

Prüfbericht-Nr.: <i>Test report no.:</i>		CN24YJ0X 001	Auftrags-Nr.: <i>Order no.:</i>		326054735	Seite 1 von 31 <i>Page 1 of 31</i>
Kunden-Referenz-Nr.: <i>Client reference no.:</i>		2513995	Auftragsdatum: <i>Order date:</i>		2024-09-25	
Auftraggeber: <i>Client:</i>		Suzhou RCT Power Energy Technology Co., Ltd 5.1.2e Suzhou, Jiangsu P.R. China				
Prüfgegenstand: <i>Test item:</i>		C&I Energy Storage System Battery Pack				
Bezeichnung / Typ-Nr.: <i>Identification / Type no.:</i>		POWER CESS PACK 47L1D2				
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>		2024-10-28				
Prüfmuster-Nr.: <i>Test sample no.:</i>		#2024102801				
Prüfzeitraum: <i>Testing period:</i>		2024-10-29 - 2024-11-15				
Ort der Prüfung: <i>Place of testing:</i>		See page 5 Testing location				
Prüflaboratorium: <i>Testing laboratory:</i>		TÜV Rheinland (Shanghai) Co., Ltd.				
Prüfergebnis*: <i>Test result*:</i>		See main report				
geprüft von: <i>tested by:</i>		5.1.2e		genehmigt von: <i>authorized by:</i>		
Datum: <i>Date:</i>		2025-01-21		Ausstellungsdatum: <i>Issue date:</i>		
Stellung / Position:		Project Engineer		Authorizer		
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						
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Test report no.:

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Anmerkungen
Remarks

1	Alle eingesetzten Prüfmittel waren zum angegebenen Prüfzeitraum gemäß eines festgelegten Kalibrierungsprogramms unseres Prüfhauses kalibriert. Sie entsprechen den in den Prüfprogrammen hinterlegten Anforderungen. Die Rückverfolgbarkeit der eingesetzten Prüfmittel ist durch die Einhaltung der Regelungen unseres Managementsystems gegeben. Detaillierte Informationen bezüglich Prüfkonditionen, Prüfequipment und Messunsicherheiten sind im Prüflabor vorhanden und können auf Wunsch bereitgestellt werden. <i>The equipment used during the specified testing period was calibrated according to our test laboratory calibration program. The equipment fulfils the requirements included in the relevant standards. The traceability of the test equipment used is ensured by compliance with the regulations of our management system.</i> <i>Detailed information regarding test conditions, equipment and measurement uncertainty is available in the test laboratory and could be provided on request.</i>
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4	Die Entscheidungsregel für Konformitätserklärungen basierend auf numerischen Messergebnissen in diesem Prüfbericht basiert auf der "Null-Grenzwert-Regel" und der "Einfachen Akzeptanz" gemäß ILAC G8:2019 und IEC Guide 115:2021, es sei denn, in der auf Seite 1 dieses Berichts genannten angewandten Norm ist etwas anderes festgelegt oder vom Kunden gewünscht. Dies bedeutet, dass die Messunsicherheit nicht berücksichtigt wird und daher auch nicht im Prüfbericht angegeben wird. Zu weiteren Informationen bezüglich des Risikos durch diese Entscheidungsregel siehe ILAC G8:2019. <i>The decision rule for statements of conformity, based on numerical measurement results, in this test report is based on the "Zero Guard Band Rule" and "Simple Acceptance" in accordance with ILAC G8:2019 and IEC Guide 115:2021, unless otherwise specified in the applied standard mentioned on Page 1 of this report or requested by the customer. This means that measurement uncertainty is not taken in account and hence also not declared in the test report. For additional information to the resulting risk based of this decision rule please refer to ILAC G8:2019.</i>

TEST REPORT ANSI/CAN/UL 9540A:2019 Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems	
Report Number.....: CN24YJ0X 001 Date of issue.....: See cover page Total number of pages.....: See cover page	
Name of Testing Laboratory preparing the Report.....:	TÜV Rheinland (Shanghai) Co., Ltd. 5.1.2e Shanghai 200072, P. R. China
Applicant's name Address	Suzhou RCT Power Energy Technology Co., Ltd Unit 01, 02, Building B, 5.1.2e 5.1.2e 5.1.2e Suzhou, Jiangsu P.R. China
Test specification: Standard.....: ANSI/CAN/UL 9540A:2019 Test procedure TÜV Rheinland Test Report Non-standard test method N/A	
Test Report Form No.: UL 9540A-C01 Test Report Form(s) Originator: TÜV Rheinland (Shanghai) Co., Ltd. Master TRF.....: Dated 2023-12-25	
General disclaimer: 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 Issuing Testing Laboratory. The authenticity of this Test Report and its contents can be verified by contacting the TÜV Rheinland (Shanghai) Co., Ltd., responsible for this Test Report.	
Other / Scope: This report presents the result of module level tests of UL 9540A: 2019. All tests were conducted at TUV Rheinland (Shanghai) Co., Ltd. and TUV Rheinland's partner labs that were under supervision of TÜV Rheinland's engineer. All tests were under supervision of TÜV Rheinland's engineer.	

List of Attachments:
Attachment A: Module Conditioning (Charge/discharge) Profiles

Attachment B: Observations and records

Attachment C: Module and Initiating Cell(s) Temperature Profiles During Testing

Attachment D: Module Smoke Release Rate and Chemical Heat Release Rate

Attachment E: Flammable gas generation and composition data

Attachment F: Sample Photos and Test Photos

Attachment G: List of Test and Measurement Instruments

Summary of testing:

Model No:	POWER CESS PACK 47L1D2
Ratings (Vdc, kWh) :	166.4V, 46.6kWh
Cells in series/parallel:	1P52S
Module dimensions:	243mm(H)*810mm(W)*1130mm(D)
Module weight (kg) :	332.5±5 kg
Module enclosure material:	SPCC
Total number of cell(s) went into thermal runaway:	3
Thermal Runaway and Propagation:	1 initiating cell went into thermal runaway and propagated to 2 adjacent cells
Maximum Smoke Release Rate (m ² /s)	3.69
Total Smoke Released: (m ²)	309.19
Total smoke released duration	13:13 to 16:51
Peak Chemical Heat Release Rate: (kW):	No flaming occurred
External Flaming:	No external flaming occurred
Location(s) of Flame Venting:	No flaming occurred
Flying Debris:	No flying debris occurred
Re-ignitions:	No further re-ignitions were observed during post test observation

Summary of Module level test Gas Analysis Data:

Gas Analysis:

Flame ionization detection	☒
Fourier-Transform infrared Spectrometer	☒
Hydrogen Sensor (palladium-nickel, thin-film solid state sensor)	☒
White light source with photo detector (smoke release rate)	☒

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

Name and address of factory (ies) : Same as applicant

Other:

N/A

UL 9540A testing information :

Cell level information		
Manufacturer :		GUANGZHOU GREAT POWER ENERGY&TECHNOLOGY COLTD
Model number :		GSP71173204F
Chemistry :		LiFePO ₄
Physical configuration :		Prismatic
Electrical rating :		Rated capacity: 280 Ah
		Nominal voltage: 3.2 V
Compliance with UL1973..... :		☒ Yes <u>Report No. : MH65212-20211122</u> <u>Cert. No. : MH64562</u> ☐ No
UL 9540A cell test report number..... :		4790143042
Average cell surface temperature at gas venting :		154.0 °C
Average cell surface temperature at thermal runaway :		210.0 °C
Gas Volume:		155.8 L
Lower flammability limit (LFL), % volume in air at the ambient temperature:		4.95 %
Lower flammability limits (LFL), % volume in air at the venting temperature:		4.35 %
Burning velocity (Su) :		71.4 cm/s
Maximum pressure (Pmax) :		111.0 psig
Cell level Gas Composition:		
Gas component		Concentration % (v/v)
Methane	CH ₄	21.346
Acetylene	C ₂ H ₂	3.470
Ethylene	C ₂ H ₄	9.771
Ethane	C ₂ H ₆	4.049
Propylene	C ₃ H ₆	0.256
Propane	C ₃ H ₈	0.134
-	C ₄ (Total)	0.143
-	C ₅ (Total)	0.010
-	C ₆ (Total)	0.011
Benzene	C ₆ H ₆	0.008
Toluene	C ₇ H ₈	0.001

Dimethyl Carbonate	$C_3H_6O_3$	1.088
Ethyl Methyl Carbonate	$C_4H_8O_3$	0.045
Hydrogen	H_2	41.183
Carbon Monoxide	CO	4.043
Carbon Dioxide	CO_2	14.442
-	Total	100

General product information

Photo of module:

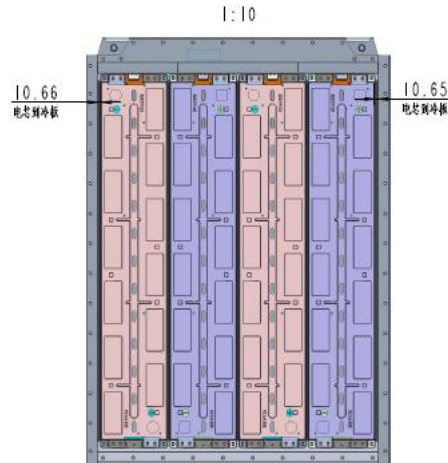


Manufacturer name :		Suzhou RCT Power Energy Technology Co., Ltd
Model number :		POWER CESS PACK 47L1D2
Physical configuration :	Nonmetallic enclosure	
	Weight: 332.5±5 kg	
	Cells in series/parallel: 1P52S	
Cooling method :		Liquid cooling
Electrical rating :	Rated capacity: 280 Ah	
	Nominal voltage: 166.4V	
Standard charge method	Charge power :	23.3kW
	End of charge voltage :	189.8 V
	Charge temperature range:	0~60 °C
	Discharge power :	23.3kW

Standard discharge method	End of discharge voltage :	130 V
	Discharge temperature range:	-30~60 °C
External dimensions (mm) :		243mm(H)*810mm(W)*1130mm(D)

Module Construction

Figure 1. Layout of the module contents



Diagrams of setup for module level testing

Figure 2. Thermocouples (no. xx) locations of initiating cell

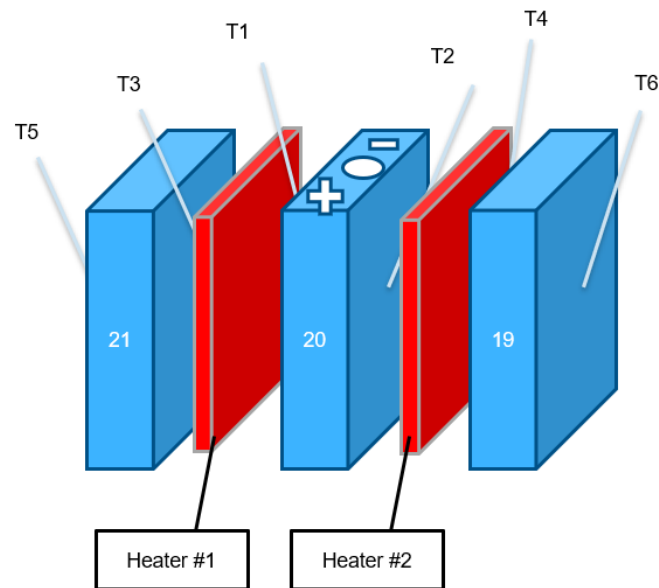


Figure 3. Cell numbering, heater location and thermocouples (no. xx) locations inside the sub-module

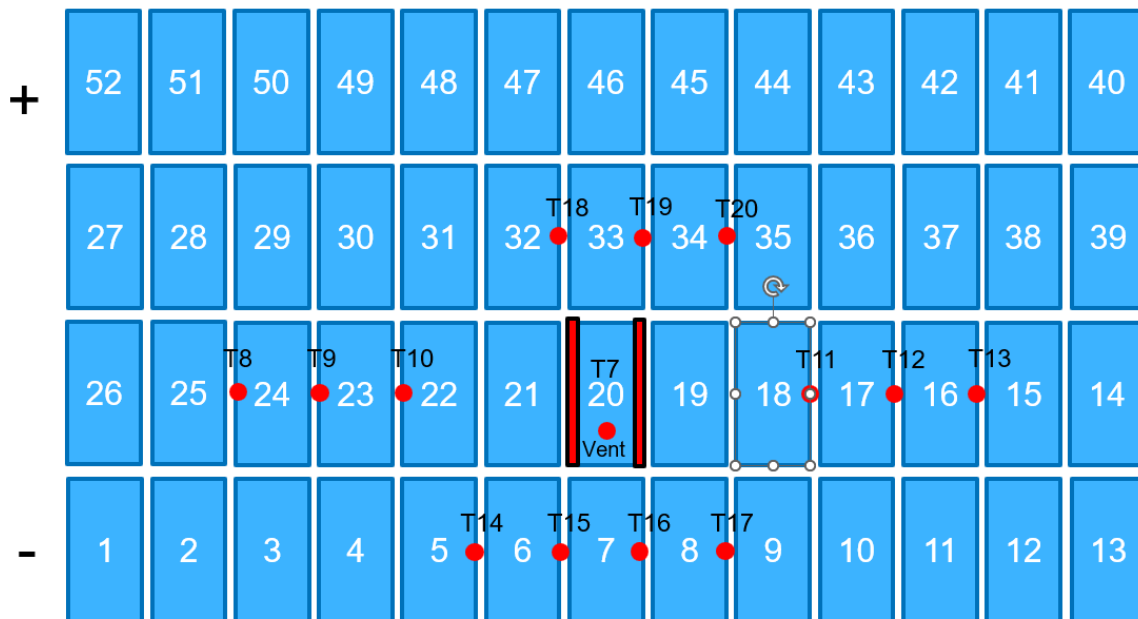
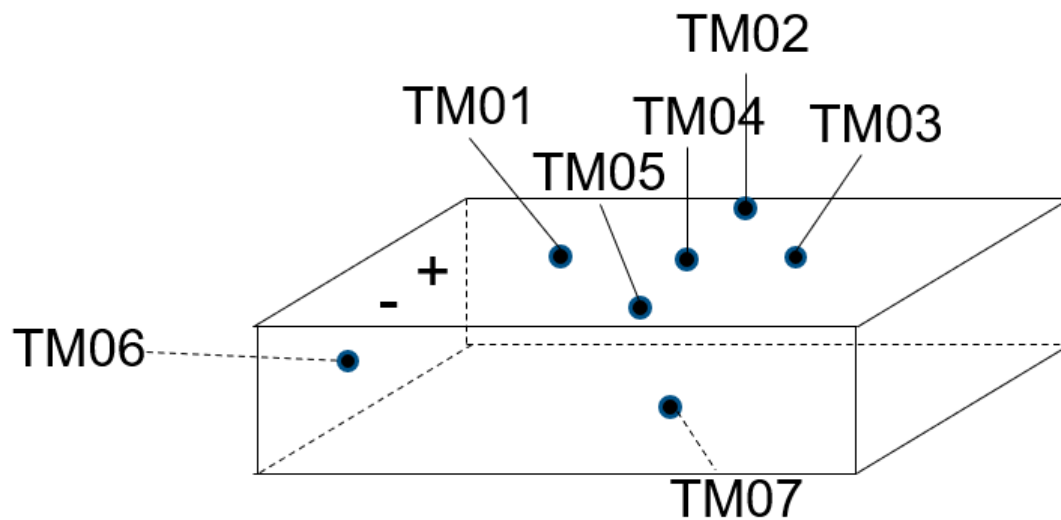


Figure 4. Thermocouples' locations outside module



ANSI/CAN/UL 9540A:2019			
Clause	Requirement + Test	Result - Remark	Verdict
CONSTRUCTION			--
5	General		--
5.1	Cell		P
5.1.1	The cells associated with the BESS that were tested shall be documented in the test report	Accepted test report by UL, test report: 4790143042	P
5.1.2	The cell documentation included in the test report shall indicate if the cells associated with the BESS comply with UL 1973		P
5.1.3	Refer to 7.6.1 for further details		N/A
5.2	Module		P
5.2.1	The modules associated with the BESS that were tested shall be documented in the test report	See Product Specification on Page 8	P
5.2.2	The module documentation included in the test report shall indicate if the modules associated with the BESS comply with UL 1973	Test with unit	N/A
5.2.3	Refer to 8.3 for further details	See 8.3	P
5.3	Battery energy storage system unit	Not applicable for module level product.	N/A
5.3.1	The BESS unit documentation included in the test report shall indicate the units that comply with UL 9540		N/A
5.3.2	For BESS units for which UL 9540 compliance cannot be determined,		N/A
5.3.3	If applicable, the details of any fire detection and suppression systems that are an integral part of the BESS shall be noted in the test report		N/A
5.3.4	Refer to 9.7, 10.4 and 10.7 for further details		N/A
5.4	Flow Batteries	Not applicable for lithium product.	N/A
5.4.1	For flow batteries, the report will cover the chemistry, as well as the electrical rating in capacity and nominal voltage of the cell stack		N/A
5.4.2	The flow battery documentation included in the test report shall indicate if the flow battery system complies with UL 1973		N/A
5.4.3	See 7.6.2 for further details		N/A
PERFORMANCE			--
6	General		--
6.1	The tests in this standard are extreme abuse conditions conducted on electrochemical energy storage devices that can result in fires, explosions, smoke, off gassing of flammable and toxic materials, exposure to toxic and corrosive liquids, and potential exposure to hazardous voltages and electrical energy. See Annex B for recommended testing practices.		P

ANSI/CAN/UL 9540A:2019			
Clause	Requirement + Test	Result - Remark	Verdict
6.2	At the conclusion of testing, samples shall be discharged in accordance with the manufacturer's specifications		P
8	Module Level		--
8.1	Sample		P
8.1.1	Module samples shall be conditioned, prior to testing, through charge and discharge cycles for a minimum of 2 cycles, using a manufacturer specified methodology	See Attachment A for profiles	P
8.1.2	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	Stablize 3 hours	P
8.1.3	Electronics and software controls such as the battery management system (BMS) are not relied upon for this testing.	Module BMS constructed but not operated during the test.	P
8.2	Test method		P
8.2.1	Ambient indoor laboratory conditions shall be 25 ±5°C (77 ±9°F) and 50 ±25% RH at the initiation of the test.	See Attachment B	P
8.2.2	The test shall be conducted under a smoke collection hood	Smoke collection hood used	P
8.2.3	The weight of the module shall be recorded before and after testing	See Attachment B	P
8.2.4	The number of cells within the module that are forced into thermal runaway can be one or multiple cells	See Figure 2 Three cells forced into thermal runaway.	P
8.2.5	The methodology used for initiating thermal runaway pursuant to 7.2 shall be used	Two external film heaters used	P
8.2.6	With reference to 8.2.5, occurrence of thermal runaway shall be verified by sustained temperature above the cell surface temperature		P
8.2.7	The module shall be placed on top of a noncombustible horizontal surface		P
8.2.8	The chemical heat release rate of the module in thermal runaway shall be measured with oxygen consumption calorimetry.		P
8.2.9	The chemical heat release rate shall be measured for the duration of the test. See 8.2.10.		P
8.2.10	The chemical heat release rate shall be measured by a measurement system consisting of a paramagnetic oxygen analyzer		P
8.2.11	With reference to 8.2.10, calculate the chemical heat release rate at each of the flows as follows: $HRR_1 = \left[E \times \phi - (E_{co} - E) \times \frac{1-\phi}{2} \times \frac{X_{co}}{X_{O_2}} \right] \times \frac{\dot{m}_e}{1+\phi \times (\alpha-1)} \times \frac{M_{O_2}}{M_a} \times (1-X_{H_2O}^o) \times X_{O_2}^o$		P
8.2.12	Vent gas composition shall be measured using a Fourier-Transform Infrared Spectrometer or equivalent gas analyzer		P

ANSI/CAN/UL 9540A:2019			
Clause	Requirement + Test	Result - Remark	Verdict
8.2.13	The hydrocarbon content of the vent gas shall be measure using flame ionization detection		P
8.2.14	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		P
8.2.15	Smoke release rate shall be calculated as follows: $SRR = 2.303 \left(\frac{V}{D} \right) \log_{10} \left(\frac{I_o}{I} \right)$		P
8.3	Module level test report		P
8.3.1	The report on module level testing shall include the following:		P
	a) Module manufacturer and model number; b) Number of cells in module; c) Module configuration;	See Test Item Description in beginning of this report.	P
	d) Module construction features;	See Page 10 Module Construction	P
	e) Module voltage corresponding to the tested SOC;	See Attachment B	P
	f) Thermal runaway initiation method used;	See Figure 2	P
	g) Heat release rate versus time data;	See Attachment B	P
	h) Flammable gas generation and composition data;	See Attachment E	P
	i) Peak smoke release rate and total smoke release data.	See Attachment D	P
	j) Observation(s) of flying debris or explosive	See Attachment B	P
	k) Observation(s) of sparks, electrical arcs, or other electrical events;	See Attachment B	P
	l) Identification/location of cells(s) that exhibited thermal runaway within the module;	See Figure 2	P
	m) Locations and visual estimations of flame extension and duration from the module shall be documented;	See Attachment B	P
	n) Module weight loss based on measurements per 8.2.3; and	See Attachment B	P
	o) Video of the test.	Recorded	P
8.4	Performance at module level testing		F
8.4.1	Unit level testing in Section 9 is not required if the following performance conditions are met during the module level test:	Unit level testing required.	F
	a) Thermal runaway is contained by module design; and		P
	b) Cell vent gas is nonflammable as determined by the cell level test.	Accepted test report by UL, test report: 4790143042	F

-- End of this report --

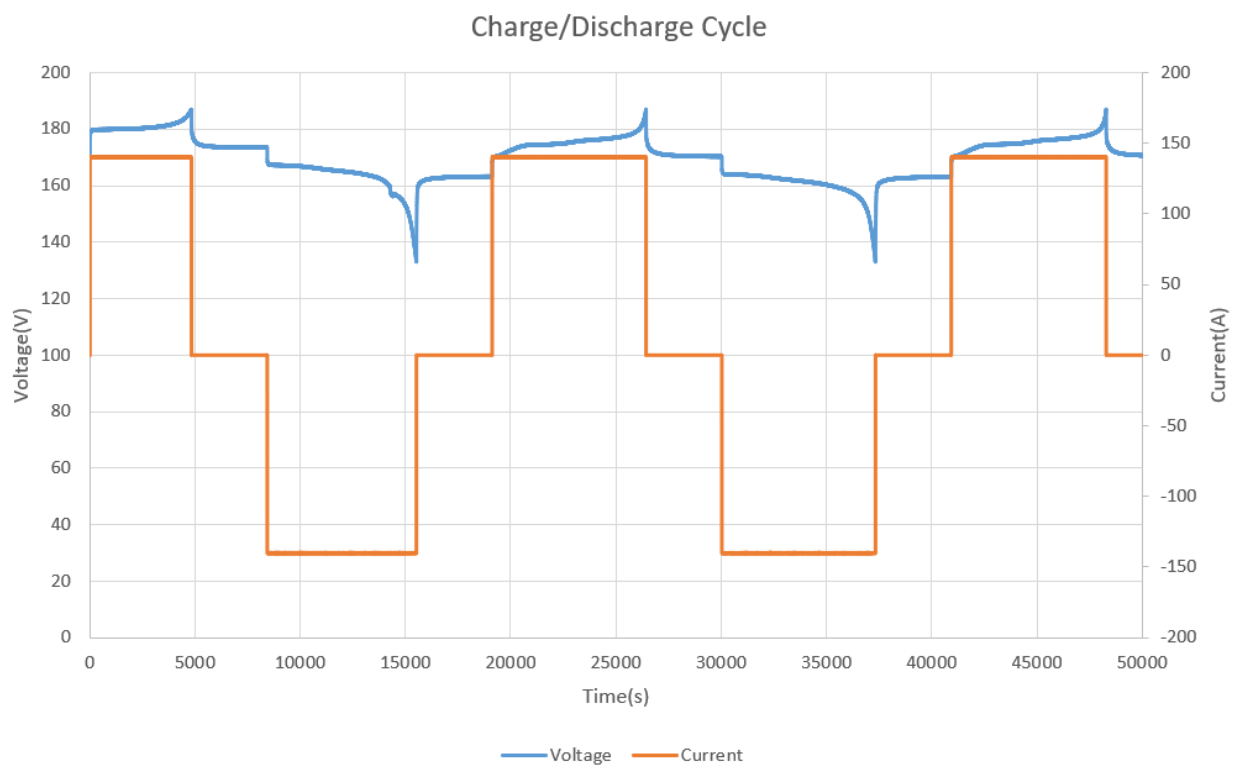
Attachment A Module Conditioning (Charge/discharge) Profiles

Module sample was conditioned, prior to testing, through charge and discharge cycles of 2 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 5. Module charge and discharge voltage/current profiles



Attachment B Observations and records

Test initiation details	
Ambient conditions at the initiation of the test. :	29.8°C, 68.6% R.H.
Sample number	#2024102801
Open circuit voltage before test (V).....	170.1
Weight before test (kg)	340.0 (with thermocouples)
Open circuit voltage after test (V).....	159.6
Weight after test (kg)	338.0 (with thermocouples)
Weight loss (kg).....	2.0

Test overview timeline		
Locations (Cell #)	Event	Time
-	Test start	13:14
20	Vent	13:55
21	Vent	14:05
22	Vent	14:09
20	Thermal runaway	14:10
21	Thermal runaway	14:16
22	Thermal runaway	14:23
23	Vent	15:37

Note:

- 1) No flying debris or explosive discharge of gases during test.
- 2) No sparks, electrical arcs, or other electrical events during test.
- 3) No flaming observed.

Attachment C Module and Initiating Cell(s) Temperature Profiles During Testing

Figure 6. Temperatures of cell #19~#21

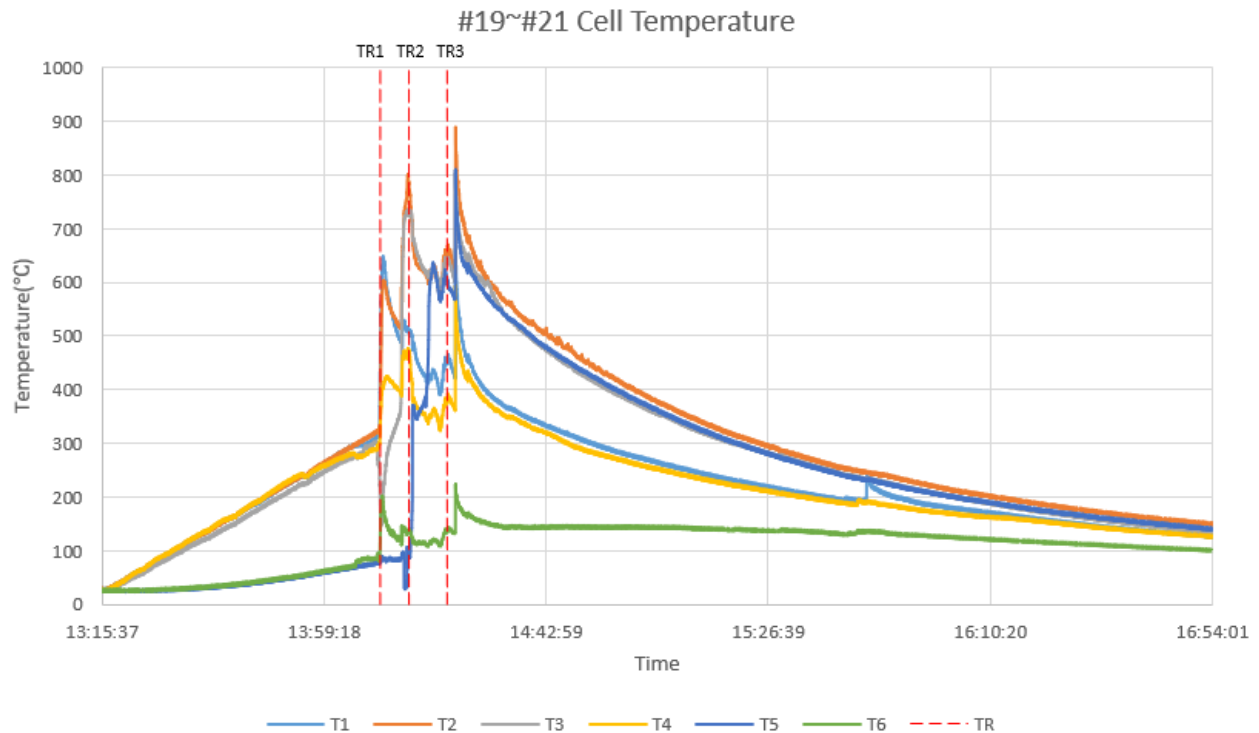


Figure 7. Temperatures of cell #16~#18 and #22~#24

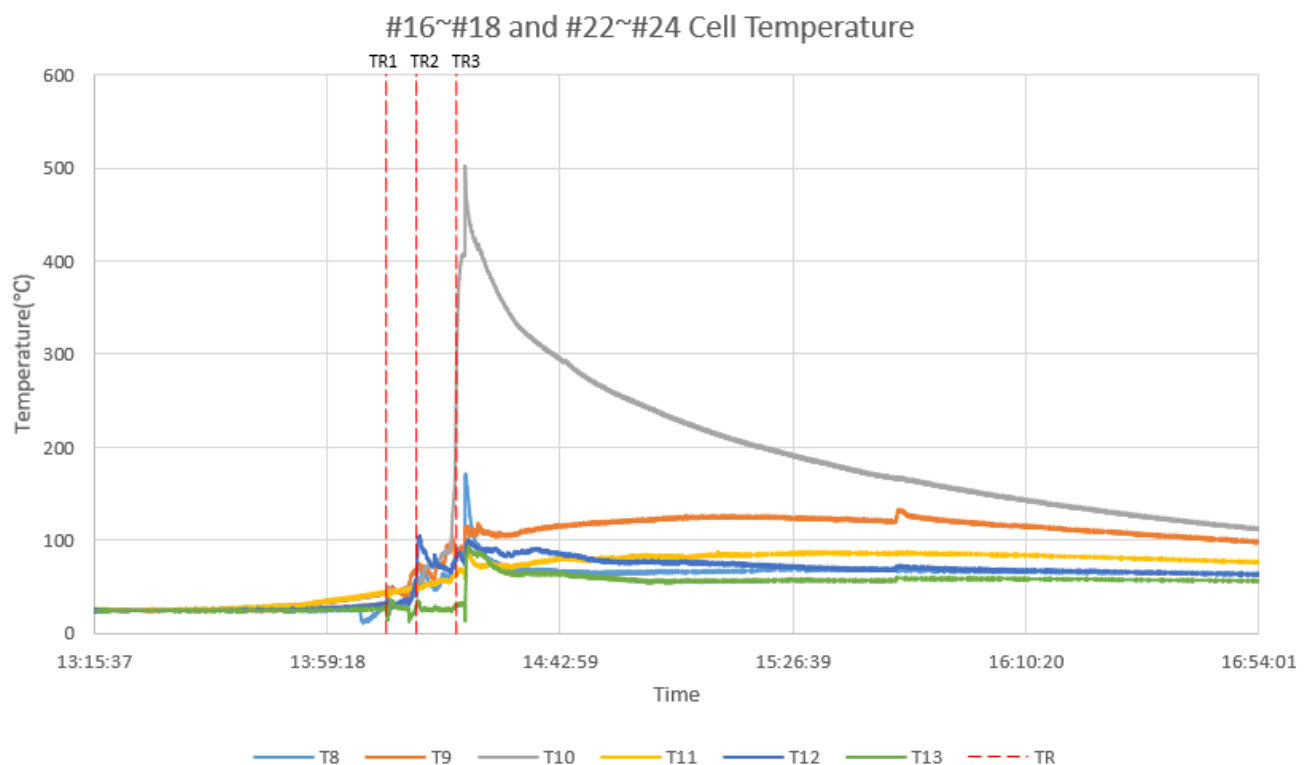


Figure 8. Temperatures of cell #5~#8

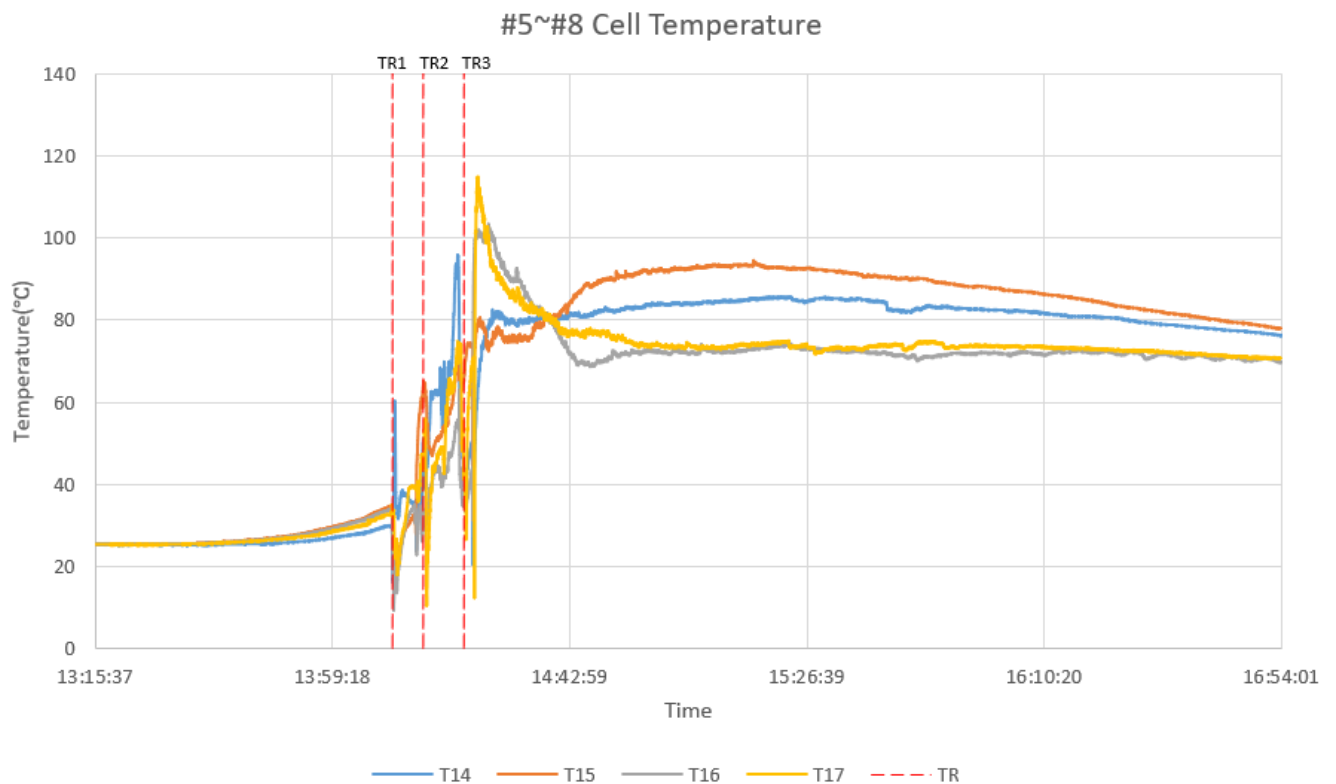


Figure 9. Temperatures of cell #32~#34

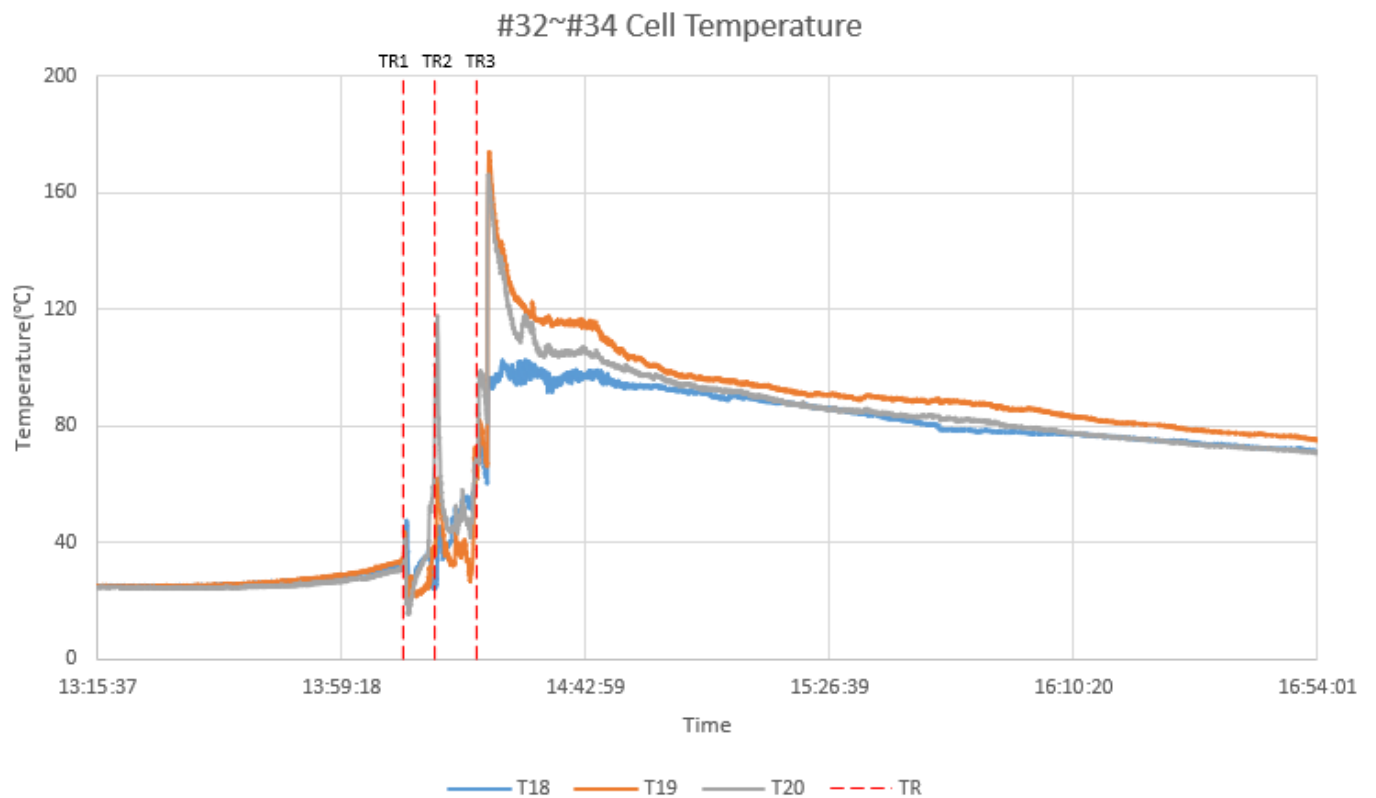


Figure 10. Temperatures of module surface

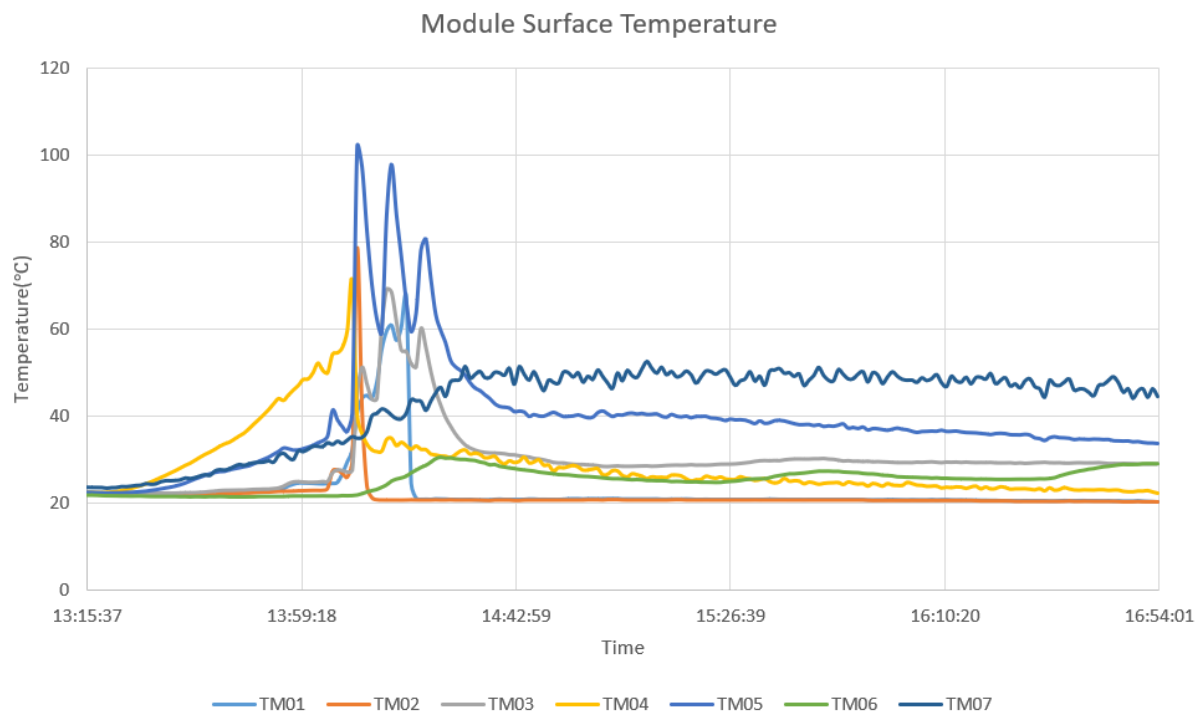
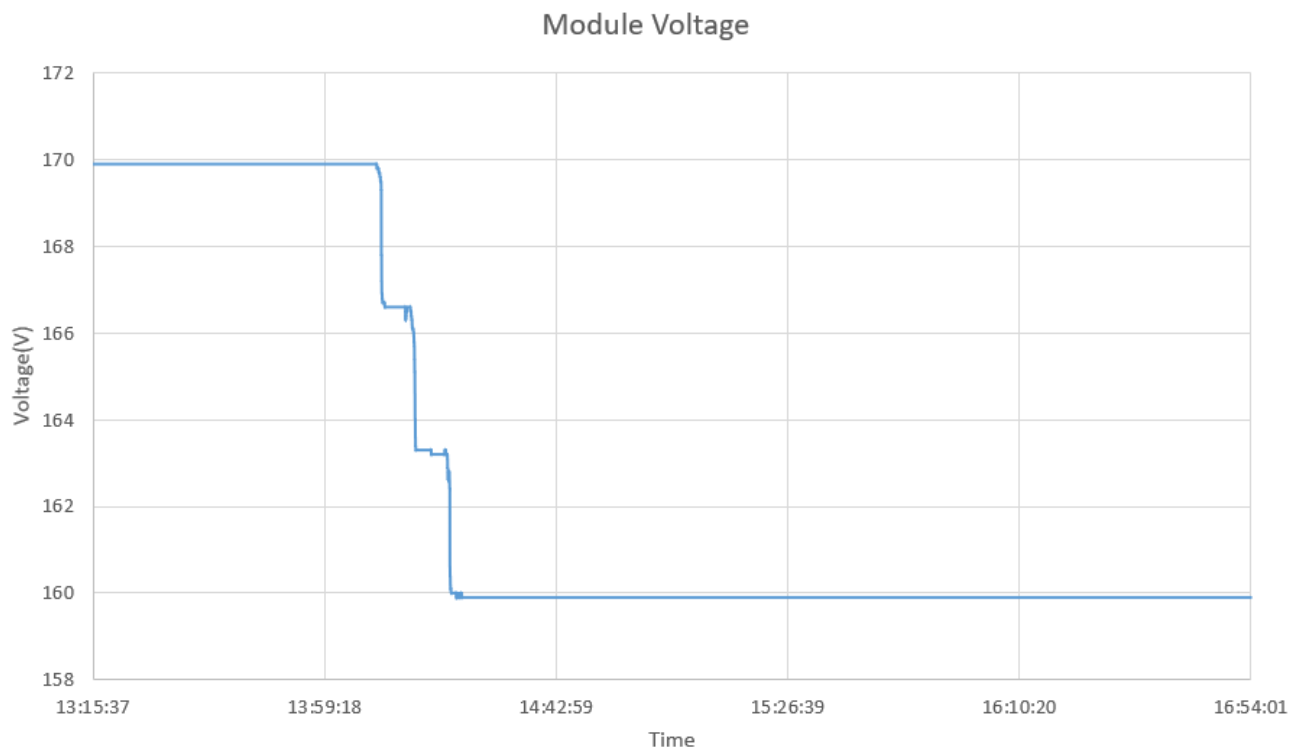


Figure 11. Module Voltage



Attachment D Module Smoke Release Rate and Chemical Heat Release Rate

Smoke and heat release rate		
Smoke Release Rate (SRR)	Maximum SRR(m ² /s)	3.69
	Total Smoke Released(m ²)	309.19
Heat Release Rate (HRR)	Peak Chemical HRR(kW)	No flaming observed
	Total Heat Release(MJ)	No flaming observed

Figure 12. SRR curve

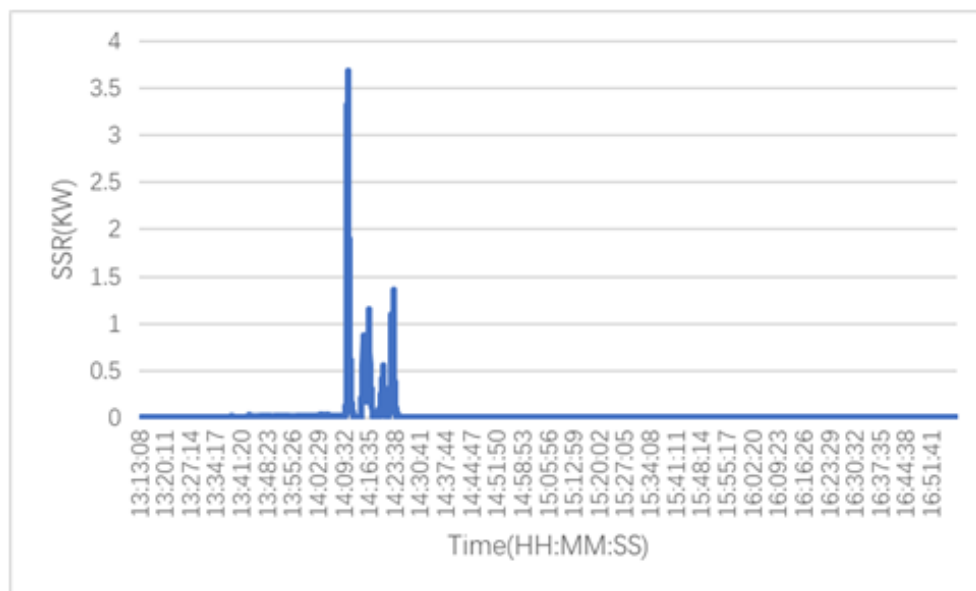
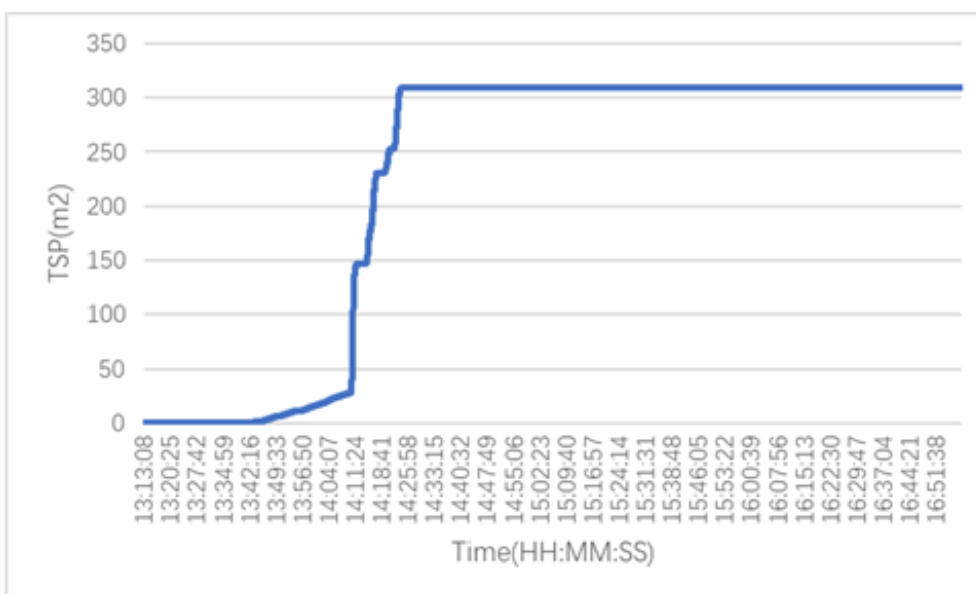


Figure 13. TSR curve



Attachment E Flammable gas generation and composition data

Measurement Method	Gas Compound	Gas Type	Pre-Flaming (L)	Post-Flaming (L)
Flame ionization detection	Total Hydrocarbons (Propane Equivalent)	Hydrocarbons	186.82	No flaming
Fourier-Transform infrared Spectrometer	Carbon Monoxide	Carbon Containing	69.09	No flaming
	Carbon Dioxide	Carbon Containing	173.11	No flaming
Solid-state Hydrogen Sensor	Hydrogen	Hydrogen	399.41	No flaming
Note: 1) The collection time is from 13:13 to 16:51.				

Measurement Method	Gas components		Total volume of gas (L)	
			Pre-Flaming	Post-Flaming
Fourier-Transform infrared Spectrometer	Methane	CH ₄	121.38	No flaming
	Ethylene	C ₂ H ₄	39.29	No flaming
	Ethane	C ₂ H ₆	7.36	No flaming
	Propylene	C ₃ H ₆	11.49	No flaming
Note: 1) The collection time is from 13:13 to 16:51.				

Figure 14. Total Hydrocarbons

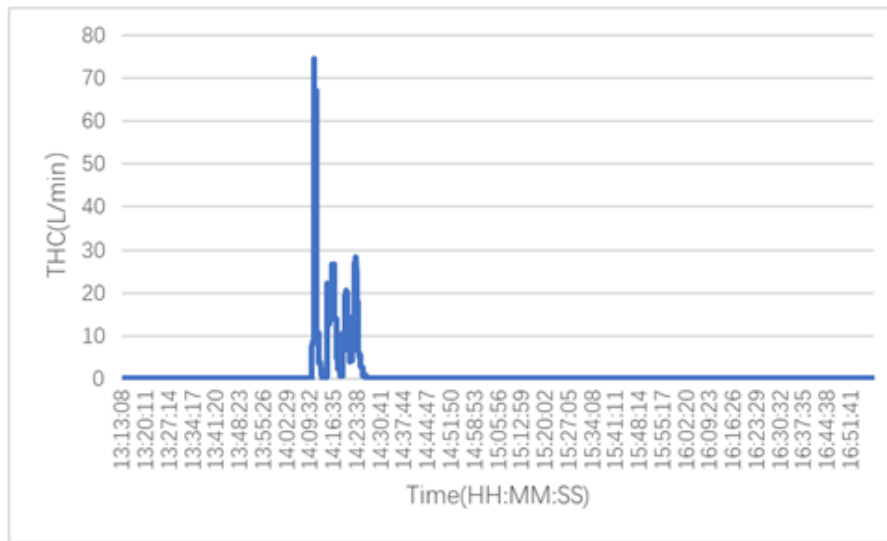
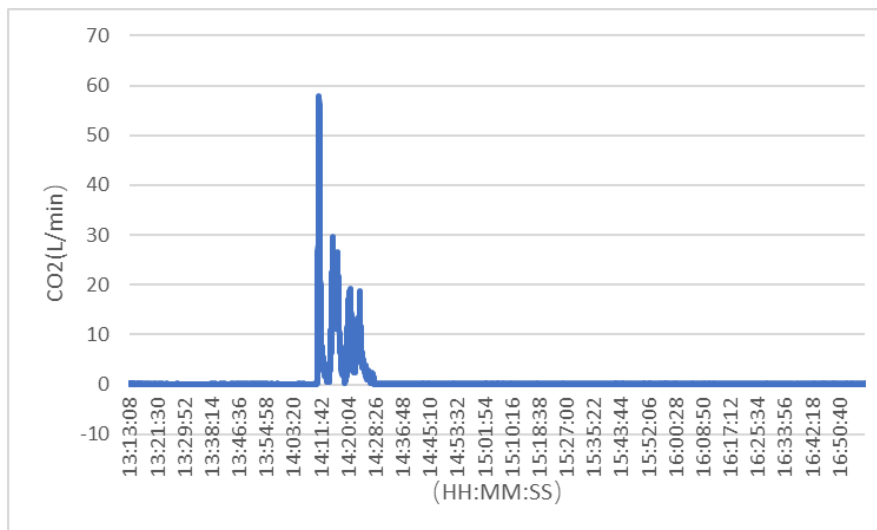
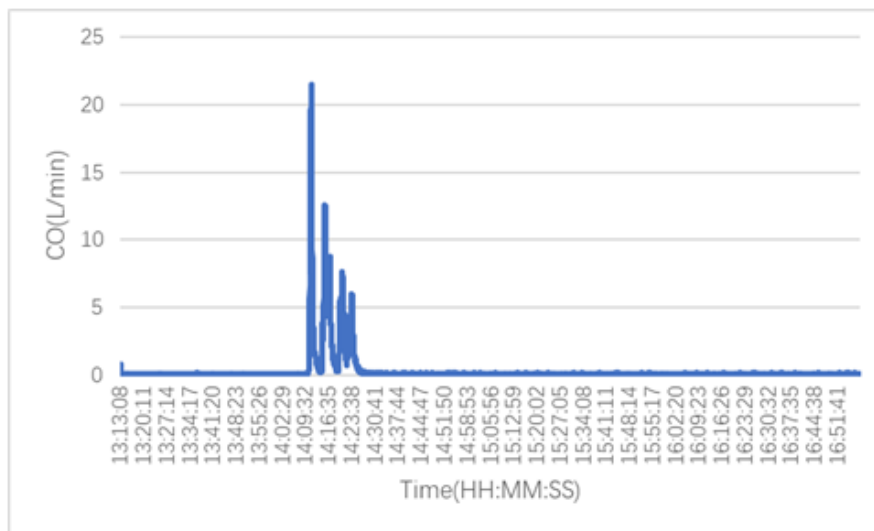

Figure 15. CO, CO₂


Figure 16. Hydrogen

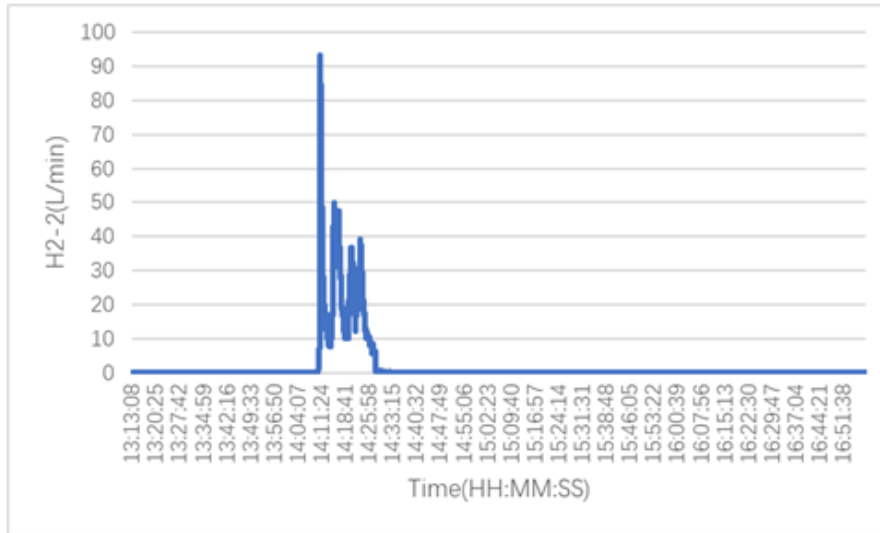
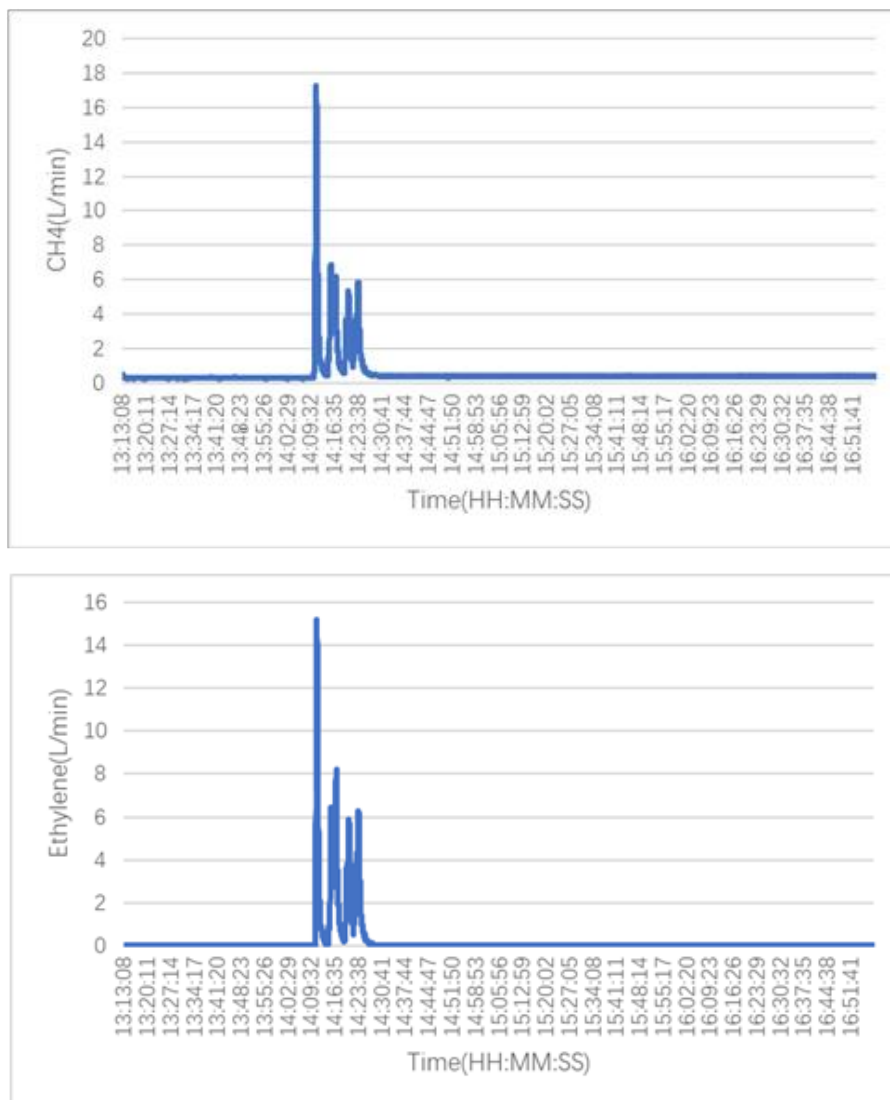
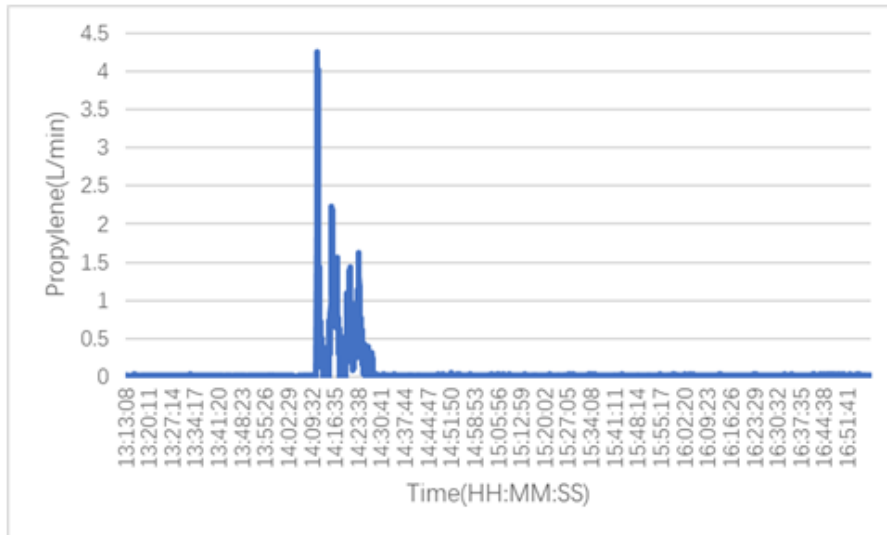
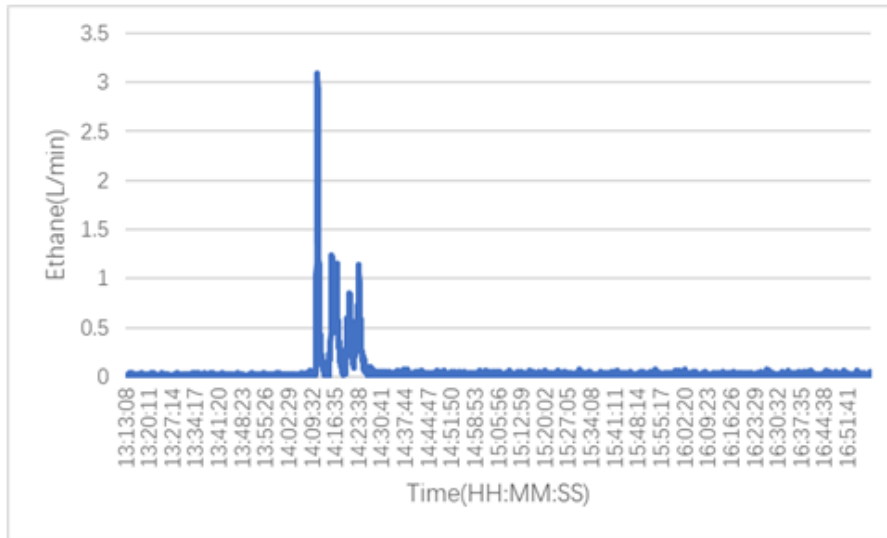


Figure 17. Hydrocarbon species





Attachment F Sample Photos and Test Photos

Figure 18. Sample before test





Figure 20. Smoke release during test

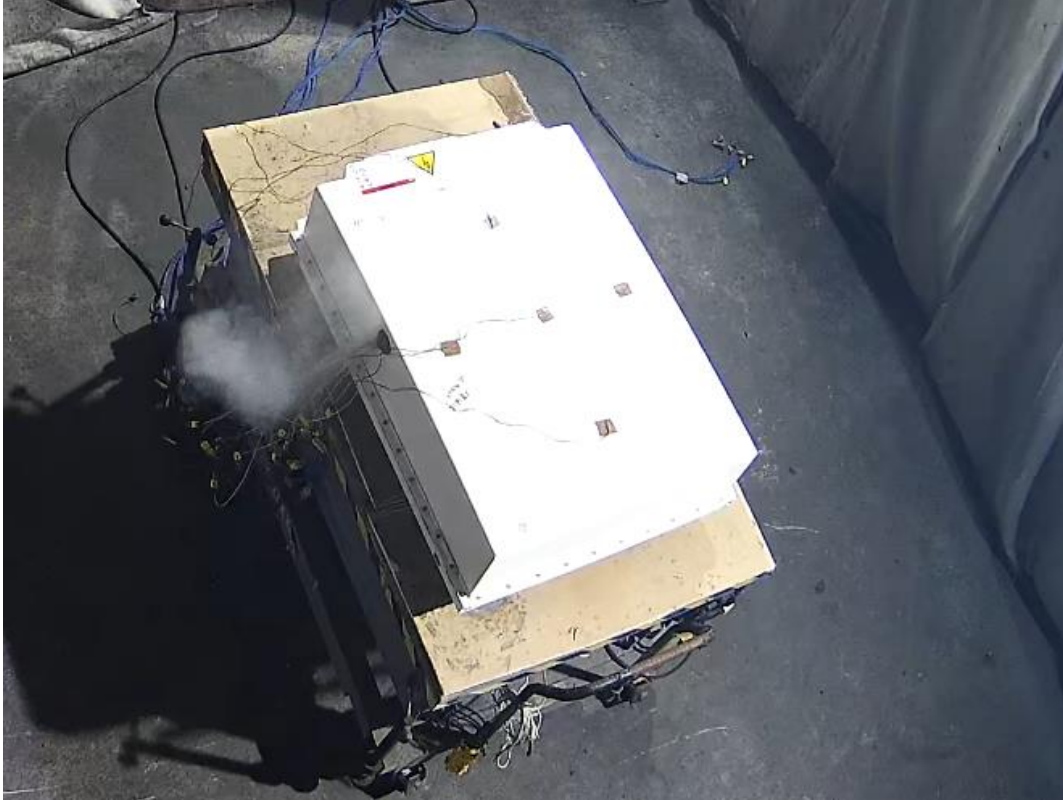
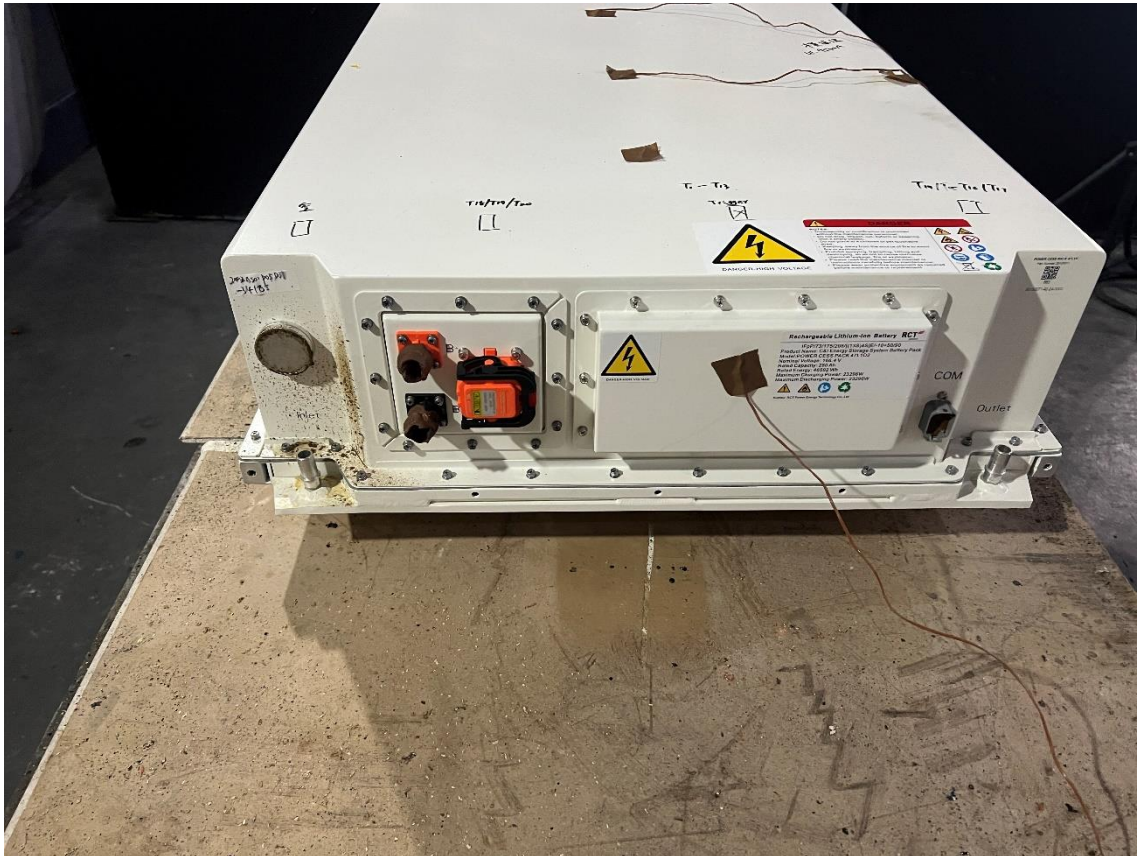


Figure 21. Sample after test





Attachment G 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	2025.2.2
2	Data acquisition equipment	DAQ970A	3-slot cardcage with 6½ digit (22 bit) internal DMM 0.004%, accuracy 0.06% Vac	TY2020000138	2025.2.2
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	2025.2.2
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	2025.2.2
5	Electronic scale	CHAOOU C1	0-500KG	65960494169	2025.2.2
6	Paramagnetic oxygen analyser	SERVOME X4100	O2: paramagnetic sensor, range 0-25%, accuracy 0.02%, response time T90 < 7S	ZY2020000018-1	2025.2.6
7	Velocity probe	2671-25L-D-11-G2-E-N	4-20mA output, range 0-250pa, accuracy ± 1% F.S	ZY2020000018-2	2025.2.6
8	Photo detector	PDA36A2	Thorlabs optical receiver, wavelength range (350-1000) nm, gain adjustable, voltage output (0-10) V, instability < 0.1%	ZY2020000018-3	2025.2.2
9	Fourier-Transform Infrared Spectrometer	atmosFIR	Spectral scanning range: 485 - 7500cm-1; Spectral repeatability: < 0.1cm-1	ZY2020000018-5	2025.3.9

10	Non-dispersive infrared carbon dioxide and carbon monoxide sensor	SERVOME X4100	CO ₂ : infrared sensor, measuring range 0-10%, accuracy 1% F.S, response time T ₉₀ < 7S Co: infrared sensor, measuring range 0-1%, accuracy 1% F.S, response time T ₉₀ < 8s	ZY20200000 18-4	2025.2.6
11	Palladium-nickel thin-film solid state sensor	MODEL 2000	Range: 0-2000ppm, temperature less than 100 °C, -90~110kPa	ZY20210002 10	2025.2.2
12	Flame ionization detector	3010	Accuracy: 2.0%	19937	2025.3.9
13	Heat flux measurement equipment	MW88-JTC08C	0 ~ ± 99999 w / m ² , - 250 ~ 980 °C, accuracy 5%, response time less than 0.1s,	ZY20200000 10	2025.2.2
14	Thermopile	RS-WD-HW-1	0-200 °C, 4-20mA, response speed < 0.15s	2834814194 2	2025.2.2

Legenda toegepaste uitzonderingsgrondslagen

In dit document zijn gegevens definitief geanonimiseerd op grond van:

Wet	Artikel	Omschrijving	Pagina's
Wet open overheid	Art. 5.1 lid 2 sub e	De eerbiediging van de persoonlijke levenssfeer	1, 3, 5, 23