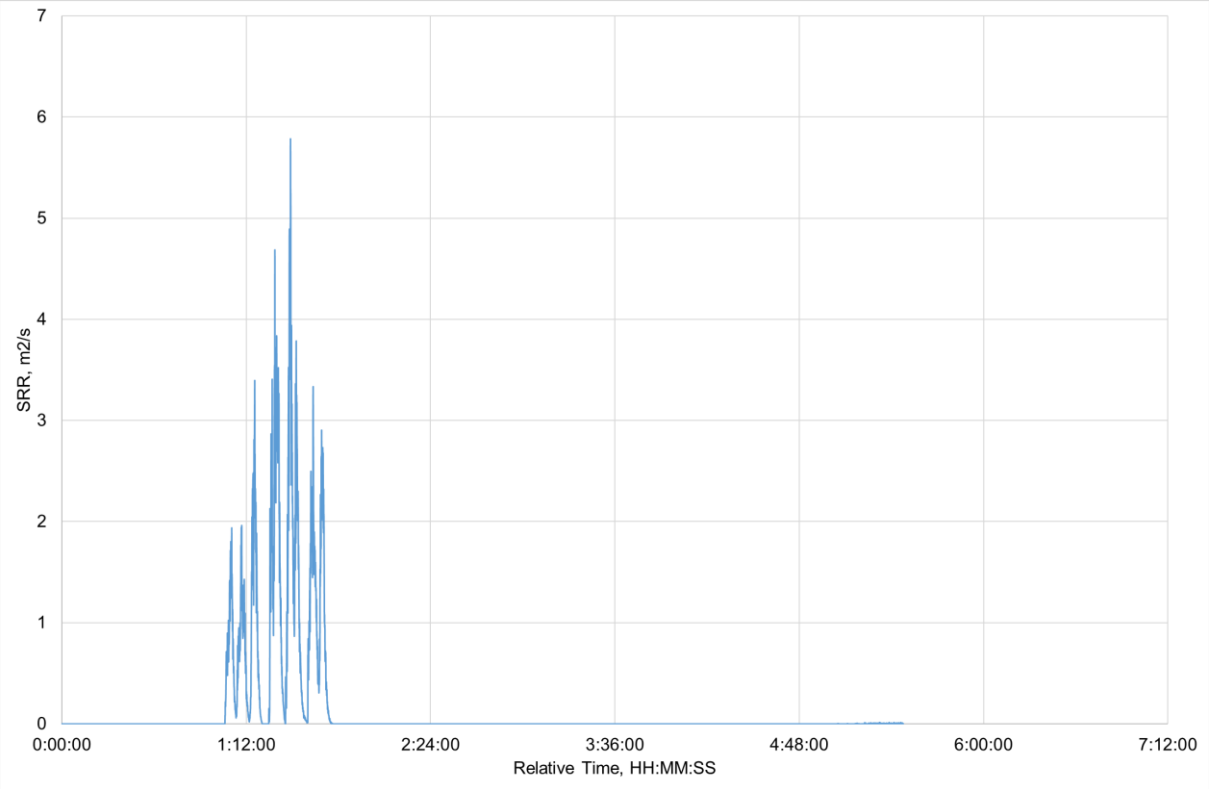

Figure 9. Smoke release rate versus time

Identification/location of cell(s) that exhibited thermal runaway within the module
Cells(s) that exhibited thermal runaway: ☒ YES ☐ NO
Description : N/A

Figure 10. View of cells that exhibited thermal runaway after test.

Locations and visual estimations of flame extension and duration from the module
Flame extension: ☐ YES ☒ NO
Description: No external flaming observed. No explosion observed. No flying debris observed.
N/A

Table 6: Data during test

Model	SOC of Battery Module Before Test, (%)	OCV of Battery Module Before Test, (V dc)	Weight of Battery Module Before Test, (Kg)	Weight of Battery Module After Test, (Kg)	Battery Module Weight Loss Rate, (%)
Pi LV1 BMU	100%	53.345	55.62	49.06	11.79
Peak Smoke Release Rate, (m^2/s)	**Total Smoke Release**	**Observation Results**			
5.754	2786.95 m^2	Gas and smoke release observed from module enclosure. No external flaming observed. No explosion observed.			
Supplementary information: No additional thermal runaway events or re-ignition occurred during post-test observations of the test module.					

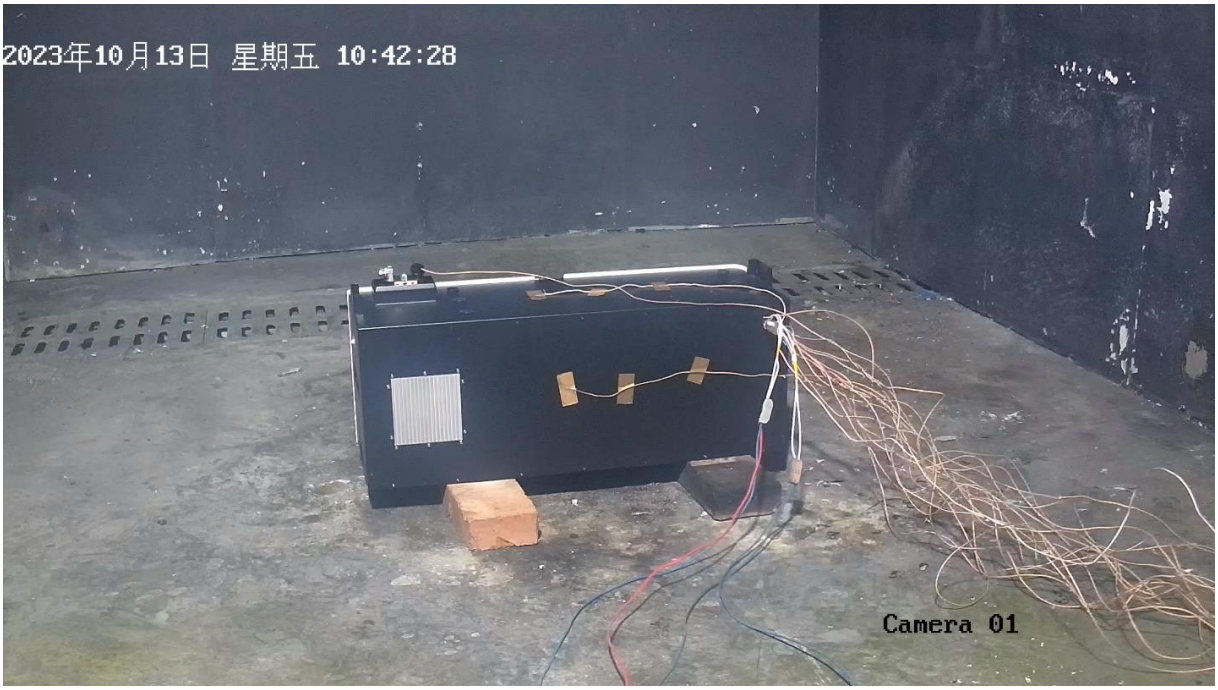

Figure 11. photo of event (E1) during test

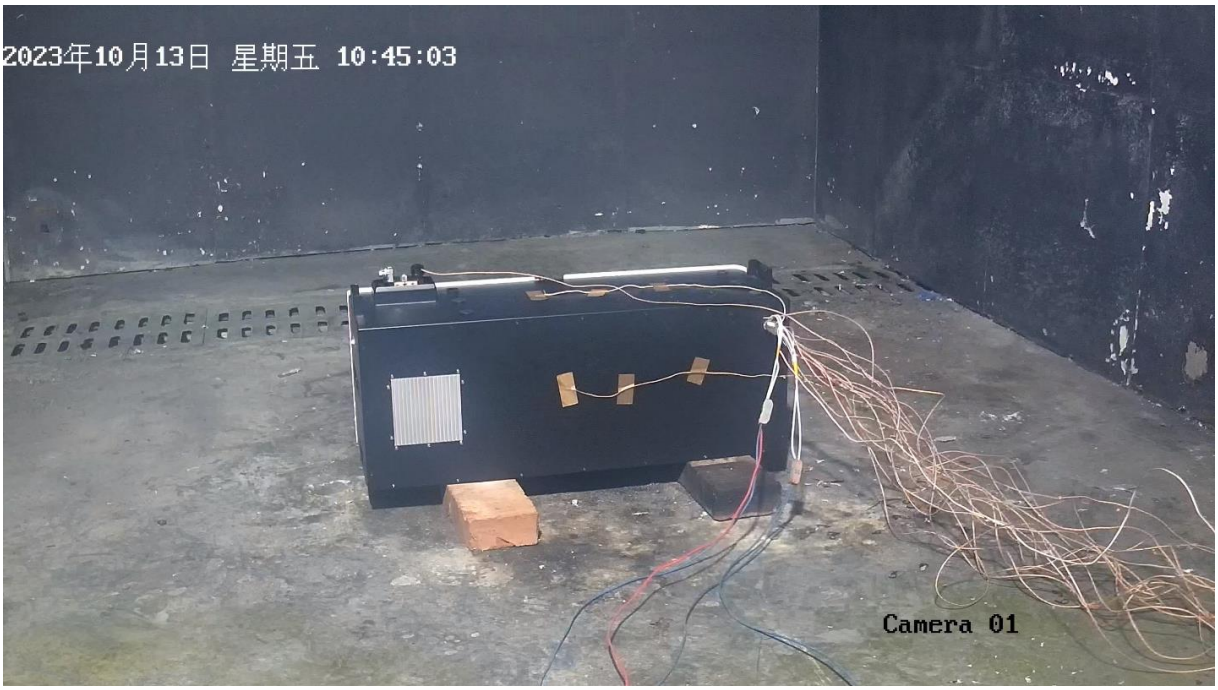

Figure 12. photo of event (E2) during test

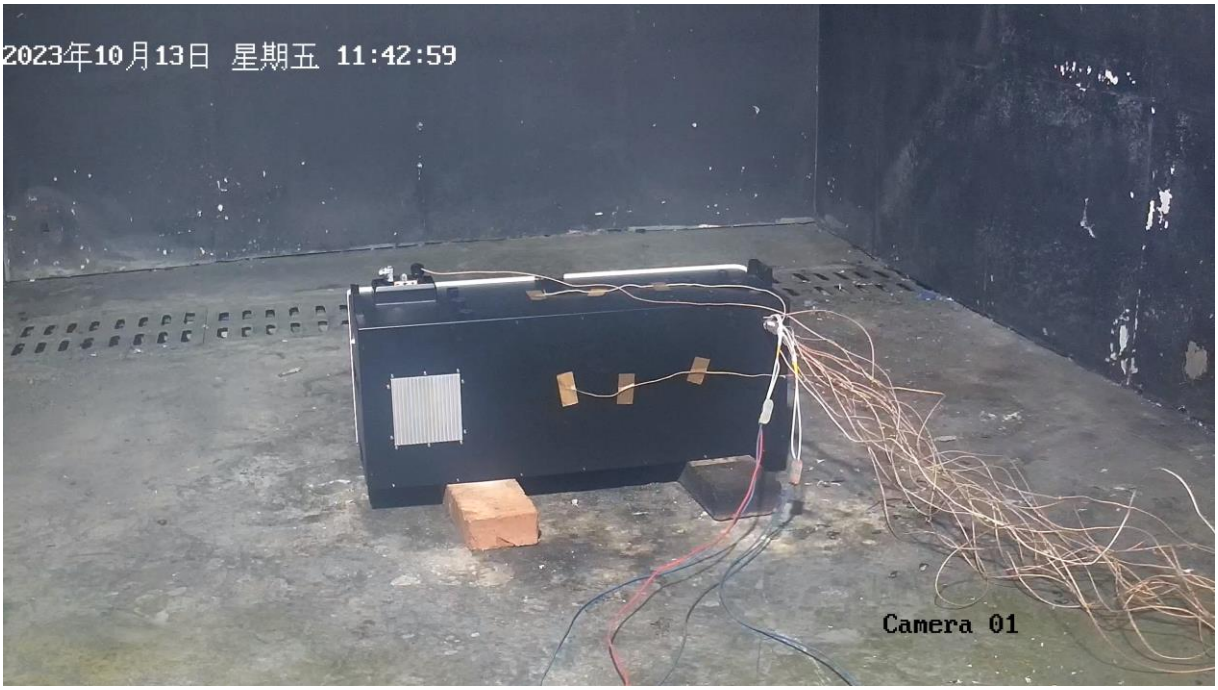

Figure 13. photo of event (E3) during test

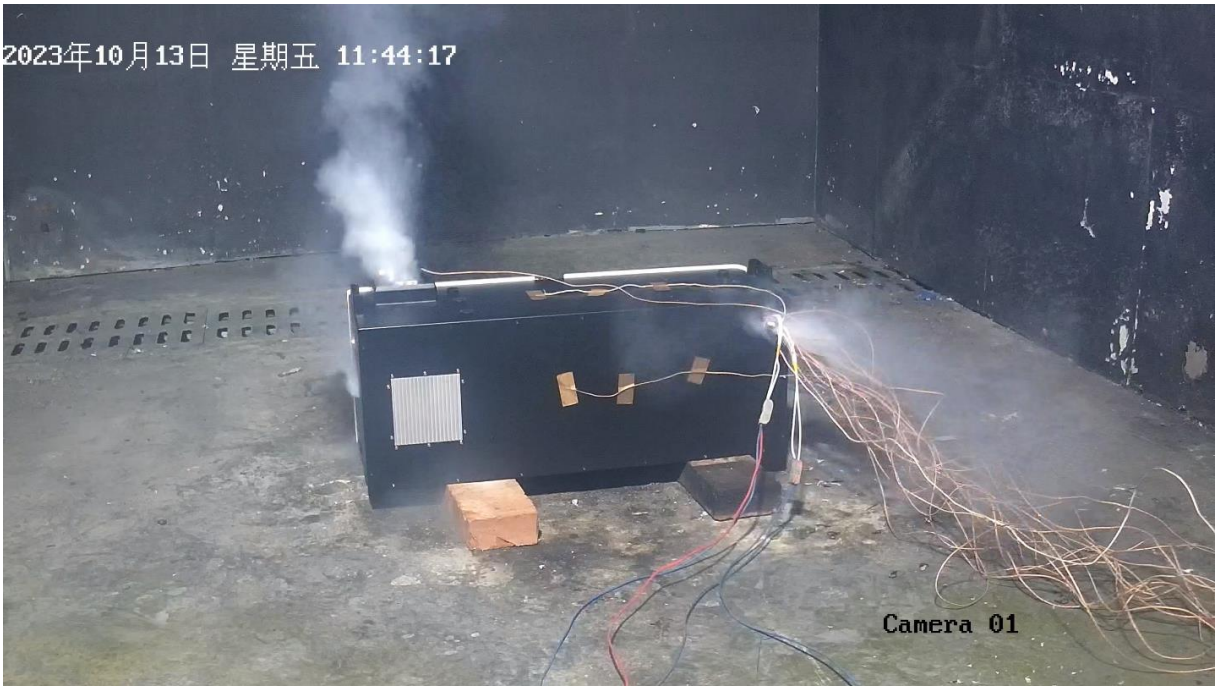

Figure 14. photo of event (E4) during test

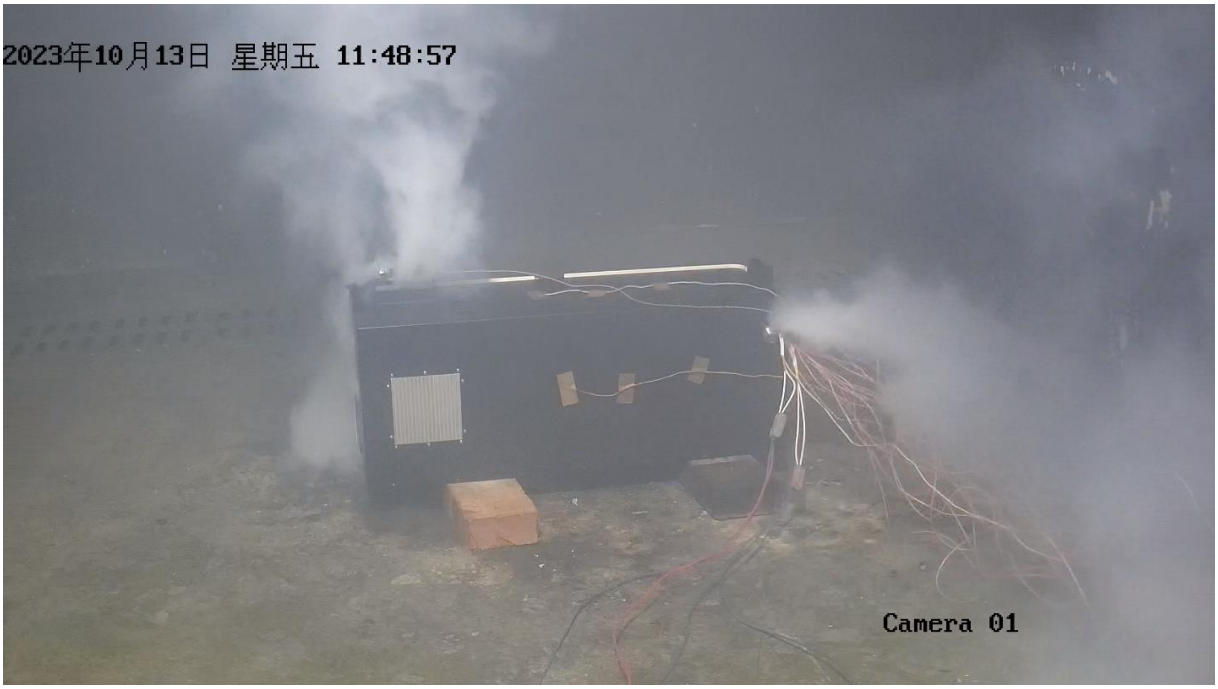

Figure 15. photo of event (E5) during test

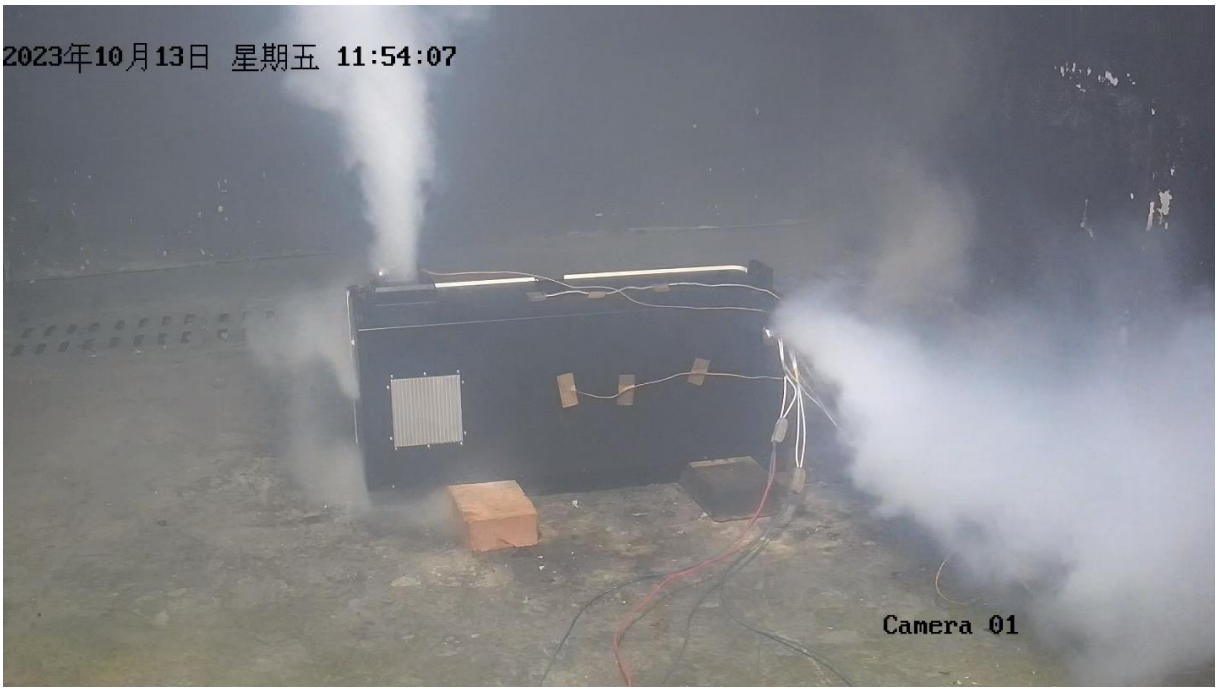

Figure 16. photo of event (E6) during test

Figure 17. photo of event (E7) during test

Figure 18. photo of event (E8) during test

Figure 19. photo of event (E9) during test

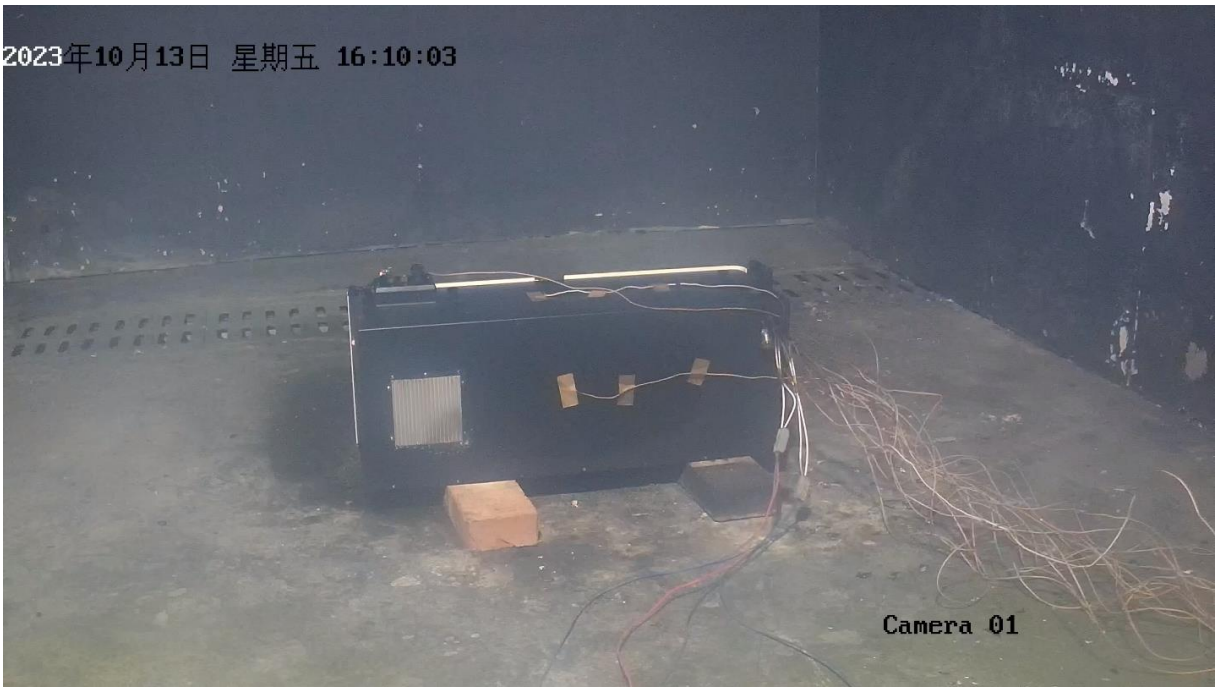

Figure 20. photo of event (E10) during test

Figure 21. Photo 1 of DUT after test

Figure 22. Photo 2 of DUT after test

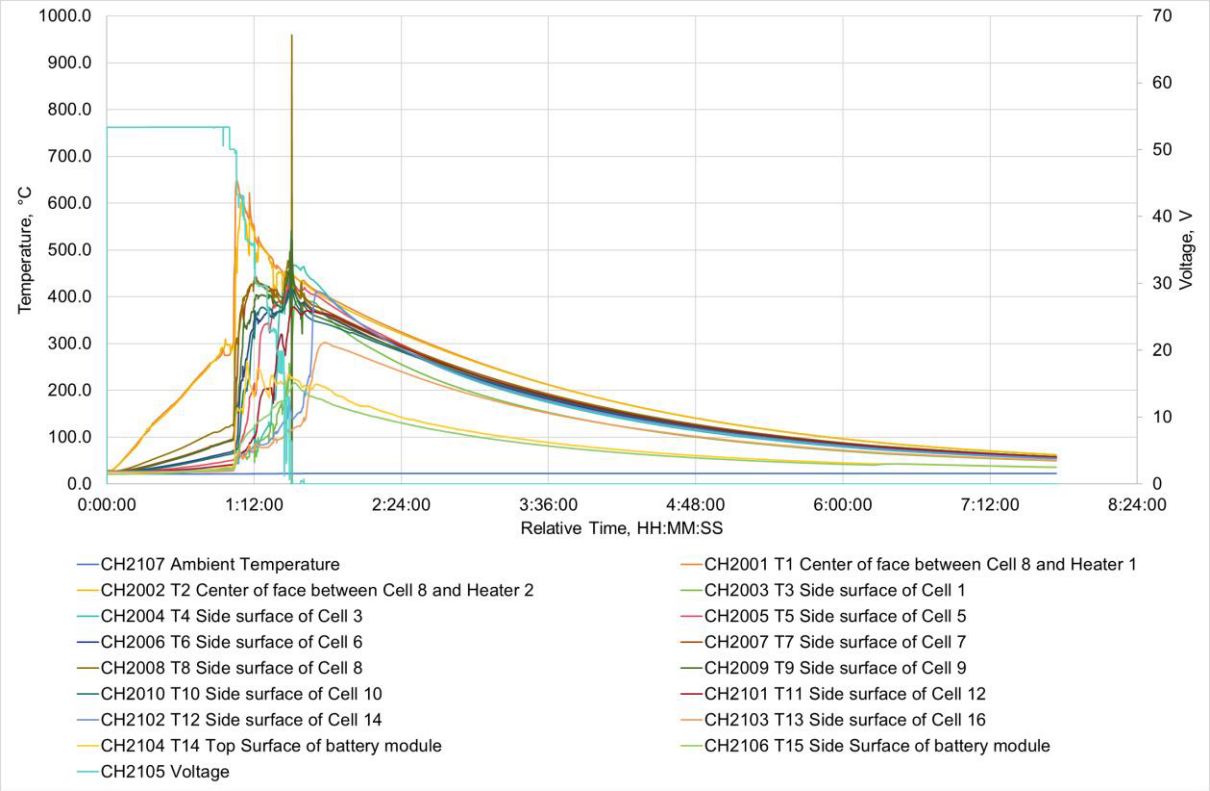

Figure 23. Temperature and Voltage measurements during test.

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2. According to the standard, instruction sheets and other texts required by the standard should be written in the official language(s) of the country in which the product is to be sold. The applicant should ensure that the product in future production fulfils the receptive standard requirements.

3. The components performed satisfactorily during testing and are considered to be suitable for use in the sample tested.

- - - End of Report - - -

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