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COFFMAN ENGINEERS



VACA DIXON POWER CENTER - VACA DIXON BESS

Hazard Mitigation Analysis

COFFMAN PROJECT NO. 251796

IFP SUBMITTAL

October 28, 2026

Prepared for: Vaca Dixon BESS LLC

HAZARD MITIGATION ANALYSIS

FOR

VACA DIXON BESS

Vacaville, California

Project Number: 251796

Revision	Date	Description
0	12/30/2025	Issued for Permit
1	10/9/2026	Change in BESS Technology

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ABBREVIATIONS

AHJ	Authorities Having Jurisdiction
BMS	Battery Management System
BOL	Beginning of Life
CATL	Contemporary Amperex Technology
CFC	California Fire Code
DC	Direct Current
EMS	Energy Management System
EOL	End of Life
ESS	Energy Storage System
FACP	Fire Alarm Control Panel
FCC	Fire Command Center
IFC	International Fire Code
HMA	Hazard Mitigation Analysis
HVAC	Heating, Ventilation, and Air Conditioning
IDLH	Immediately Dangerous to Life and Health
kV	Kilovolt
LFL	Lower Flammability Limit
LPC	Local Plant Controller
MW	Megawatt
MWh	Megawatt-hour
MV	Medium Voltage
NEC	National Electric Code
NESC	National Electric Safety Code
PCS	Power Conversion System
PEL	Permissible Exposure Limits
PG&E	Pacific Gas and Electric Company
SCADA	Supervisory Control and Data Acquisition
UPS	Uninterruptible Power Supply

1 PROJECT BACKGROUND

1.1 Introduction

Coffman Engineers, Inc. provides this Hazard Mitigation Analysis (HMA) in accordance with the 2025 California Fire Code (CFC), as amended and adopted by the City of Vacaville, for the Vaca Dixon Battery Energy Storage System (BESS) facility located in Vacaville, California. The site utilizes CATL (model #CP1) enclosures containing Prismatic Lithium Iron Phosphate (LFP) batteries, totaling 57 Megawatts (MW) of battery energy storage.

This HMA for the Vaca Dixon BESS facility has been prepared for Vaca Dixon BESS LLC and is being submitted to the California Energy Commission (CEC) for review and approval. The CEC is the entity responsible for licensing the Vaca Dixon BESS facility including review (in consultation with the Vacaville Fire Department) and approval of fire-related plans and design related to the BESS facility. The Vacaville Fire Department is the Fire Marshal and is considered the AHJ for the purposes of Fire and Life Safety matters (e.g., emergency response planning and incident response). The life safety of personnel shall be the highest priority during any event.

1.2 Site Location

The Vaca Dixon BESS facility, with a capacity of 57MW/57MWh, is located on a 4.25-acre portion of a 10-acre parcel (APN 0133-060-060). The separate Arges BESS facility, with a capacity of 100MW/400MWh, is located to the north on a 5.75-acre portion of the same parcel. The project is located within Solano County, Kilkenny Rd, Vacaville, CA 95377 with coordinates 38°23'46.4"N 121°55'17.3"W. See Figure 1.2.1 and figure 1.2.2 for site location and layout.

Project Summary	
Owner	VACA DIXON BESS LLC
Utility	Pacific Gas and Electric Company (PG&E)
ESS Enclosure Type	Enclosure Type IP-55 CATL CP1 (C04285P10L0)
Number of ESS Enclosures	21 BOL (29 EOL)
Total Site Footprint	4.25 acres
Capacity	57 MW / 57 MWh

The project will utilize CATL CP1 outdoor-rated energy storage system (ESS) enclosures and associated on-site support facilities including inverters, collection lines, fencing, access roads, SCADA, switchgear, and other ancillary equipment. The Vaca Dixon switchgear is located on-site to the west of the Vaca Dixon BESS.

The typical equipment arrangement is a block of four CATL ESS enclosures connected to a single power conversion system (PCS) which is then connected to the site switchgear via buried medium voltage (MV) circuits.

The project includes a separate BESS yard (Arges BESS) that is located to the north of the Vaca Dixon BESS yard and is outside the scope of work and will not be addressed within this HMA. A separate HMA has been prepared for the Arges BESS facility.

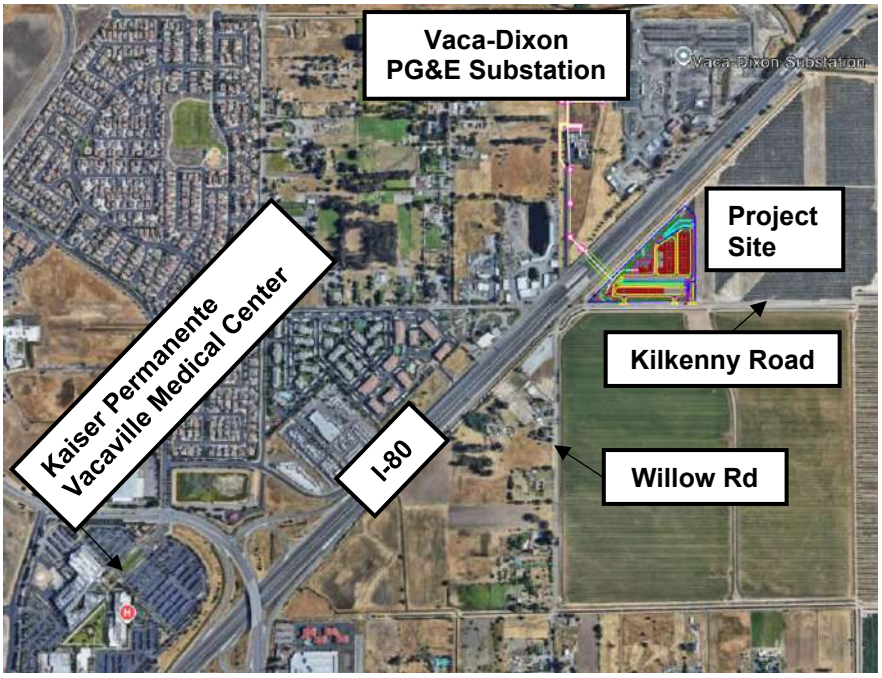


Figure 1.2.1 – Vaca Dixon BESS Vicinity Map (North ↑)

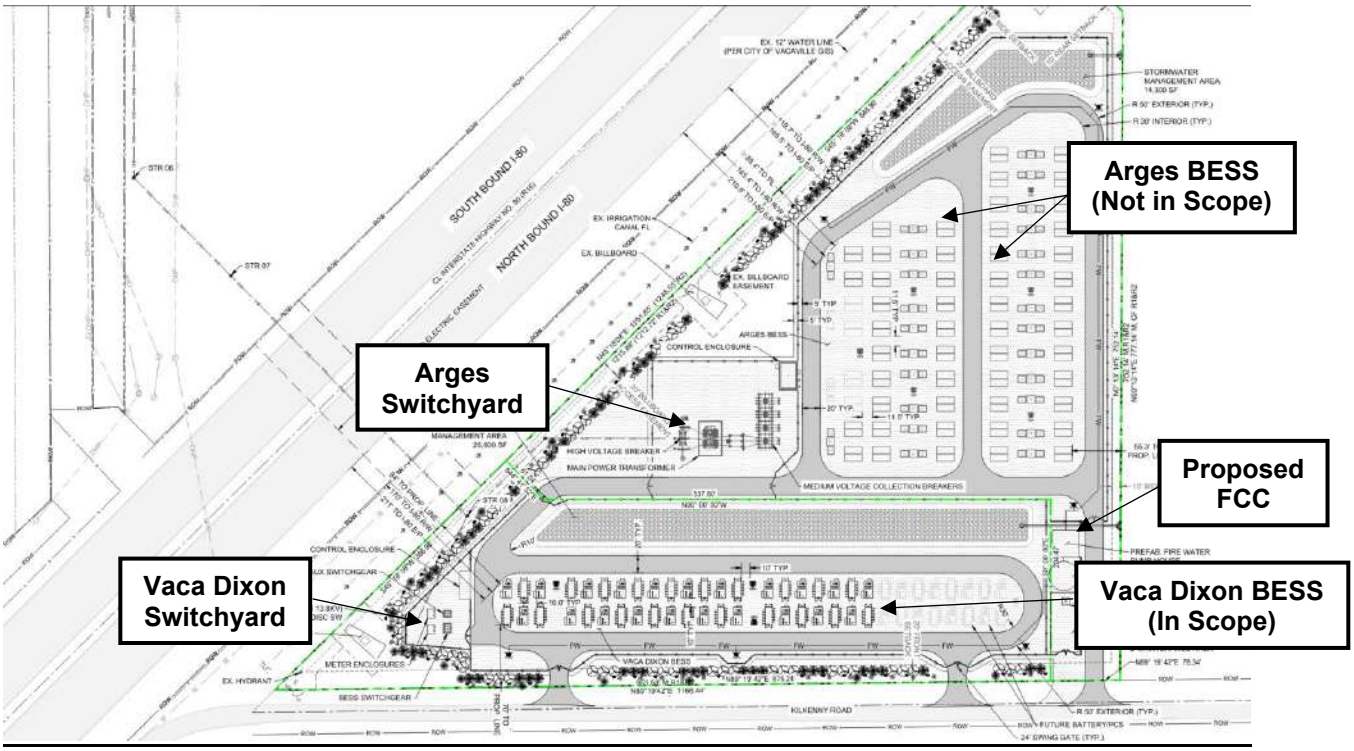


Fig 1.2.2 – Vaca Dixon BESS (North ↑)

1.3 Project and Code Summary

1.3.1 Enclosure and Battery Requirements

ESS REQUIREMENTS		
Code	Requirement	Compliance Status
Equipment Listing: *CFC §1207.3.2*	ESS shall be listed in accordance with UL 9540.	**Compliant.** CATL CP1 ESS Enclosure, certified to ANSI/CAN/UL 9540, 2024 by TÜV Rheinland under test report no. CN237GL9 003. Certificate #: CU 72403736 0003. *Additional details: HMA Appendix A*
ESS Type: *CFC §202 CFC 2025 Edition Definition)*	An Energy Storage System Cabinet is defined as a system where personnel cannot enter the enclosure other than reaching in to access components for maintenance purposes.	**Compliant.** Classification: Energy Storage System Cabinet Note: "ESS enclosure", and "non-walk-in" are used synonymously with "Energy Storage System Cabinet" in this report. All terms refer to the CATL enclosure. *Additional details: HMA Section 1.6*
Technology: *CFC §1207.6*	Requires lithium-ion ESS to comply with provisions relating to thermal runaway and explosion control.	**Compliant.** ESS Enclosures are provided with an Energy Management System and explosion prevention system.
Size and Separation: *CFC §1207.5.1, 1207.5.2*	Allows groups to exceed 50 kWh with less than 3 ft spacing based upon large-scale testing. The ESS's Maximum allowable stored energy (600 kWh) to be exceeded where an HMA and large-scale testing justify an increase.	**Compliant.** 5,030 kWh total per enclosure. Large-scale testing (UL 9540A) has been conducted to justify reduced spacing. The distance between the instrument wall and the initiating BESS is 10ft, the maximum wall surface temperature was 225°F *Additional details: HMA section 2.4 and Appendix H.*
Hazard mitigation analysis: *CFC §1207.1.6*	The ESS's Maximum allowable stored energy (600 kWh) to be exceeded where an HMA and large-scale testing justify an increase.	**Compliant.** Hazard Mitigation Analysis will be submitted to the AHJ for final Approval.
Thermal Runaway: *CFC §1207.6.5*	Listed device or approved method required to preclude, detect, and minimize the impact of thermal runaway.	**Compliant.** Thermal runaway mitigation provided via UL9540A tested design and UL1973 listed Battery Management System (BMS) which actively monitors the voltage and temperature of all cells. *Additional details: HMA Section 3.3*
Explosion Control: *CFC 1207.6.3*	Explosion prevention or deflagration venting measures required.	**Compliant.** NFPA 69 Explosion Protection by Mechanical Ventilation system has been included. *Additional details: HMA Section 3.4*
Fire Detection: *CFC §1207.5.4*	Requires a smoke fire detection system be installed in all rooms containing ESS	**Compliant.** The CATL enclosure is equipped with an automatic fire detection system (smoke and heat detectors) and a gas detection system. *Additional details: HMA Section 3.1*

1.3.2 ESS Site Requirements

SITE REQUIREMENTS		
Code	Requirement	Compliance Status
Outdoor ESS Installation Type: *CFC §1207.8*	Outdoor ESS installations less than 100 ft from adjacent to site exposures, buildings, lot lines, or public ways shall be classified as "Near Exposures." Installations greater than 100 feet are "Remote locations.	**Compliant.** Classification: Outdoor ESS installations, location near exposures.
Clearance to Exposures: *CFC §1207.8.3*	A 10 ft clearance from ESS to lot lines, public ways, buildings, combustible materials, and other potential exposure hazards is required to prevent fire spread. Clearances to exposures other than buildings may be reduced to 3 ft where approved and supported by large-scale fire testing of the ESS	**Compliant.** The installation complies with the clearance to exposure requirement based on the results from UL 9540A Test. A minimum of 10 feet is provided in all directions within the BESS Yard to the nearest lot line. *Additional details: HMA Figure 1.6.1*
Site Fire Water Source: *CFC §507.1 (inferred)*	Requires adequate on-site fire water source.	**Compliant**. UL 9540A testing was completed without water suppression. Water availability for site non-ESS fire events will be provided via three on-site hydrants, which are supplied by an on-site 120,000 gal water storage tank. *Additional details: HMA Section 3.2*
Vegetation Control: *CFC §1207.5.7*	Areas within 10 ft on each side of outdoor ESS shall be cleared of combustible vegetation and other combustible growth.	**Compliant.** Decomposed granite or paved areas are provided at least 10 ft on all sides of the ESS enclosures.
Fire Department Access: *CFC Chapter 5*	Ensures adequate site access for emergency events and would require proper features including road widths, turnarounds, grade/surface and signage/markings.	**Compliant.** The site will incorporate all requirements within these access provisions established by CFC Chapter 5 subject to AHJ requirements and approval. The Vaca Dixon facility will be provided with two access points, one off of Kilkenny Rd and one via the Vaca Dixon facility.
Impact Protection: *CFC §1207.4.5*	ESS shall be located or protected to prevent physical damage from impact where such risks are identified.	**Compliant.** There is limited risk to vehicle impact without individual bollards based upon the following: 1) Completely fenced off area with no public access. 2) Only technicians familiar with the site will access the site. 3) Enclosures are located at least 5 ft from the edge of the access roads 4) Vehicle traffic speeds will be limited to 10 mph. At a minimum there will be bollards placed at the corners of the road for turning protection.

Security of installation *CFC §1207.4.9*	ESS shall be secured against unauthorized entry and safeguarded in an approved manner.	**Compliant.** A 7 ft fence is provided around the entire site with no public access. The entrance gates are manually opened, and pad locked closed.

1.3.3 ESS Provisions not Applicable to this Project

REQUIREMENTS NOT APPLICABLE TO THIS PROJECT		
Code	Requirement	Compliance Status
Fire Area Separation: *CFC §1207.7.4*	Rooms or spaces containing ESS shall be separated from other areas of the building by 2-hour fire barriers.	**Not Applicable.** Enclosures have no fire rating requirement as they are not installed in a building.
Exhaust Ventilation: *CFC §1207.6.1*	N/A for Lithium-Ion technology	**Not Applicable.** Not required/applicable as it does not off gas during normal charging operations.
Fire Suppression Systems: *CFC §1207.5.5*	Requires rooms containing ESS systems shall be equipped with an automatic sprinkler system installed.	**Not Applicable.** No suppression is required per the UL 9540 listing of the enclosure. (9540A testing shows limited propagation with no suppression). Enclosures are also non-walk type. Additional details: HMA Section 3.2
Spill Control: *CFC §1207.6.2*	N/A for lithium-ion technology	**Not Applicable.** Not required/applicable as the electrolyte is sealed.
Safety Caps: *CFC §1207.6.4*	N/A for Lithium-Ion technology	**Not Applicable.** Not required/applicable.
Means of Egress Separation: *CFC §1207.5.8*	A 10 ft separation between ESS enclosures and egress paths is required to ensure safe escape routes in case of fire.	**Not Applicable.** The ESS enclosures are not installed in a building, occupied areas, or adjacent to an egress path. No egress path separation provisions apply.

1.4 Code Requirements

1.4.1 Applicable Codes and Standards

The applicable codes with regards to fire protection and life safety, with local amendments, are listed below.

- CFC, California Fire Code, (2025 Edition), as adopted by the City of Vacaville
- NFPA 72, National Fire Alarm and Signaling Code (2025 Edition)
- NFPA 70, National Electrical Code (NEC) (2023 Edition)
- NFPA 69, Standard on Explosion Prevention Systems (2024 Edition)
- NFPA 855, Standard for the Installation of Stationary Energy Storage Systems (2023 Edition)
- UL 9540, Standard for Energy Storage Systems and Equipment (2020 Edition)
- UL 9540A, Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems (2019 Edition)

The following standards, not adopted by the CFC, are used as guidance:

- NFPA 855, Standard for the Installation of Stationary Energy Storage Systems (2026 Edition)
- Pre-incident planning per NFPA 1620, Standard for Pre-incident Planning (2020 Edition)

The referenced editions exceed the requirements of the existing guides and standards referenced in the 2025 CFC.

1.5 Hazard Mitigation Analysis

1.5.1 Purpose

This HMA report is required by CFC § 1207.1.6 to support the approval of maximum energy storage quantities greater than 600 kWh for lithium-ion battery installations.

1.5.2 Basis of Analysis

This HMA report is a technical assessment conducted by a qualified professional fire protection engineer (compliant with CFC § 104.2.2) to evaluate the consequences of single failure modes as required by CFC § 1207.1.6.1.

The fire protection and life safety strategies incorporated into the HMA are informed by manufacturer documentation, results of full-scale fire testing (UL 9540A), and site planning for the Vaca Dixon BESS. Manufacturer documentation is included in the appendix.

The HMA should be kept in a safe location and reviewed annually by the site operator and owner. As part of the management of change process, any modifications or changes to equipment type could trigger a permit by the AHJ. As the Engineer of Record for this project, revisions to this document must be completed by Coffman Engineers.

1.5.3 AHJ Evaluation Criteria

The AHJ may approve increased maximum energy storage quantities. An approved HMA must support this approval. The HMA should evaluate the consequences of the following hazard and incorporate large-scale fire testing evidence and analysis.

CFC	Hazard Consequences Evaluated	Compliance Assessment
§ 1207.1.6.2 (1)	Fires will be contained within unoccupied ESS rooms or areas for the minimum duration of the fire-resistance-rated walls identified in Section 1207.7.4.	This minimum duration of the fire-resistance-rated walls provision is not applicable to this project as the ESS is an outdoor installation and is not a room within a building. There is no requirement for fire-resistance-rated separations.
§ 1207.1.6.2 (2)	Fires involving the ESS will allow occupants or the general public to evacuate to a safe location.	This project is classified as an outdoor unoccupied ESS installation and is not open to the public.
		While toxic gases will be released in the event that a fire occurs involving an ESS, there are no buildings on site and the site is considered to be unoccupied, and the toxic gases released will not reach a concentration level in excess of the IDLH where occupants or the general public will be located.
		The batteries are hermetically sealed and do not vent under normal charging or discharging operating conditions. Flammable gases are not released during normal operations.
		There is potential that the battery cells will vent flammable gases in the event of an internal short within a battery cell, overcharging, in the event of a BMS or EMS failure, or other abnormal conditions. Fires or explosion hazards will be mitigated with an explosion prevention system designed to maintain flammable gas concentrations below 25% of the lower flammability limit (LFL), to prevent development of an explosion hazard with the potential to injure service personnel and emergency responders.

Table 1.5.3 - AHJ Evaluation Criteria

1.6 System Overview

The CATL CBDC0 ESS enclosure is designed as an outdoor installation complying with CFC Section 1207. The site layout allows for potential expansion, and any future installations will necessitate an updated HMA to maintain code compliance. See Appendix for additional information.

1.6.1 ESS System Description

The CATL enclosures are non-walk-in outdoor steel ESS Cabinets. They are not intended for occupancy and will be accessed externally for maintenance only. See the configuration in the table below for a high level of each component.

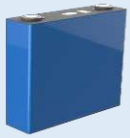
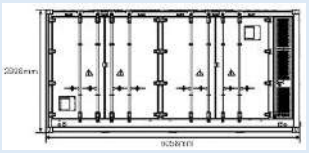
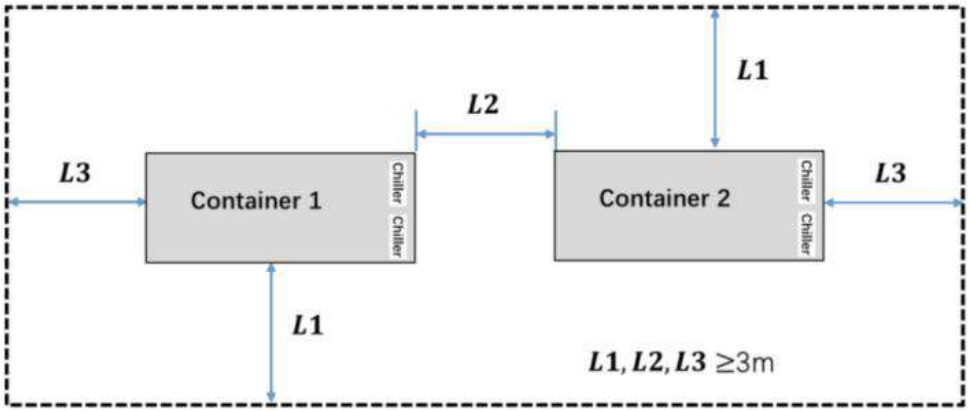
				
Component	**Cell**	**Module**	**Rack/Unit**	**CATL Enclosure**
Manufacturer	CATL Jiangsu Co., Ltd Co., Ltd.	CATL	CATL	CATL
Model	CBDC0	M01285P10L01	M01285P10L01	C1P(C04285P10L01)
Nominal Voltage (V)	3.2	166.4	1331.2	1331.2
Nominal Capacity (kWh)	0.896	46.6	373	3,727
Weight (lbs.)	12	716	5,732	79,366
Dimensions (in)	6.88 x 8.15 x 2.82	45.2in × 31.9in × 9.5 in	48.46in × 32.76in × 82.99 in	20 ft x 8 ft x 9.5 ft
Configuration / Chemistry	Lithium Iron Phosphate (LiFePO4)	52 Cells (1P52S)	8 Modules 8S1P	10 Racks 2x5P
Thermal Management	n/a	Liquid Cooling System	Liquid Cooling System	Liquid Cooling System
Listing / Certification	UL 1973	UL 1973	UL 1973	UL 9540

Table 1.6.1 - CATL Configuration



- At least 3m around each container shall be kept free due to maintenance and safety reason.
- Airflow requirement: 15000 m^3/h

Figure 1.6.2 – ESS Separation Requirements per CATL (Manufacturer)

2 FIRE TEST ANALYSIS

Test Standard: UL 9540A, Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems, 4th Edition, November 12, 2019.

2.1 Cell Test

2.1.1 Setup and Conditions

A lithium iron phosphate (LiFePO4, LFP) battery cell (Model CP1), certified to UL 1973, was tested according to UL 9540A. Thermal runaway was induced using an external heater. Vent gas was captured in a 176.3L pressure vessel for analysis. Gas flammability was assessed using the ASTM E918 method at both ambient and cell vent temperatures.

The cell level test document that was references for this report was published by UL (Changzhou) Quality Technical Co., Ltd. Dated 10/24/2025, test report no. 4791943570. The UL9540A Cell Level Test can be found in Appendix B.

2.1.2 Cell Test Results

The cell's average venting temperature was 161 °C (321.8 °F), with an average thermal runaway temperature of 220 °C (428 °F). Vent gas analysis confirmed flammability when mixed with air. The LFL was 8.05% (vol in air) at 25°C, decreasing to 7.545% at vent temperature. The vent gas contained significant amounts of hydrogen, carbon dioxide, carbon monoxide, and various hydrocarbons.

2.2 Module Test

2.2.1 Setup and Conditions

This test evaluates fire hazards within a battery module as part of an ESS installation. Measurements include chemical heat release rate, maximum temperature, vent gas composition, enclosure integrity, and the presence of explosions, hazardous ejections, and external flaming. Thermal runaway was induced using external heaters at a rate of 4-7°C per minute.

The module level test document that was references for this report was published by UL (Changzhou) Quality Technical Co., Ltd. Dated 10/29/2025, test report no. 4791943679. The UL9540A Module Level Test can be found in Appendix B.

2.2.2 Module Test Results

The module level test was performed by heating one cell using film heaters. Each module contains 52 cells. A total of four cells within the module went into thermal runaway. Gas and smoke venting was observed. No external flaming or sparking and no explosion or flying debris was observed.

2.3 Unit Test

2.3.1 Setup and Conditions

This test evaluated fire behavior and propagation within a CATL ESS unit with a focus on containment and preventing flying debris or explosive gas discharge. Thermal runaway was induced using external heaters at a rate of 4-7°C per minute. No BMS or fire suppression systems were active.

The unit level test document that was references for this report was published by UL (Changzhou) Quality Technical Co., Ltd. Dated 10/28/2025, test report no. 4791943683. The UL9540A Unit Level Test can be found in Appendix B.

2.3.2 Unit Test Results

The unit level test was performed by heating one cell using film heaters. The enclosure level test results demonstrate that thermal runaway propagation was limited to 1 cell. Module-to-module propagation of thermal runway was observed. Explosion hazards were not observed, including deflagration or detonation. Gas and smoke venting was observed. External flaming, sparking, and explosion or flying debris were not observed.

2.4 Large Scale Test

2.4.1 Setup and Conditions

This test was designed to evaluate a worst-case battery failure event within a CATL C04285P10L01 (3.79 MWh) ESS enclosure, with a focus on eight cells being driven into thermal runaway by film heaters within a single module while introducing an electric igniter to ignite the flammable vent gases. The intent is to show that a fully developed fire in one ESS enclosure will not propagate to a neighboring enclosure. This large-scale fire test was conducted in accordance with the June 2025 draft of UL 9540A and CSA/ANSI C800:25 and meets the intent of both NFPA 855 and the IFC for large-scale fire testing. Active fire protection and thermal runaway mitigation measures were disabled for this test. The BMS and fire, smoke, and gas detection in the enclosure of origin were active with their outputs disabled. The Large-Scale Test can be found in Appendix B.

2.4.2 Large Scale Test Results

Observations during the test included flaming that was induced by the igniter approximately 59 minutes into the test, and a partial volume deflagration in the enclosure of origin approximately 1 hour and 36 minutes later. The deflagration ejected flaming debris that self-extinguished after approximately one minute. It did not significantly damage the enclosure of origin or affect the adjacent enclosures. Visible exterior flaming stopped approximately 15 hours and 27 minutes into the test. Thermocouple temperatures were recorded at more than 200 locations across all enclosures throughout the test. All cell temperatures in the target enclosures remained below the cell vent temperature of 161 °C (321.8 °F), with a maximum of 43.9 °C (111.0 °F). No fire or thermal runaway propagation was observed to the adjacent enclosures.

3 ESS SAFETY SYSTEMS

Battery storage ESS enclosures at the Vaca Dixon BESS site will incorporate the following safety features:

3.1 Fire Detection and Alarm

Each ESS enclosure is provided with an internal fire detection and alarm system, consisting of an internal Fire Alarm Control Panel (iFACP) with two smoke detectors, two heat detectors, and two gas detectors (hydrogen detector) within the main ESS container, as well as one smoke detector within the enclosure's integration cabinet. All internal Fire Alarm Control Panel (iFACP) are connected to a site Fire Alarm Control Panel (FACP), which monitors all fire alarm signals from each ESS enclosure. The site Fire Alarm Control Panel (FACP) reports to the Fire Command Center (FCC), which is in an approved location. ESS Status indicators will be visible at the FCC and the ESS container's associated FACP.

3.1.1 Code Requirements

While CFC §1207.5.4 does not mandate fire detection in outdoor, non-walk-in energy storage systems, the CATL CP1 ESS enclosures will exceed minimum requirements with an NFPA 72-compliant fire alarm system.

3.1.2 System Description

The fire alarm system incorporates multiple detection technologies, integrated actions, and redundant monitoring:

- Detection: Each CATL ESS container will contain smoke detectors, heat detectors, and combustible gas detectors. These detectors, compliant with NFPA 72 standards, were not active during the UL 9540A unit (rack) level test.
- Integration: Detection systems also transmit signals to the BMS system. Upon gas detection, the system automatically shuts down the HVAC, halts charge/discharge processes and activates off-gas ventilation.
- Monitoring: The stand-alone site level fire alarm panels are monitored at the Fire Command Center (FCC) featuring an annunciator display. All alarms, supervisory, and trouble signals are transmitted to the FCCs and off-site monitoring service. FACPs include an uninterruptible power supply (UPS) for 24 hours of standby plus 2 hours of alarm.

3.1.3 Safety Assessment

The fire alarm system's design aligns with relevant sections of CFC and NFPA 72 standards to provide the following benefits:

- Fire Detection: Detection enables reliable identification of thermal runaway hazards with overlapping coverage.
- Redundancy: Networked FACPs and off-site monitoring ensure continuous oversight and minimize response delays.
- Proactive Mitigation: Automatic ventilation triggered by gas detection reduces the risk of flammable gas buildup.

3.2 Fire Suppression System

3.2.1 Code Requirements

The CATL ESS enclosures are classified as outdoor, non-occupiable installations. CFC § 1207.5.5 requires “rooms” containing stationary storage battery systems to be equipped with an automatic sprinkler system and designed in accordance with NFPA 13. As they are not considered "rooms" within buildings, CFC § 1207.5.5 does not require in-unit fire suppression systems.

3.2.2 System Description

While the CATL ESS enclosures have the infrastructure to support a water spray system, they were tested without an automatic water supply in accordance with UL 9540A unit (unit) testing procedures. It should also be noted that the ESS containers can come preinstalled with a manual dry sprinkler system with a fire department connection but will not be connected or used.

3.2.3 Safety Assessment

UL 9540A tests demonstrated that the CATL ESS design successfully prevents thermal runaway propagation between modules without an internal suppression system. This indicates that the ESS enclosure design effectively contains fire hazards. The decision to rely on the fire department for water supply aligns with CFC provisions for outdoor, non-occupiable installations while still offering a level of fire protection.

Fire water will be accessed from the three on-site fire hydrants located around the perimeter of the Vaca Dixon BESS facility along the fire department access road. The on-site fire hydrants will be served by an on-site 120,000 gal fire water storage tank connected to a fire pump. The fire pump is located in a prefabricated fire pump house, and the fire pump and water storage tank are located to the north of the Vaca Dixon site. The Emergency Response Plan (ERP) should be further referenced for recommendations.

3.3 Thermal Runaway Protection

3.3.1 Code Requirements

The design of the CATL ESS system aligns with the fire safety provisions outlined in the CFC regarding thermal runaway prevention in lithium-ion ESS:

- CFC § 1207.6.5: This paragraph mandates the use of listed devices or other approved methods to prevent, detect, and minimize the impact of thermal runaway events.
- CFC § Table 1207.6: Table emphasizes the necessity of specific protection against potential fire and explosion hazards associated with thermal runaway in lithium-ion batteries.
    - Footnote E, Table 1207.6: This footnote clarifies that thermal runaway mitigation strategies can be incorporated into the BMS, provided the BMS has been evaluated in conjunction with the battery using UL 1973 standards.

3.3.2 System Description

The CATL ESS module employs a thermal runaway design prevention based on thermal management and is comprised of the following elements:

- Battery Management System (BMS): The BMS plays a central role in monitoring and safeguarding the health of the batteries. It continuously tracks critical parameters, including voltage, temperature, and state of charge. See Appendix D for additional information. Essential BMS functions include:
    - Fault Detection: The BMS monitors for over-temperature, over-charge, over-discharge, over-current conditions, and overall system health. Upon detection of faults or parameters exceeding safe tolerances, the BMS will isolate affected battery strings and transmit alarm signals to the Emergency Management System (EMS).
    - Thermal Management: The BMS actively oversees temperature monitoring and control, ensuring optimal operating conditions to prevent thermal events.
- Liquid Cooling System: Cooling liquid powered by an internal pump will circulate inside battery modules and take the heat from the batteries and will circle back to a heat exchanging tank. This design feature actively cooling the batteries to reduce the potential of thermal runaway, reducing the risk of cascading failures.
- LFP Chemistry: Lithium Iron Phosphate (LFP) batteries are inherently more stable and resistant to thermal runaway when compared to other lithium-ion chemistries, offering a foundational layer of fire safety.

3.3.3 Safety Assessment

The effectiveness of the ASCE ESS design in containing and mitigating thermal runaway events has been validated through UL 9540A unit (rack) level testing. Key findings from these tests include:

- Containment: In tests initiating thermal runaway, the event was successfully confined to a small number of cells resulting in no sparks, flaming, electrical arcs, or other electrical events during test.
- Minimal Hazards: The tests observed no deflagration, external flaming, projectiles, explosive events, or other hazards that could pose a risk to personnel or surrounding property.

3.4 Explosion Control Systems

3.4.1 Code Requirements

The CATL ESS installation incorporates an explosion control system to mitigate the risks associated with flammable gas release during potential fire events. This system aligns with the following code requirements (reference Appendix F for NFPA 69 report):

- CFC § 1207.6.3: Mandates explosion control measures for ESS installations.
- CFC § 911: Permits the use of NFPA 69 or NFPA 68 compliant systems.
- NFPA 69 Section 8.3.1: Requires the maintenance of flammable gas concentration below 25% of the Lower Flammability Limit (LFL).

3.4.2 System Description

The explosion control system within the CATL ESS enclosure employs a proactive approach that integrates gas detection devices, ventilation system, and operational safeguards:

- Gas Detection: Each ESS container houses two gas detectors specifically designed to detect Hydrogen (factory calibrated) typically released during lithium-ion battery thermal runaway.
- Exhaust Ventilation (NFPA 69): Upon gas detection, Exhaust fans activate to remove flammable gases from the ESS container. Reference Appendix F for the full report.
- Deflagration Venting Panels (NFPA 68): Eight panels located on the enclosure roof will activate based on pressure, relieving pressure in the event of an explosion, should the exhaust ventilation system fail.
- Operational Controls: Detection triggers several actions: alarms are sent, charging/discharging processes halt, off-gassing valves open, and exhaust ventilation activates.

3.4.3 Safety Assessment

An analysis of UL 9540A Testing supports the design and effectiveness of the explosion control system. Gas release data obtained during these tests provides a reliable prediction of the expected gas concentration, composition, and LFL release from a thermal runaway event to validate the ventilation system design.

Even with the explosion control system in place, strict safety protocols are essential. During fire or thermal runaway events, personnel must not approach ESS containers until the ventilation system has effectively cleared flammable gases and all alarm conditions have been reset.

The explosion control system implemented in the CATL ESS design is based on testing and validated analysis and aligns with relevant fire codes. These proactive measures, in conjunction with safety procedures, significantly reduce the risk of explosion hazards.

FAULT CONSEQUENCE ANALYSIS

Failure	Safety Compliance Level	System Response	Failure Consequence	Severity Risk Analysis
Thermal Runaway §1207.1.6.1 (1)	Containment of fire/gas within the originating module or ESS unit, preventing spread to adjacent units.	Thermal runaway contained to the originating module. Detection of combustible gas, smoke, or heat triggers a fire alarm. The ventilation system activates, purging gases. BMS monitors parameters and disconnects power if necessary.	A thermal runaway event remains confined to the affected module, or unit (rack). Potential smoke/gas release is likely. A fire alarm signal is transmitted.	While a thermal runaway event is disruptive, the demonstrated containment capability limits the potential damage. The fire alarm signal alerts personnel and triggers further mitigation measures.
BMS Failure §1207.1.6.1 (3)	System design and safeguards prevent thermal runaway, even without the BMS.	Affected battery modules cease charging/discharging.	Failure of the BMS (not caused by thermal runaway) results in halted charging/discharging. However, isolated batteries still store electrochemical energy. Other fire and gas detection remains active.	A BMS failure removes an active layer of protection but does not eliminate the inherent energy storage risk of electrochemical batteries. The continued function of other detection systems provides a crucial safety net.
Voltage Surge §1207.1.6.1 (3)	Surge protection prevents widespread equipment damage or immediate fire risks. No unsafe conditions or thermal events were created.	Protective relays/breakers shut down affected ESS portions. Surge arresters divert excess voltage. BMS monitors and shuts down affected segments if anomalies are detected.	Electrical code compliance, surge arresters, and the BMS minimize the potential for severe damage to CATL ESS components from voltage surges.	The system incorporates multiple layers of protection against voltage surges, significantly reducing the likelihood and severity of potential damage.
Short Circuit (Load Side) §1207.1.6.1 (3)	Overcurrent protection prevents widespread damage within the ESS. No unsafe conditions or thermal events were created.	Overcurrent protection devices activate, isolating the fault.	Adherence to electrical codes and the UL 9540 certification of the CATL ESS significantly reduce the likelihood and potential severity of load-side short circuit events.	Code compliance and UL 9540 certification provide a high degree of confidence in the system's ability to withstand and manage short-circuit events safely.
Ventilation or Exhaust System Failure §1207.1.4.1 (3)	A transmitted trouble signal to initiate an investigation or shutdown reduces the risk of thermal runaway. No unsafe conditions or thermal events were created.	Batteries remain in a normal, non-off-gassing state. Combustible gas and smoke detectors trigger a fire alarm signal.	A ventilation system failure in isolation has minimal immediate impact. In a dual-fault scenario with thermal runaway, redundant detection systems, alarms, and procedures alert personnel and prevent unsafe approaches.	While a ventilation failure alone poses minimal risk, its consequences become more severe if coupled with thermal runaway. The presence of redundant safety systems and emergency procedures significantly reduces the likelihood and potential severity of this dual-fault scenario.
Fire Detection Equipment Failure §1207.1.6.1 (3)	Immediate trouble signals provide impairment notification. Detection redundancies ensure monitoring continues. No unsafe conditions or thermal events were created.	Redundant detection (smoke, heat, gas) remains operational. Smoke detector failure transmits a trouble signal. EMS triggers ESS container shutdown upon smoke/heat detector failure. The tiered alarm system activates. NFPA 72 maintenance minimizes failure likelihood.	Delayed detection of smoke or heat is possible. However, redundancy, trouble signaling, automated EMS shutdown, and proactive maintenance significantly reduce the risk and potential severity posed by a single detector failure.	While complete detection system failure is a remote possibility, the multiple safeguards and maintenance protocols in place significantly mitigate the likelihood and adverse consequences of such an event.

FAULT CONSEQUENCE ANALYSIS

Failure	Safety Compliance Level	System Response	Failure Consequence	Severity Risk Analysis
FACP Failure §1207.1.6.1 (4)	Immediate trouble signals provide impairment notification. Redundant FACPs or signaling pathways ensure continued alarm functionality or notification of impairment.	Trouble signals were sent to FCC, EMS, and LPC. EMS initiates shutdown of the affected ESS container group. Redundant fiber-optic pathways ensure signaling for other ESS container groups.	An FACP failure primarily affects only the directly connected ESS container group. Trouble signals, shutdown procedures, and redundant pathways mitigate the potential consequences.	The localized impact, automated response, and redundant signaling design limit the severity of an FACP failure. While disruption to the affected ESS container group is likely, the overall ESS installation maintains a high level of protection.

4 FAULT CONSEQUENCE ANALYSIS

4.1 Thermal Runaway in a Single ESS Module or Rack/Unit

This analysis assesses the potential for a thermal runaway event within a single CATL ESS module, or rack/unit.

4.1.1 Mitigation and System Response

- **Containment:** UL9540A test results confirm that thermal runaway will not propagate to adjacent modules, racks/units. This containment feature significantly reduces the potential impact of the event.
- **Early Detection:** Initial signs of thermal runaway are likely to include the detection of combustible gas released from off-gassing battery cells or the presence of smoke. Detection triggers a fire alarm signal transmitted to the fire alarm panel and a monitored location.
- **Ventilation:** Upon detection, the eight ventilation panels activate to purge combustible gases, maintaining concentrations below 25% of the LFL.
- **Battery Management System (BMS):** The BMS continuously monitors battery voltage, temperature, and other operational parameters. In the event of irregularities, the BMS will proactively disconnect power to help prevent the escalation of an abnormal condition into a thermal runaway event.

4.1.2 Consequence and Severity

The UL 9540A testing demonstrates successful containment of a thermal runaway event within the originating module. Additional measures of protection beyond the test configuration include integrated fire detection and gas detection system, exhaust ventilation, and proactive BMS intervention, which significantly reduce the potential severity of a single module thermal runaway event within the CATL ESS system. These integrated safety measures are designed to prevent a localized module failure from cascading into a catastrophic event.

4.2 Failure of Battery or Energy Management System

This analysis assesses the impact of a failure within the CATL ESS battery system or its associated BMS.

4.2.1 Mitigation and System Response

- **BMS Functionality:** The CATL ESS incorporates a BMS designed to protect battery modules from common triggers for off gassing or thermal runaway, including over/under voltage, excessive temperatures, and short circuits.
- **BMS Failure Response:** Upon BMS failure, the affected battery modules immediately cease charging and discharging. This mitigates electrical conditions that could exacerbate a hazardous situation.

4.2.2 Consequence and Severity

While a BMS failure removes active charging and discharging, it does not eliminate the inherent energy storage risk of electrochemical batteries. Even in isolation, batteries can still pose a hazard. Fire safety and emergency response plans, compliant with relevant CFC guidelines, address the potential consequences of this residual risk.

4.3 Failure of the Emergency Ventilation System

This analysis assesses the impact of a ventilation system failure within a CATL ESS installation.

4.3.1 Mitigation and System Response

- **Normal Operation:** Under normal operating conditions, CATL ESS batteries do not off-gas. This minimizes the immediate impact of a ventilation failure.
- **Dual-Fault Scenario:** In the unlikely event of a ventilation failure coinciding with a thermal runaway event, several safeguards remain in place: Combustible gas, smoke, and heat detectors continue to function. Alarms are transmitted to remote fire alarm panels, the ESS yard entrance annunciator, and a constantly monitored location. Emergency procedures mandate that personnel maintain a safe distance until safety checks are complete and alarms are silenced.

4.3.2 Consequence and Severity

A ventilation system failure in isolation carries minimal immediate risk due to the lack of off-gassing during normal battery operation. In the unlikely dual-fault scenario involving thermal runaway, redundant detection systems and emergency procedures alert personnel and prevent unsafe approaches. While a complete ventilation failure coupled with a thermal runaway could have severe consequences, the layered safety measures in place significantly reduce the likelihood and potential severity of such an event.

4.4 Voltage Surges on the Primary Electric Supply

This analysis assesses the impact of voltage surges on the primary electrical supply to CATL ESS.

4.4.1 Mitigation and System Response

- **Electrical Code Compliance**: System design adheres to electrical code standards, including protective relays and breakers that trigger ESS shutdown in response to voltage fluctuations outside operational limits.
- **Surge Arresters**: Switchgear switches for each MV feeder are equipped with 35kV surge (lightning) arresters. These limit the severity of surges by diverting excess current to ground.
- **Battery Management System (BMS)**: The BMS continuously monitors battery voltage (individual cells and total). If excessive charge or discharge voltage is detected, the BMS immediately shuts down the affected ESS portion.

4.4.2 Consequence and Severity

The combination of code-compliant design, surge arresters, and the BMS significantly minimizes the potential for damage to the ESS from voltage surges. While surges present an inherent risk, these layered mitigation strategies reduce the likelihood of a severe incident.

4.5 Short Circuits on the Load Side of the ESS

This analysis assesses the potential impact of short circuits occurring on the load side of the CATL ESS installation. Short circuits pose a risk of electrical arcing, which could lead to fires or damage to ESS components.

4.5.1 Mitigation and System Response

The system incorporates several safeguards to address load-side short circuits:

- **Electrical Code Compliance:** The entire system design adheres to all relevant electrical codes, including specific provisions for short circuit protection. This ensures the use of appropriate overcurrent protection devices and system design practices to minimize the risk and severity of short-circuit events.
- **UL 9540 Certification:** The CATL ESS has achieved UL 9540 certification. This assessment includes short circuit studies, verifying the system's ability to withstand and manage potential short circuit faults.

4.5.2 Consequence and Severity

The combined effect of code compliance and UL 9540 certification reduces the likelihood and potential severity of load-side short circuit events in the CATL ESS.

4.6 Failure of the Fire Detection Equipment System

This analysis assesses the impact of a smoke or heat detector failure within a CATL ESS container. While detector failure poses a risk, the system incorporates multiple safeguards to mitigate potential consequences.

4.6.1 Mitigation and System Response

- **Redundancy:** The system employs overlapping detection capabilities with smoke, heat, and combustible gas detectors. Failure of a single detector is unlikely to disable fire detection fully.
- **Trouble Signaling:** Smoke detector failures automatically transmit a trouble signal to the site fire alarm panel and a monitored location, alerting personnel to the need for system maintenance.
- **EMS Response:** Failure of either smoke or heat detection triggers an automatic shutdown of the affected ESS container via the Energy Management System (EMS). This puts the batteries into an idle state, reducing the risk of thermal runaway. The ESS container remains offline pending manual inspection and restoration.
- **Alarm Tiers:** A tiered alarm system (Level 1, Level 2) ensures a graduated response. A single smoke or heat detector activation (Level 1) initiates alarm bell while a second

smoke or heat detector activation (Level 2) initiates HVAC shutdown, EMS alert, external notification, cessation of charge/discharge operations, and clean agent system releasing.

- **Inspection & Maintenance:** A formal documented inspection, testing, and maintenance program compliant with NFPA 72 standards proactively minimizes the likelihood of fire detection system failures.

4.6.2 Consequence and Severity

The combination of redundant detection systems, trouble signaling, automated EMS shutdown, tiered alarms, and strict maintenance protocols significantly reduces the risk and potential severity posed by a single smoke or heat detector failure. While complete system failure remains a remote possibility, these integrated safeguards mitigate the impact of such an event.

4.7 Failure of the Local FACP

This analysis addresses the impact of an FACP failure within a CATL ESS enclosure.

4.7.1 Mitigation and System Response

- **Localized Impact:** An FACP failure primarily affects the CATL ESS enclosure in which the compromised FACP is located in. Other ESS enclosures, served by separate FACPs, maintain operational status.
- **Trouble Signaling:** An FACP failure automatically transmits trouble signals to the monitoring Fire Command Center (FCC), the site Energy Management System (EMS), and the Local Plant Controller (LPC). This alerts personnel and triggers corrective actions.
- **EMS Shutdown:** Upon receiving a trouble signal, the EMS initiates a shutdown of the affected ESS container group. Batteries enter an idle state, significantly reducing the risk of thermal runaway. The ESS container group remains offline until FACP functionality is restored.

4.7.2 Consequence and Severity

The combination of localized impact, proactive trouble signaling, automated EMS shutdown, and redundant signaling pathways significantly minimizes the potential consequences of an FACP failure. At the same time, the affected ESS enclosure will experience temporary disruption.

5 CONCLUSIONS

Coffman Engineers, Inc. has prepared this HMA report to satisfy the requirements of CFC § 1207.1.6 to permit the installation of the ESS with lithium batteries which exceeds the limit of 600 kWh from CFC Table 1207.5. The HMA has summarized the fire protection features of the proposed ESS outdoor installation and addressed the single failure modes addressed by CFC § 1207.1.6.1.

The analysis is supported by UL 9540A full scale fire testing results (Appendix B) and aligns with the Emergency Response Plan, prepared by Coffman Engineers, to aid emergency responders and AHJs with regards to safety surrounding CATL products.

The Emergency Response Plan can be used as guidance to first responders and development of emergency response fire-fighting procedures. Additional supporting documentation for this HMA can be found in the appendices.

Your consideration of the information presented in this report is appreciated. If there are any questions regarding the content of this report, please contact our office.

APPENDICES

Appendix A

UL 9540 CERTIFICATE

TÜVRheinland®

Date: 2024-09-29

Contemporary Amperex Technology
Co., Limited
No.2, Xingang Road,
Zhangwan Town, Jiaocheng District
Ningde City
352100 Fujian
P.R. China

Ref: CU US + Canada Certificate

Type of Equipment	:	Rechargeable Lithium-ion Battery System
Certificate No.	:	CU 72403736 0003
Report No.	:	CN237GL9 003
Engineer/Contact	:	Anhui Wu
Standards	:	ANSI/CAN/UL 9540:2023

Dear Madame or Sir,

Enclosed you will find the additional page of certificate No. CU 72403736 0003.

Please keep this page with your original certificate.

Call the TUV hotline at 1-TUV-Rheinland (1-888-743-4652) to get answers for all your compliance needs. If we can be of any further assistance to you, please do not hesitate to contact us.

With kind regards,

Certification Body



Weichun Li

Enclosure

Certificate

Certificate no. CU 72403736 0003

License Holder:
Contemporary Amperex Technology
Co., Limited
No.2, Xingang Road,
Zhangwan Town, Jiaocheng District
Ningde City
352100 Fujian
P.R. China

Manufacturing Plant:
Contemporary Amperex Technology
Co., Limited
No.2, Xingang Road,
Zhangwan Town, Jiaocheng District
Ningde City
352100 Fujian
P.R. China

Report Number: CN237GL9 003
Client Reference: Wang Jianquan
Certification acc. to: ANSI/CAN/UL 9540:2023

Product Information

Certified Product: Rechargeable Lithium-ion Battery System
Model Designation: C04285P10L01
Technical Data: As CU 72403736 0001-0002

Modification

Change : CDF

From : 1.0
To : 1.1

Remarks:
Appendix: 1, 1-14

Date of issue: 2024-09-29
(yr/mo/day)

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TUV Rheinland of North America, Inc.
400 Beaver Brook Rd, Boxborough, MA 01719
Tel +1 (978) 266 9500, Fax +1 (978) 266-9992

Prüfbericht-Nr.: *Test report no.:*	**CN237GL9 003**	**Auftrags-Nr.:** *Order no.*:	326042441 P01588350	
Kunden-Referenz-Nr.: *Client reference no.*:	2057436	**Auftragsdatum:** *Order date:*	2024-07-29	

Auftraggeber: *Client*:	Contemporary Amperex Technology Co., Limited. No. 2, Xingang Road, Zhangwan Town, Jiaocheng District,Ningde City, 352100 Fujian, P.R. China
Prüfgegenstand: *Test item*:	Rechargeable Li-ion Battery System
Bezeichnung / Typ-Nr.: *Identification / Type no.*:	C04285P10L01
Auftrags-Inhalt: *Order content*:	cTÜVus Mark approval
Prüfgrundlage: *Test specification*:	ANSI/CAN/UL 9540: 2023

Wareneingangsdatum: *Date of sample receipt*:	2023-07-29
Prüfmuster-Nr.: *Test sample no:*	A003795267-001
Prüfzeitraum: *Testing period*:	2024-08-01 to 2024-08-02
Ort der Prüfung: *Place of testing*:	See page 6 for detials
Prüflaboratorium: *Testing laboratory:*	TÜV Rheinland (Shanghai) Co., Ltd.
Prüfergebnis*: *Test result*:	Pass



geprüft von:
tested by: Trainer: David Zhou, Trainee: Anhui Wu

Datum:
Date: 2024-09-23

genehmigt von:
authorized by: Wilson Zhou

Ausstellungsdatum:
Issue date: 2024-09-23

Stellung / Position: Sachverständige(r)/Expert

Stellung / Position: Sachverständige(r)/Expert

Sonstiges /
Other: See the following pages for General product information and comment for details.

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

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

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Prüfbericht-Nr.: CN237GL9 003
Test report no.:

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Test Report issued under the responsibility of:

TÜVRheinland®

TEST REPORT
ANSI/CAN/UL 9540:2023
STANDARD FOR SAFETY
Energy Storage Systems and Equipment

Report reference No. .....:	CN237GL9 003
Date of issue ..... :	see cover page
Total number of pages ..... :	see cover page
Testing Laboratory ..... :	TÜV Rheinland (Shanghai) Co., Ltd.
Address ..... :	No. 177, Lane 777, West Guangzhong Road, Jing'an District, Shanghai 200072, P. R. China
Manufacture's name ..... :	Contemporary Amperex Technology Co., Limited.
Address ..... :	No. 2, Xingang Road, Zhangwan Town, Jiaocheng District,Ningde City, 352100 Fujian, P.R. China
Test specification:	
Standard ..... :	ANSI/CAN/UL 9540:2023
Test procedure ..... :	cTÜVus mark approval
Non-standard test method……..:	N/A
Test Report Form No. ..... :	UL 9540_2023
Test Report Form(s) Originator .... :	TÜV Rheinland (Shanghai) Co., Ltd.
Master TRF ..... :	Dated 2023-08

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Factory:	**Contemporary Amperex Technology Co., Limited.** No. 2, Xingang Road, Zhangwan Town, Jiaocheng District,Ningde City, 352100 Fujian, P.R. China

Purpose of This Report: Certificate

Report History:

History of amendments and modifications:		
Report No.	**Date**	**Modification**
CN237GL9 001	2024-01-05	Original report
CN237GL9 002	2024-08-08	1.The EMC report is updated to CN23MG3J 003. 2.Constructional Data Form (CDF) for Electrical Appliances added fire protection system and MSD. 3.The standard is updated from ANSI/CAN/UL 9540:2020 to ANSI/CAN/UL 9540:2023.
CN237GL9 003	2024-09-23	1.Update the label and arc flash label. 2.Cell test report updated 3.Update the Max short circuit current declared by manufacturer (Update short circuit test data): 1) Rechargeable Li-ion Battery Rack updated from 13kA to 13.7 kA. 2) Rechargeable Li-ion Battery System updated from 65kA*2 to 68.5 kA*2. 4.Constructional Data Form (CDF) for Electrical Appliances added Two Upper cover plate secondary supplier information (Refer to the bolded section of table of Critical components information).

Responsible Testing Laboratory (as applicable), testing procedure and testing location(s):			
☒	**Testing Laboratory:**	TÜV Rheinland (Shanghai) Co., Ltd.	
Testing location/ address ..... :		No. 177, Lane 777, West Guangzhong Road, Jing'an District, Shanghai 200072, P. R. China	
Tested by (name, function, signature) ..... :		See cover	
Approved by (name, function, signature) .. :		See cover	
☒	**Testing procedure: CTF Stage 1/TMP:**	Contemporary Amperex Technology Co., Limited.	
Testing location/ address ..... :		No. 2, Xingang Road, Zhangwan Town, Jiaocheng District,Ningde City, 352100 Fujian, P.R. China	
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Testing location/ address ..... :			
Tested by (name + signature)..... :			
Witnessed by (name, function, signature) . :			
Approved by (name, function, signature) .. :			
☐	**Testing procedure: CTF Stage 3/SMT:**		
☐	**Testing procedure: CTF Stage 4:**		
Testing location/ address ..... :			
Tested by (name, function, signature) ..... :			
Witnessed by (name, function, signature) . :			
Approved by (name, function, signature) .. :			
Supervised by (name, function, signature) :			
List of Attachments (including a total number of pages in each attachment): N/A			

Tests performed (name of test and test clause):

Following tests performed during evaluation:

Clause(s)	Test(s)
cl. 32	Dielectric Voltage Withstand Test
cl. 33	Impulse Test

The DUT was complied with the requirements of UL 9540:2023.

Testing location:

Contemporary Amperex Technology Co., Limited.

No. 2, Xingang Road, Zhangwan Town, Jiaocheng District,Ningde City, 352100 Fujian, P.R. China

Test item particulars:	
Description ..... :	See cover page
Trademark..... :	CATL
Model and/or type reference ..... :	See cover page
Electrical Ratings:	See Page 9
Input Voltage/Current…….. :	-
Output Voltage/Current…….. :	-
Maximum Operating ambient…….. :	-
Additional Rating Information:	See Page 9
Input voltage range ..... :	-
Energy (kWh)	-
Power (MW)	-
Output Short Circuit Current ..... :	-
Maximum Current per DC Feed	-
Maximum Number of Battery Racks	-
Installation mode..... :	-
Additional Product Information:	See Page 9
Software/Firmware tested within the unit……..:	-
Pollution degree ..... :	PD3(outside) PD2(inside)
Overvoltage category..... :	OVC II
Rated ambient temperature..... :	-
Enclosure index / type ..... :	IP55(Battery room); IP55(Electrical room); IP67(Chiller control box)
Equipment mobility ..... :	-
Protection class of equipment ..... :	I
Mass of equipment (Kg) ..... :	36000
Overall size (W x D x H) ..... :	20’ x 8’ x 9’6 ft
Possible test case verdicts:	
- test case does not apply to the test object..... :	N/A
- test object does meet the requirement ..... :	P(ass)
- test object does not meet the requirement ..... :	F(ail)
Testing:	
Date of receipt of test item ..... :	See cover page
Date(s) of performance of tests ..... :	See cover page

Product Description:

The model C04285P10L01 Battery container is the core unit in the energy storage system and acts as the equipment for storing electrical energy. It can be applied to many applications including renewable energy integration, frequency regulation, and voltage regulation.

Battery container includes battery, battery management system, thermal management system (TMS), auxiliary distribution system, and fire suppression system (FSS).

The battery system is composed of 2 battery groups. Each battery group consists of 5 battery racks in parallel. Each battery rack contains 8 battery modules. Each battery module is composed of 52S battery cells in series connection.

Total 52 lithium iron cells (285Ah/3.2V) in series connection are used for every battery module.

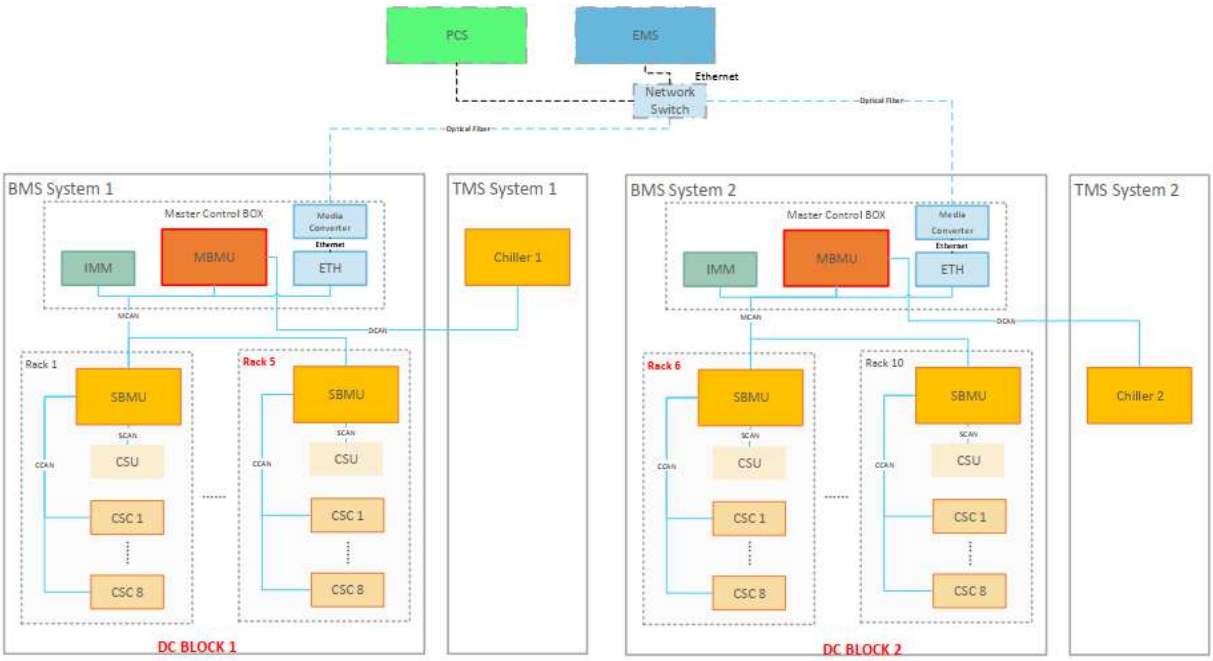
The auxiliary distribution box is for providing the auxiliary power for whole BMS control system and TMS liquid cooling system, and the battery system is composed of 2 DC blocks, every block includes 5 battery racks in parallel.

There is no manual switch and overcurrent protection on the DC side, which needs to be added externally, as required in the manual. The AC input to the control loop requires an external manual switch as a maintenance switch, which is described in the manual. For safety protection, an internal high speed DC fuse is included.

The MBMU (Master battery management unit), IMM (Insulation monitoring Module), ETH (Ethernet Module), Fiber Conversion Module are integrated to master control box together.

The BMS functional safety was evaluated according to IEC 60730-1 Annex H and UL 60730-1 Annex H by TÜV Rheinland.

Block diagram as below:



The main features of battery system are shown as below:

Item	Specifications			
Product name	Rechargeable Li ion Cell	Rechargeable Li ion Battery Module	Rechargeable Li-ion Battery Rack	Rechargeable Li ion Battery

				System
Type/model	CBDC0	M01285P10L01	C04285P10L01-R	C04285P10L01
Nominal voltage	3.2V	166.4V	1331.2V	1331.2V
Rated capacity	285Ah	285Ah	285Ah	1425Ah*2
Voltage range	2.5V~3.65V	130~189.8V	1040~1500V	1040~1500V
Upper limit charging voltage	3.95V	-	-	-
Recommended charging current by manufacturer	285A	285A	285A	1425A*2
Recommended charging power by manufacturer	912W	47.424kW	379.39kW	1896.96kW*2
Maximum continuous charging current	285A	285A	285A	1425A*2
Recommended discharging current by manufacturer	285A	285A	285A	1425A*2
Recommended discharging power by manufacturer	912W	47.424kW	379.39kW	1896.96kW*2
Maximum continuous discharging current	364.8A	285A	285A	1425A*2
Standard temperature range for charging	0°C to 60°C	-	-	-
Standard temperature range for discharging	-20°C to 60°C	-	-	-
Operating ambient temperature range	-	-	-	-25°C to 55°C
Storage temperature range	-30°C to 60°C	-	-	-30°C to 60°C
Standard charging method by manufacturer	Charge at constant current/power 285.0A/912W until voltage reaches 3.65V	Charge at constant power 47.424kW until any cell voltage reaches 3.65V then derate until charge with 0.05P till 189.8V or any cell voltage	Charge at constant power 379.39kW until any cell voltage reaches 3.65V then derate until charge with 0.05P till 1500V or any cell voltage	Charge at constant power 1896.96kW*2 until any cell voltage reaches 3.65V then derate until charge with 0.05P till 1500V or any cell voltage

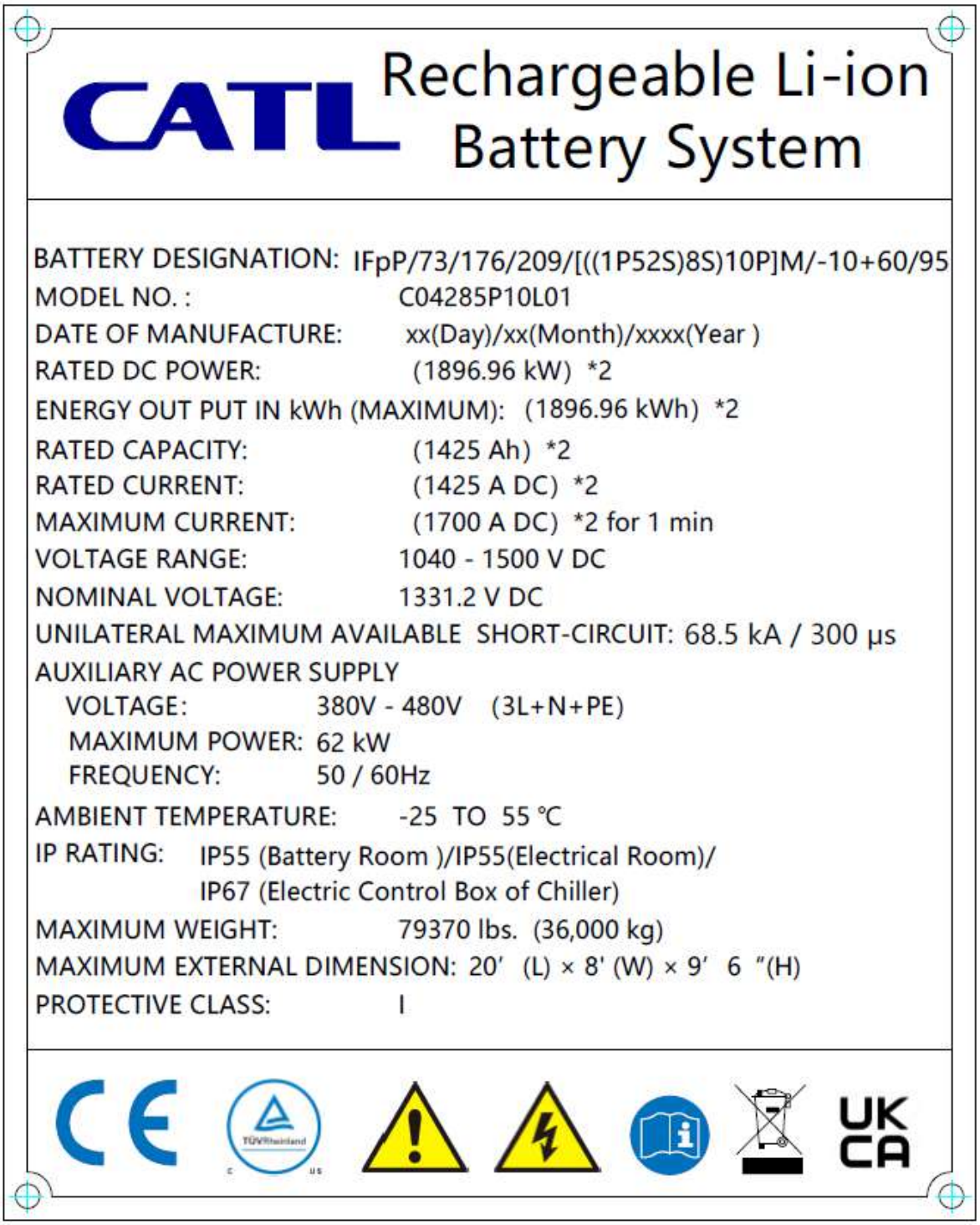
		reaches 3.65V	reaches 3.65V	reaches 3.65V
Charging method for internal short-circuit test	Charge at constant current 285A until voltage reaches 3.95V, then charge at constant voltage 3.95V till charge current is 0.05 I_t A(14.25A)	-	-	-
Standard discharging method by manufacturer	Discharge at constant current 285A until voltage reaches 2.5V	Discharge at constant power 4 7.424kW until 130V or any cell voltage reaches 2.5V	Discharge at constant power 379.39kW until 1040V or any cell voltage reaches 2.5V	Discharge at constant power 1896.96kW*2until 1040V or any cell voltage reaches 2.5V
Lower limit discharging voltage	2.0V	-	-	-
Over voltage protection value	-	-	-	Power limit to 0, when max. cell voltage reaches 3.81V, and after 10s, the relay will be cut off
Under voltage protection value	-	-	-	Power limit to 0, when max. cell voltage reaches 2.32V, and after 10s, the relay will be cut off
Overcurrent protection value	-	-	-	Max(I*135%, 10A)
Over temperature protection value	-	-	-	55°C
Dimension	T*W*H(mm) (71.55±0.80) *(174.3±0.80) *(207.3±0.80)	D*W*H (mm) 1150*810*241.5	D*W*H (mm) 1221.5*828*2148	D*W*H (mm) 2462*6058*2896
Weight	(5400±300)g	(330±10)kg	(2560±80)kg	Approx. 36000kg
Configuration	-	52S	(1P52S)8S	((52S)8S)5P*2
Max.short circuit current declared by manufacturer	-	-	13.7 kA	68.5 kA*2

Duration at max.short circuit current declared by manufacturer	-	-	300 μs	300 μs

The Operating ambient temperature range is the outdoor temperature.

The container controls the temperature of cell through the chiller,so that the cell can work within the operating temperature range of the cell.

Nameplate, Warning, and Label, etc.:



WARNING **AVERTISSEMENT**

DO NOT OPEN UNDER LOAD
NE PAS MANOEUVRER EN CHARGE

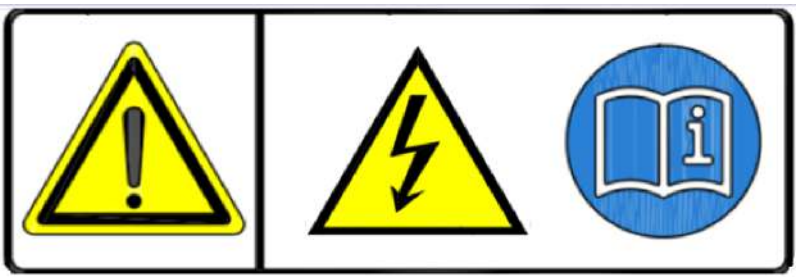
WARNING
AVERTISSEMENT

Arc Flash and Shock Hazard
Appropriate PPE Required
risque d'arc électrique et de choc électrique
Un équipement de protection individuelle approprié est nécessaire

4'-6.0"	Flash Hazard Boundary
10.8	cal/cm2 Flash Hazard at 1.5 ft
#3	PPE Level

1.5	kV Shock Hazard when cover is removed
5'- 0"	Limited Approach
1'- 8"	Restricted Approach

Equipment Name: EnerC Battery Container
VALID FOR NORMAL SYSTEM CONFIGURATION ONLY.



UL 9540			
Clause	Requirement + Test	Result - Remark	Verdict

ELECTRICAL TESTS			
32	**Dielectric Voltage Withstand Test**	See table 32, 33	**P**
32.1	Purpose of Test		P
32.2	Test Potential		P
32.3	Locations of test		P
32.4	Locations of Test (enclosure)		P
32.5	Duration of Test		P
32.6	Test Equipment		P
32.7	Result of Test		P
33	**Impulse Test**	See table 32, 33	**P**
33.1	The impulse voltage test is intended to evaluate the energy storage system's ability to withstand lightning or similar surges. Systems provided with protection that has already been evaluated for voltage surges (e.g. inverters meeting the Standard for Interconnecting Distributed Resources with Electric Power Systems, IEEE 1547 criteria) need not be tested.		P
33.2	Impulse test voltage and waveform		P
33.3	Application of the pulses		P
33.4	No insulation puncture, flashover, or spark-over		P

UL 9540			
Clause	Requirement + Test	Result - Remark	Verdict

32, 33	Table: Dielectric Strength and Impulse		P
Test Location	**Dielectric Applied Voltage**	**Impulse Voltage**	**Pass / Fail**
Battery system HV (+) to PE (BI)	4200Vd.c.	6000	Pass
Battery system HV (-) to PE (BI)	4200Vd.c.	6000	Pass
Battery system HV (+) to Communication circuit (RI)	4700Vd.c.	8000	Pass
Battery system HV (-) to Communication circuit (RI)	4700Vd.c.	8000	Pass
Busbar HV (+) to PE (BI)	4414Vd.c.	6000	Pass
Busbar HV (-) to PE (BI)	4414Vd.c.	6000	Pass
Note(s):			

--End of test report--

Constructional Data Form (CDF) for Electrical Appliances

License holder	:	**Contemporary Amperex Technology Co., Limited.** No. 2, Xingang Road, Zhangwan Town, Jiaocheng District,Ningde City, 352100 Fujian, P.R. China
Factory Address	:	**Contemporary Amperex Technology Co., Limited.** No. 2, Xingang Road, Zhangwan Town, Jiaocheng District,Ningde City, 352100 Fujian, P.R. China
Type of Appliance	:	Rechargeable Lithium-ion Battery System
Type Designation	:	C04285P10L01
Rating	:	See model list
Protection Class	:	Class I equipment
Supply connection	:	☐ fixed power cord ☐ permanent connection ☐ appliance inlet ☐ direct plug in ☒ Special Connector

Contemporary Amperex Technology Co., Limited

Date	Name	Signature
2024.09.20	Chen Xueping	Shirley Chen

TÜV Rheinland Group

Date	Name	Signature
2024.09.20	Wilson Zhou	Wilson

Model list:

Item	Specification			
Product name	Rechargeable Li ion Cell	Rechargeable Li ion Battery Module	Rechargeable Li-ion Battery Rack	Rechargeable Li ion Battery System
Type/model	CBDC0	M01285P10L01	C04285P10L01-R	C04285P10L01
Nominal voltage	3.2V	166.4V	1331.2V	1331.2V
Rated capacity	285Ah	285Ah	285Ah	1425Ah*2
Voltage range	2.5V~3.65V	130~189.8V	1040~1500V	1040~1500V
Upper limit charging voltage	3.95V	-	-	-
Recommended charging current by manufacturer	285A	285A	285A	1425A*2
Recommended charging power by manufacturer	912W	47.424kW	379.39kW	1896.96kW*2
Maximum charging current	285A	340A	340A	1425A*2
Recommended discharging current by manufacturer	285A	285A	285A	1425A*2
Recommended discharging power by manufacturer	912W	47.424kW	379.39kW	1896.96kW*2
Maximum discharging current	364.8A	285A	285A	1425A*2
Standard temperature range for charging	0°C to 60°C	-	-	-
Standard temperature range for discharging	-20°C to 60°C	-	-	-
Operating ambient temperature range	-	-	-	-25°C to 55°C
Storage temperature range	-30°C to 60°C	-	-	-30°C to 60°C
Standard charging method by manufacturer	Charge at constant current/power 285.0A/912W until voltage reaches 3.65V	Charge at constant power 47.424kW until any cell voltage reaches 3.65V then derate until charge with 0.05P till	Charge at constant power 379.39kW until any cell voltage reaches 3.65V then derate until charge with 0.05P till 1500V or any cell voltage reaches 3.65V	Charge at constant power 1896.96kW*2 until any cell voltage reaches 3.65V then derate until charge with 0.05P till 1500V or any cell voltage reaches 3.65V

Contemporary Amperex Technology Co., Limited

2024.09.20 Chen Xueping Shirley Chen

Date **Name** **Signature**

TÜV Rheinland Group Wilson

2024.09.20 Wilson Zhou

Date **Name** **Signature**

		189.8V or any cell voltage reaches 3.65V		
Charging method for internal short-circuit test	Charge at constant current 285A until voltage reaches 3.95V, then charge at constant voltage 3.95V till charge current is 0.05 I_t A(14.25A)	-	-	-
Standard discharging method by manufacturer	Discharge at constant current 285A until voltage reaches 2.5V	Discharge at constant power 47.424kW until 130V or any cell voltage reaches 2.5V	Discharge at constant power 379.39kW until 1040V or any cell voltage reaches 2.5V	Discharge at constant power 1896.96kW*2until 1040V or any cell voltage reaches 2.5V
Lower limit discharging voltage	2.0V	-	-	-
Over voltage protection value	-	-	-	Power limit to 0, when max. cell voltage reaches 3.81V, and after 10s, the relay will be cut off
Under voltage protection value	-	-	-	Power limit to 0, when max. cell voltage reaches 2.32V, and after 10s, the relay will be cut off
Overcurrent protection value	-	-	-	Max(I*135%, 10A)
Over temperature protection value	-	-	-	55°C
Dimension	T*W*H(mm) (71.55±0.80) *(174.3±0.80) *(207.3±0.80)	D*W*H (mm) 1150*810*241.5	D*W*H (mm) 1221.5*828*2148	D*W*H (mm) 2462*6058*2896
Weight	(5400±300)g	(330±10)kg	(2560±80)kg	Approx. 36000kg
Configuration	-	52S	(1P52S)8S	((52S)8S)5P*2
Max.short circuit current declared by manufacturer	-	-	13.7 kA	68.5 kA*2
Duration at max.short circuit current declared by manufacturer	-	-	300 μs	300 μs

Object/part no.	Manufacturer/ trademark	Supplier cord	Type/model	Technical data	Standard	Mark(s) of conformity [1)]
1. Enclosure	Nantong CIMC-Special Transportation Equipment Manufacture Co., Ltd.	CIMC	NT-S-2596G	Material: high weather resistance rolled steel, THK: 1.6mm to 12mm Size: 6058mm(D)* 2462mm(W)* 2896mm(H)	-	Test with unit
2. Sealing strip on containers	ASIA LANNERET SCIENCE & TECHNOLOGY CO LTD	-	EPDM-2015	Tensile Str: 2606.7psi, Min Service Temperature: -40°C, Min Service Temperature: 70°C	UL 157	UL MH60816
3. Liquid chiller	Sanhe Tongfei Refrigeration Co., Ltd	0000026799	LCI-400CR-01(A)Z-3487U	380VAC±15%, 980*630*2400 mm Cooling 40kW Heating 16kW -30°C to 55°C	CSA C22.2 NO.236-15 UL1995 EN ISO 12100:2010 EN 60204-1:2018 IEC 61000	UL-CA-2304599-0 UL SA44500 230100606SHA-V1
-Alternative	Songz Automobile Air Conditioning Co., Ltd.	0000014130	BTMS-400-ES	380VAC to 480VAC, 50/60Hz, 980*630*2400mm, Cooling 40kW, Heating 16kW, -30°C to 55°C	UL 471 IEC 61000	US 72228377 01 CN21GB2X 001 TW202210-028-1
4.Fire protection system	Kentec	0000018065	/	/	/	/
-Fire alarm control panel	Kentec	0000018065	K1810-13	Size(mm):368x310 x90 230VAC	UL 864	S8485
-Smoke detector	HOCHIKI	0000018065	SOC-24V	150mA max. @24 VDC	UL 268	S1383
-Detector base	HOCHIKI	0000018065	NS4-100	150mA @ 15.0-33.0V MAX	UL 268	S1383
-CO detector	Honeywell	0000018065	Sensepoint XCL	24 V DC,850mA	UL 2075	UL E486160
-Pull station	HOCHIKI	0000018065	HPS-DAK-WP	10A @ 120 VAC -35 °C ~66°C	UL 464 and UL 1638	S6512

-Abort switch	Kentec	0000018065	K1823-10	Size(mm):102 x 102 x 59 21 to 30 V DC, 0.033A	UL 864	S8485
-Horn/ Strobe (waterproof)	HOCHIKI	0000018065	WHEC24-75WR	24 VDC, 112mA	UL 464 UL 1638 NFPA 72	S3597
-Aerosol generator	Firepro	0000018065	Firepro,FP-500S	Mass of FPC compound:500 g Dimensions (Diameter : Height):84 mm : 295 mm (incl. connector housing)	UL 2775 NFPA 10: A, B, C	UL EX6960
-Aerosol generator	Firepro	0000018065	Firepro,FP-200S	Mass of FPC compound:200 g Diameter: 84 mm, Height: 185 mm (incl. connector housing)	UL 2775 NFPA 10: A, B, C	UL EX6960
-Alternative	Hubei Jiandun Fire Technology Co., Ltd.	0000018065	JAD300-U01	0.9A, 24V -40°C to 54°C	UL 2775	UL EX26592
5.Fire protection system	Potter	0000018065	/	/	/	/
--Fire alarm control panel	Potter	0000018065	ARC-100	2.0 Amps @ 240 VAC 50/60 HZ	UL 864	UL S735
--Smoke detector	Potter	0000018065	PAD100-PD	24 VDC,300 µA Height: 1.35 in (34mm) Diameter: 3.93 in (100 mm)	UL 268	UL S24776
--CO detector	Honeywell	0000018065	Honeywell,XCL	24 V DC,850mA	UL 2075	UL E486160
-Pull station	Potter	0000018065	MPEX Series	120VaC, 60Hz,6A	UL 864	UL E195352
--Abort switch	Potter	0000018065	ABORT	2.5 A @ 24 VDC (5 mA minimum)	UL 864	UL S2930
--Horn/ Strobe (waterproof)	Potter	0000018065	S/HS-WP Series	24VDC, 112 mA	UL1638	UL S3247
-- DISABLEMENT SWITCH	Potter	0000018065	RCDS-1	24 VDC, 10mA -30°C to 60°C	UL 864	UL S2930

--Aerosol generator	Firepro	0000018065	Firepro,FP-500S	Mass of FPC compound:500 g Dimensions (Diameter : Height):84 mm : 295 mm (incl. connector housing)	UL 2775 NFPA 10: A, B, C	UL EX6960
--Aerosol generator	Firepro	0000018065	Firepro,FP-200S	Mass of FPC compound:200 g Diameter: 84 mm, Height: 185 mm (incl. connector housing)	UL 2775 NFPA 10: A, B, C	UL EX6960
--Addressing input module	Potter	0000018065	PAD100-MIM	24V, 200μA	UL 864	UL S735
6.Fire protection system	KENTEC	/	/	/	/	/
--Fire alarm control panel	KENTEC	0000018065	Syncro XT+(A31164 M4)	Dimensions (l x h x p) / Weight: 385 /700 / 145mm / 10 kg Color: lid & boxBS 00 A 05 grey - fine texture, control panel & labels RAL 7047 light grey - satin 1.2mm mild sheet steel/ip30 Battery:	EN12094-1 EN54-2 EN54-4	EN/CE 2797 CPR 496748
-Heat Detector	Context Plus	0000034524	55000-145IMC	52mA max. @24 VDC	UL 521	UL S5053
--Smoke detector	Apollo	0000018065	SA5100-600	Dimensions:100 mm diameter x 36 mm height (48 mm height with XPERT 8 Intelligent Mounting Base) Working Temp: –40°C to 70°C Operating voltage:17–35 V dc Air humidity: 0% to 95% RH (no condensation or icing)	EN 54-7 EN 54-17	LPCB ref.No. 010bc/01 VdS Approval No.G216027

-Detector base	Apollo	0000018065	SA5000-200	"Dimensions:100mm diameter x 20mm height (Base with Soteria Optical Smoke Detector 48mm height)"	EN 54-7	LPCB ref.No. 010bd/01 VdS Approval No.G216026
-Heat detector	Apollo	0000018065	SA5100-400	Dimensions: 100 mm diameter x 36 mm height (48 mm height with XPERT 8 Intelligent Mounting Base) Working Temp: –40°C to 70°C Operating voltage: 17 V – 35 V dc Air humidity: 0% to 95% RH (no condensation or icing)	EN 54-5	LPCB ref.No. 010bd/01 VdS Approval No.G216026
-Pull station	KAC	0000018065	WCP3A -B (W3A-B000SG-K013-66)	Dimensions: 97.5mm×105mm×75.5mm Working Temp: -25°C to 70°C Operating voltageL: 30VDC	EN 12094-3	CE QF-QSI-C2-052-11-1.3
--Abort switch	Potter	0000018065	ABORT	2.5 A @ 24 VDC (5 mA minimum)	UL 864	UL S2930
--Horn/ Strobe (waterproof)	Apollo	0000018065	55000-005	Dimensions: 104 mm diameter x 97.5 mm height Working Temp: -10°C to +55°C Operating voltage: 17-28 V dc polarity sensitive Protection category: IP65	EN 54-3	0823-UKCA-CPR-F1016 EU No 305/2011 2831-CPR-F2104BRE Global Ldt Approved Body 0832 LPCB:No:010ak
--DISABLEMENT SWITCH	Potter	0000018065	RCDS-1	24 VDC, 10mA -30°C to 60°C	UL 864	UL S2930

--Aerosol generator	Ji An Dun	0000004840 5	JAD300-U01	Dimension: D 76mm x 192mm Voltage:24V_Curre nt:0.9A Weight: 2.1KG Operating temperatur range: -40~54°C	EN 15276	JAD-YF-JL-027
--Addressing input module	Apollo	0000018065	SA4700-104APO	Operating voltage: 17 V – 35 V dc Operating current: 0.5 mA Maximum current: 3.5 mA	EN 54-17 EN 54-18	EN 54-17, EN 54-18, CPR , LPCB, VdS, BOSEC, SBSC, FG
7. Limit switch	Schneider Electric (China) Co., Ltd.	0000005695	XCMD2102L 1	Uimp: 4kV, Ith: 6A, -25°C to 70°C	UL 508	UL E164353
-Alternative	Honeywell	0000003876	NGCM A10BX01A2 B-L40	24Vdc, 15mA, -40°C to 75°C	UL 508 EN 45545-2	UL E37138 HF88700T
8. Emergency stop switch	Schneider Electric Industries SAS	0000018065	XB4BS8444 1	24Vdc, 4A -40°C to 70°C	UL 508 IEC 60947	UL E352710
-Alternative	Fuji Electric FA Components & Systems Co., Ltd	0000009800	AY22V2R-12R	24Vdc, 4A -40°C to 70°C	UL 508 IEC 60947	UL E44592
9. Indicator light	ABB Xinhui Low Voltage Switchgear Co Ltd	0000005695	CL2-502	24V, 16mA, -25°C to 70°C	UL 508	UL E496500
-Alternative	SIEMENS ELECTRICAL APPARATUS LTD	0000009800	AD16-22B	24V, 15mA, -25°C to 55°C	UL 508	UL E233165
Alternative	Shanghai TAYEE Electric Co., Ltd.	9897851	AD17-22	24V, 20mA, -40°C to 70°C	UL 508	UL-CA-2327476-0
10. Internal connecting cable for battery	DONGGUAN NISTAR TRANSMITTIN G TECHNOLOGY CO INC	0000009966	Style 3932	2000V, 125°C, 95mm2	UL 758	UL E214184
-Tubing for cable	CHANGYUAN ELECTRONICS GROUP CO LTD	0000009818	CB-DWT	VW-1, 125°C, THK: 0.85mm	UL 224	UL E180908

11. Bonding wire	DONGGUAN NISTAR TRANSMITTING TECHNOLOGY CO INC	0000009966	Style 3666	XLPE, 600V, 105°C, 6mm2	UL 758	UL E214184
12. Output line gasket (through the oil)	Jiangyin Haida Rubber and Plastic Co., Ltd.	CIMC	SILICONE RUBBER	THK: 3.9mm, Fire-proof level: V-0, Material: EPDM	UL 94	AJFS2105004443RS
13. Busbar	CATL	-	-	Copper, 860mm(L)* 150mm(W)*12mm(T) Max. 3200A	-	Test with unit
-Material of Insulator	JIANGSU BI-GOLD NEW MATERIAL STOCK CO LTD	0000007989	SB6040M10	40mm(D)*60mm(H), 2400V Unsaturated Polyester (UP), RTI: 130°C, CTI: 600V, V-0	UL 94 UL 746A UL 746B	UL E240680
-Insulating sheet	CHENGDU KANGLONGXIN PLASTICS CO LTD	0000011523	KLX FRPC-1880B	THK: 0.75mm, V-0, 125°C	UL94 UL746C	UL E315185
14. Auxiliary power system	CATL	-	-	380VAC to 480VAC, 50/60Hz, 70kW	-	-
15. Surge Protective Devices	DEHN Surge Protection (Shanghai) Co. Ltd	0000009812	DG S 600 FM (952 096)	Uc: 600Vac;Up≤2.5kV; tA≤25ns In: 15kA	UL 1449 DIN EN 61643-11(VDE 0675-6-11):2019-03 EN 61643-11:2012+A11:2018	UL E319777-20090622 553000-1181-0019/282015
-alternative	CITEL	14964	DS44S-690	UC: 690Vac, 400Vac; In: 20kA	UL 1449 IEC 61643-2011 EN 61643-11:2012+A11:2018	UL E326289 874102119804-00
16. ACDC for UPS	PHOENIX CONTACT GMBH & CO. KG	0000009976	QUINT4-PS/1AC/24DC/40 - 2904603	Input: 100~240Vac, 13A-5.4A, 50/60HZ output:24vdc,40A. 960W -25°C ~70°C	UL508 UL 60950-1 EN IEC 61010-2-201:2018 EN IEC 61000-6-2:2019 EN 61000-6-3:2007+A1:2011+AC:2012 EN IEC 63000:2018	UL E123528 2904603.CE.01

-alternative	Weidmüller Interface GmbH & Co. KG	0000009800	PRO MAX 960W 24V 40A	Input: 85~277Vac, 10A~2.8A, 45~65Hz output: 24Vdc, 40A, 960W -25°C ~70°C	UL 508 UL 60950-1 EN60950-1:2011 SEMI F47-0706	UL E258476-20140822 E255651-A34-UL K569/04/14 SET2014-02581
-alternative	Beijing Noldor technology development Co.,Ltd	36114	ND 1AC/24DC/40	Input: 110~240Vac, 11.5A-4.5A, 50/60HZ Output:24vdc,40A max.960Wmax -25°C ~70°C	UL 508 CB+CE-LVD IEC/EN62368, CE-EMC	UL E497541 WTN22N12260503S
17. UPS DCDC	PHOENIX CONTACT GMBH & CO. KG	0000009976	QUINT4-UPS/24DC/24DC/40	Input: 24vdc output1:24vdc,40A ,output2:24Vdc,5A Max(for battery charing) -25°C ~70°C	UL 61010-2-201 UL 61010-1 UL 508 EN IEC 61000-6-2:2019 EN IEC 63000:2018	UL E123528 2907077.CE.01
-alternative	Weidmüller Interface GmbH & Co. KG	0000009800	CP DC UPS 24V 40A	Input: 24vdc, 43~51A output1:24vdc,40A -25°C ~70°C	UL 2367 EN60950-1/A11:2009	UL E258476 B110176015004
-alternative	Beijing Noldor technology development Co.,Ltd	36114	ND DUPS 24DC/24DC/40	Input: 24.5vdc, 43A output1:24vdc,40A ,output2:24Vdc,2.5A(for battery charing) -25°C ~70°C	EN 60204 CB CE-LVD IEC/EN60950 CB CE-LVD IEC/EN62368 UL 508 UL 1604 1 CLASS 1,Division2,Groups A,B,C,D EN 50178(VDE 0160)	UL E497541 WTN22N12260721S
18. UPS battery	PHOENIX CONTACT GMBH & CO. KG	0000009976	UPS-BAT/LI-ION/24DC/120WH	Nominal voltage:24VDC Nominal capacity:120Wh Ambient temperature:-20~60	EN 60950-1/VDE 0805 (SELV) EN 50178/VDE 0160 (PELV) UL60950-1 UL 508 EN 61000-6-3:2007+A1:2011+AC:2012 EN IEC 63000:2018	UL E123528 2320351.CE.03

-alternative	Weidmüller Interface GmbH & Co. KG	0000009800	DURA ECO LA-BAT 24V 7AH	Nominal voltage:24VDC Nominal capacity:7Ah Max.charging current:1.08A Ambient temperature:-20~60°C	UL1989 EN IEC 63000:2018 EN 55024:2010	UL MH47211 DE PA5200 160310 004 ISS 03
-alternative	Beijing Noldor technology development Co.,Ltd	36114	ND BAT/24DC/7.2Ah	Nominal voltage:24VDC Nominal capacity:7.2Ah Max.charging current:1.8A Ambient temperature:0-40°C	ANSI/UL 1973 UL 1989 EN IEC 61000-6-1:2019	UL MH66457 UL MH19884 S3M22107-0015-108700
Component Connector for ETH	AVIC JONHON OPTRONIC TECHNOLOGY CO., LTD		CT63F	Rated current: 5A Rated Voltage: 32V DC Temperature range: -40°C ~125°C	UL 1977	UL E203642

Below list is for the critical components of main control box (10pcs for battery system)

-External cable	DONGGUAN NISTAR TRANSMITTING TECHNOLOGY CO INC	0000009966	Style 3932	2000V, 125°C, 95mm^2	UL 758	UL E214184
-Connector (B+)	Sanco New Energy Technology Co., Ltd	0000004160	ES095	1500Vdc, 310A, -40°C to 125°C	IEC 61984 UL 1977	TUV report 50331326 001 TUV report 50331326 002
--Alternative	Sichuan Recodeal interconnect System Co., Ltd	0000007975	REA4-ZBOD2-A (Socket) REA4-WTBO-95-A (Plug)	1500V, 300A, -40°C to 125°C, V-0	UL 4128	UL-US-221323-0 REA4202110210 4
-Connector (HV+)	Sanco New Energy Technology Co., Ltd	0000004160	ES095	1500Vdc, 310A, -40°C to 125°C	IEC 61984 UL 1977	TUV report 50331326 001 TUV report 50331326 002

--Alternative	Sichuan Recodeal interconnect System Co., Ltd	0000007975	REA4-ZDOD2-A (Socket) REA4-WTDO-95-A (Plug)	1500V, 300A, -40°C to 125°C, V-0	UL 4128	UL-US-221323-0 REA42021102104
-Connector (B-)	Sanco New Energy Technology Co., Ltd	0000004160	ES095	1500Vdc, 310A, -40°C to 125°C	IEC 61984 UL 1977	TUV report 50331326 001 TUV report 50331326 002
--Alternative	Sichuan Recodeal interconnect System Co., Ltd	0000007975	REA4-ZCBD2-A(Socket) REA4-WTCB-95-A (Plug)	1500V, 300A, -40°C to 125°C, V-0	UL 4128	UL-US-221323-0 REA42021102104
-Connector (HV-)	Sanco New Energy Technology Co., Ltd	0000004160	ES095	1500Vdc, 310A, -40°C to 125°C	IEC 61984 UL 1977	TUV report 50331326 001 TUV report 50331326 002
--Alternative	Sichuan Recodeal interconnect System Co., Ltd	0000007975	REA4-ZABD2-A(Socket) REA4-WTAB-95-A(Plug)	1500V, 300A, -40°C to 125°C, V-0	UL 4128	UL-US-221323-0 REA42021102104
-Enclosure	CATL	-	-	Material: steel DC01, Min. THK: 1mm 741.4(D)*711.5 (W)*239.3 (H)	-	-
-Sealing strip of main control box	ASIA LANNERET SCIENCE & TECHNOLOGY CO LTD	-	EPDM-2015	Tensile Str: 2606.7psi, Min Service Temperature: -40°C, Min Service Temperature: 70°C	UL 157	UL MH60816
-Circuit breaker (QS1)	SOCOMEC SAS	0000014964	INOSYS LBS	400A, 1500Vdc, -20°C to 75°C	UL 98A UL 98B	UL E346418
--Alternative	SHANGHAI LIANGXIN ELECTRICAL CO LTD	0000015215	NDG3VH-400(U)	400A, 1500Vdc, -30°C to 70°C	UL 98A UL 98B	UL E521747
-Main contactor (K1, K2)	Kunshan GuoLi Electronic Technology Co.,Ltd	0000010668	GLFWH350	350A, 1500Vdc, Coil: 24Vdc, Auxiliary contact: 25Vdc, 2A, -40°C to 85°C	UL60947-4-1 and CSA C22.2 No. 60947-4-1	UL E360145
--Alternative	LS ELECTRIC Co Ltd	0000009812	GPR-H500-A	500A, 1500Vdc, Coil: 24Vdc, Auxiliary contact: 30Vdc, 0.1A, -40°C to 85°C	IEC 60947-1 IEC 60947-4-1 UL 508	CB certificate no. DK-64268-UL (test report: 4787859810) E465782

-Current sensor (I1)	Honeywell	0000003876	CSNV500M-151	-500A to +500A, Uc: 12V, -40°C to 85°C	UL 61010-031	UL E239665
--Alternative	Honeywell	0000003876	CSNV500M-351	-500A to +500A, Uc: 12V, -40°C to 85°C	UL 61010-031	UL E239665
--Alternative	Honeywell	0000003876	CSNV700N-352Z	-700A to +700A, Uc: 12V, -40°C to 85°C	UL 61010-031	UL E239665
-Pre-charge relay (K3)	XIAMEN HONGFA ELECTROA COUSTIC CO LTD	0000008199	HFE82P-20/1000-24-H-Q2M-1	1500Vdc, 15A, -40°C to 85°C	UL 60947-4-1	UL E133481
-Pre-charge resistor	ShenZhen Zenlthsun Electronlcs Tech. Co.,Ltd	0000010327	ASZ6030 200W100R	100Ω, 200W	-	-
-Fan (for inside use)	ASIA VITAL COMPONE NTS CO LTD	0000012648	DATA0838B4 U-043	24Vdc, 0.66A, -10°C to 75°C	UL 507	UL E158191
-Busbar	CATL	-	-	Copper, THK: 4mm, Max. 540A	-	-
--Insulator	JIANGSU BI-GOLD NEW MATERIAL STOCK CO LTD	0000007989	YD0304(E)	24mm(D)*45mm(H), 130°C, V-0	UL 94 UL 746A UL 746B	UL E240680
--Cable tubing	CHANGYUA N ELECTRONI CS GROUP CO LTD	0000009818	CB-DWT	VW-1, 125°C, THK: 0.85mm	UL 224	UL E180908
-Main fuse (2pcs)	XI'AN SINOFUSE ELECTRIC CO LTD	0000008199	RSZ307-3-RAZ-450A1500V	1500Vdc, 450A, Breaking capacity: 250kA -40°C to 85°C	UL 248-1 EN 60269-1 EN 60269-4	UL-US-2210093-0 TUV R50538625 AN 50538999 0001
--Alternative	COOPER BUSSMANN LLC	0000007572	ESS3-450-D-450A1500V	1500Vdc, 450A, Breaking capacity: 250kA -50°C to 100°C	IEC60269.4 UL248-13	TUV J50513088 UL-US-2018760-0
-Miniature circuit breaker (QF1)	SHANGHAI LIANGXIN ELECTRICA L CO LTD	0000015215	NDB2-63C6/2P	125VDC, 6A Rating short circuit capability: 7.5kA Impulse withstand voltage: 4kV, -40°C to 80°C	UL 1077	UL E300669

-Power wire for auxiliary power supply	DONGGUAN NISTAR TRANSMITTING TECHNOLOGY CO INC	0000009966	Style 3666	600V, 105°C, 6mm2	UL 758	UL E214184
-Lead wire for high voltage sampling circuit	DONGGUAN NISTAR TRANSMITTING TECHNOLOGY CO INC	0000009966	Style 3932	2000V, 125°C, 1mm2	UL 758	UL E214184
-Fuse for high voltage sampling circuit	COOPER BUSSMANN LLC	0000007572	PV-15A10F85L	1500Vdc, 15A, -40°C to 85°C	EN 60269 UL 248-19	DOC CE1700190 E335324
--Fuse Holder	COOPER BUSSMANN LLC	0000007572	CHPV15L85	1500Vdc, 32A, -40°C to 80°C	EN 60269 UL 4248-1	DOC DCB 337 E348242
- Below list is the critical components of SBMU PCB board in main control box						
-SBMU PCB	CATL	-	Hardware version: CATL0683-B1-V1 Software version: ASBMUF18A	-	-	-
-SBMU PCB material	VICTORY GIANT TECHNOLOGY (HUIZHOU) CO LTD	0000007727	SH10	V-0, 130°C, CTI>600, 1.6mm	UL 94 UL 796 UL 746A	UL E248779
-alternative	Shennan circuits co.,LTD.	14902	M45	Fire rating: 94V-0 Maximum ambient temperature: 130°C Thickness: 2mm Grade of materials: FR4	UL 796	UL E108467
-SBMU HV connector (J700)	LOTES	0000000254	AAUS07AP5-010K0254 (female) AAUS07AS0-010K0154 (male)	Rated Current: 1A/PIN Rated Voltage: 1000V	-	-
--Plastic material of SBMU HV connector	KURARAY CO LTD	0000000254	GN2330(#)	THK: 0.75mm, V-0, 150°C	UL 94 UL 746B	UL E187055

-SBMU MCU (U914)	Freescale	0000007727	MPC5644C	SMD, 5V, -40°C to 105°C	-	-
-Sampling resistor (R700, R701, R702, R703, R709, R710, R712, R713, R714, R716, R718, R720, R2834, R2835, R2836, R2837)	Vishay	0000003886	TNPW1206200KBEEA,TNPW1206200KBEEN	Total 200 kΩ, -55°C to 125°C	-	-
-Sampling resistor (R723, R727)	Susumu	000010316	RG3216P-3600-B	Total 360 kΩ, -55°C to 125°C	-	-
-Optocoupler (OM17, OM18)	Broadcom	0000013695	QCPL-A58JV-500E	VISO: 5000 VRMS -40°C to 105°C		
-Alternative						
-Transformer (T9)	Pulse Electronics Corporation	0000009527	PH9384.089NL	Class B	-	-
--Bobbin	SUMITOMO BAKELITE CO LTD	0000009527	PM-9630	V-0, 150°C, Min THK: 0.16mm, HWI: 4	UL 1694 UL 94	UL E41429
--Triple insulation wire	YOSHIKURA TECHNO CO LTD	0000009527	KFIW(x)-F	Reinforced insulation, 155°C, 3000V	UL 60950-1	UL E353894
--Coating	DOW SILICONES CORP	0000009527	1-2577 #@, 1-2577 Low VOC #@	V-0, 130°C	UL 94 UL 746E	UL E81611
18. Below list is the critical components of battery module, model: M01285P10L01						
-Metal enclosure	CATL	-	-	Material: AL3003MOD-O, Min THK: 1mm	-	-
-Plastic enclosure	Hunan Jiyongsheng Co., Limited	0000005701	PP	V-0, 85°C, THK: 1.1mm	UL 94	Intertek 20890002-MT-3
-Alternative	GUANGZHOU KEYUAN INNOVATIVE MATERIALS CO LTD	0000011407	FRPP303-V0	V-0, 90°C, THK: 1.5mm	UL 94	UL E201440
-Alternative	KINGFA SCI & TECH CO LTD	0000019197	NHPP-FR EXBK008	V-0, 87.7°C, THK: 1.1mm	UL 94 UL 746B	UL E171666

-Alternative	**East Asia Electrical Equipment Co., Ltd.**	**0000036890**	**DYDQ-PP-B-I02**	**V-0, 85 °C**	**UL 94 UL 746**	**UL E171666**
-Alternative	**Jiangsu Xinquan Automotive Trim Co., Ltd.**	**0000013277**	**XQ-PP-B-I02**	**V-0, 85 °C**	**UL 94 UL 746**	**UL E171666**
-Mica paper	Hubei Ping an Electrical Materials Co., LTD	0000014138	GM-S	5600VDC@60s, 1mA; 500MΩ@1000V DC	UL 94	SCH21070294-02B
-Waterproof ring of battery module	ASIA LANNERET SCIENCE & TECHNOLOGY CO LTD	-	EPDM-2015	Tensile Str: 2606.7psi, Min Service Temperature: -40°C, Min Service Temperature: 70°C	UL 157	UL MH60816
- Lithium Ion Cell (52pcs provided)	CATL	-	CBDC0	3.2Vd.c., 285Ah	UL 1973:2022 IEC 62619:2022	UL MH62898 085-282360269-100
-Connector (B+)	Sanco New Energy Technology Co., Ltd	0000004160	ES095	1500Vdc, 310A, -40°C to 125°C	EN 61984:2009	TUV report 50331326 001
--Alternative	Sichuan Recodeal interconnect System Co., Ltd	0000007975	REA4-ZBOD2-A (Socket) REA4-WTBO-95-A (Plug)	1500V, 300A, -40°C to 125°C, V-0	UL 4128	UL E526230
-Connector (B-)	Sanco New Energy Technology Co., Ltd	0000004160	ES095	1500Vdc, 310A, -40°C to 125°C	EN 61984:2009	TUV report 50331326 001
--Alternative	Sichuan Recodeal interconnect System Co., Ltd	0000007975	REA4-ZCBD2-A(Socket) REA4-WTCB-95-A (Plug)	1500V, 300A, -40°C to 125°C, V-0	UL 4128	UL E526230
-External cable between modules	DONGGUAN NISTAR TRANSMITTING TECHNOLOGY CO INC	0000009966	Style 3932	2000V, 125°C, 95mm2	UL 758	UL E214184

Contemporary Amperex Technology Co., Limited

2024.09.20 Chen Xueping Shirley Chen

Date **Name** **Signature**

TÜV Rheinland Group Wilson

2024.09.20 Wilson Zhou

Date **Name** **Signature**

-Cable tubing	CHANGYUAN ELECTRONICS GROUP CO LTD	0000009818	CB-DWT	VW-1, 125°C, THK: 0.85mm	UL 224	UL E180908
-Voltage sampling wire	DONGGUAN NISTAR TRANSMITTING TECHNOLOGY CO INC	0000009966	Style 3932	2000V, 10A, 125°C, 0.35mm²	UL 758	UL E214184
-Plastic material for sampling connector	Shanghai Laimu Electronics Co., Ltd	0000013562	PA66 GF25	V-0, THK: 0.35mm, -40°C to 125°C	UL 94	EG190813001R02Zver.1
-NTC (8 pcs)	Hoverbird	0000008559	HD2I103C0-18010	10K	-	-
--Temperature sampling wire	TAIZHOU RISHUN ELECTRIC APPLIANCE DEVELOPMENT CO LTD	0000008559	Style 4484	300V, 150°C, 0.35mm2	UL 758	UL E237675
--AP	SEMITEC CORP	0000008559	103AP-2	R25: 10kΩ±1%, B25/85: 3976K±0.5%, -40°C to 125°C	UL 1434	UL E92669
-Fuse for one module	XI'AN SINOFUSE ELECTRIC CO LTD	0000008199	RSZ307-1-TMZ-500A250V-N	250Vdc, 500A, Breaking capacity: 250kA, -40°C to 85°C	UL 248-1 EN 60269-1 EN 60269-4	UL-CA-L353337-4111-71019102-2 TUV R50448323 AN 50553975 0001
-Plastic cover for fuse	SILVER AGE ENGINEERING PLASTICS (DONGGUAN) CO LTD	0000008199	PA66-640G00	V-0, 65°C, Min THK: 0.8mm	UL 94 UL 746B	UL E225348
-Explosion relief valve	DONGGUAN PUW MATERIAL CO LTD	13358	PDA3K-50G	Discharge pressure: 3kPa	-	-
-Maintenance switch service plug	AVIC JONHON OPTRONIC TECHNOLOGY CO., LTD	0000003981	DLQ4A	1500 V d.c. 300Ad.c. -40°C to 105°C	IEC/EN 61984 UL 1977 R8.19	TUV J 50455616 AK 50455660

- Below list is the critical components of CSC PCB board in battery module						
-CSC	CATL		Hardware version: CATL0812-A2-V1 Software version: ACCSCF001	Monitoring the cells' temperature, voltage etc.	-	-
-CSC PCB material	VICTORY GIANT TECHNOLOGY (HUIZHOU) CO LTD	0000007727	SH10	V-0, 130°C, CTI>600, 1.6mm	UL 94 UL 796 UL 746A	UL E248779
-Plastic material for Cover of CSC	CHENGDU KANGLONG XIN PLASTICS CO LTD	0000007541	Polycarbonate	V-0, 125°C, THK: 0.8mm	UL94 UL 746	UL E315185
CSC Transformer (T2)	Pulse Electronics Corporation	0000014256	ALTWR-F14TF	Class B	-	-
- Bobbin	SUMITOMO BAKELITE CO LTD	0000014256	PM-9630	V-0, 150°C, minimum THK: 0.16mm, HWI: 4	UL1694 UL94	UL E41429
- Triple insulation wire	YOSHIKURA TECHNO CO LTD	0000014256	KFIW(x)-F	Reinforced insulation, 155°C, 3000V	UL60950-1	UL E353894
- Coating	DOW SILICONES CORP	0000014256	1-2577 #@, 1-2577 Low VOC #@	V-0, 130°C	UL 94 UL 746E	UL E81611
CSC MCU (U4)	Freescale	0000007860	MC9S12G	SMD, 5V, -40°C to 105°C	-	-
--Alternative	AutoChips	CATL	AC7811QBFE	SMD, 5V, -40°C to 125°C	-	-
CSC Battery Cell Controller IC (U10)	Freescale	0000007860	MC33771B	SMD, 9.6V to 61.6V, -40°C to 105°C	-	-

Appendix B

UL 9540A TEST REPORTS

CELL LEVEL TEST REPORT
UL 9540A
Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems (AACD)

Project number	4791943570
File number	N/A
Date of issue	2025-10-24
Total number of pages	37
UL Report Office	**UL(Changzhou) Quality Technical Service Co., LTD**
Applicant name	**Contemporary Amperex Technology Co., Limited**
Applicant address	No 2 Xingang Road Zhangwan Town Jiaocheng District NingdeFujian 352100 China
Standard	UL 9540A:2025, Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems, 5th Edition, March 12, 2025
Test procedure	Section 7
Non-standard test method	N/A

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General disclaimer

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

UL LLC did not select the sample(s), determine whether the sample(s) were representative of production samples, witness the production of the test sample(s), nor were we provided with information relative to the formulation used in the test sample(s).

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Photo of cell/Stack:





Test Item Charge/Discharge Specifications:	
• **Charge current, A:**	**285**
• **Charge Power, W**	**912**
• **Standard full charge voltage, Vdc:**	**3.65**
• **Charge temperature range, °C:**	**0~60**
• **End of charge voltage, V:**	**3.65**
• **Discharge current, A:**	**285**
• **Discharge Power, W**	**912**
• **End of discharge voltage, Vdc:**	**2.5**
• **Discharge temperature range, °C:**	**-20~60**

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Cell information	
Model number	CBDC0
Rating, Vdc	3.2
Rating, Ah	285
Chemistry of test item	Lithium Iron Phosphate
Format	Prismatic
Overall dimensions, mm	174.3±0.8mm (depth) by 71.55±0.8mm (width) by 207.3±0.8mm (height)
Cell weight, g	5460 ± 300
Original equipment manufacturer (OEM)	Contemporary Amperex Technology Co., Limited
Branding manufacturer (if not OEM)	N/A
Standard test item certified to	UL 1973
Organization that certified test item	UL (MH 62898)
Summary of cell test results	
Average cell surface temperature at gas venting, °C	161
Average surface temperature at thermal runaway, °C	220
Gas volume, L	176.3
Lower flammability limit (LFL), % volume in air at the ambient temperature	8.05
Lower flammability limit (LFL), % volume in air at the venting temperature	7.545
Burning velocity, (S_u) cm/s	64.13
Maximum pressure, (P_{max}) psig	94.29

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Cell gas composition

Gas		Measured %
Carbon Monoxide	CO	10.610
Carbon Dioxide	CO2	30.116
Hydrogen	H2	43.569
Methane	CH4	6.625
Acetylene	C2H2	0.188
Ethylene	C2H4	4.159
Ethane	C2H6	1.245
Propadiene (Allene)	C3H4	0.005
Propylene	C3H6	1.056
Propane	C3H8	0.292
-	C4 (Total)	0.443
-	C5 (Total)	0.089
-	C6 (Total)	0.034
Benzene	C6H6	0.015
Toluene	C7H8	0.002
Dimethyl Carbonate	C3H6O3	1.477
Ethyl Methyl Carbonate	C4H8O3	0.077
Total	-	100

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Cell failure test method performed
☒ External heating using thin film heater ☐ Nail Penetration ☐ Overcharge ☐ External short circuit ☐ Overdischarge ☐ Flow Battery with 2 active electrolyte methods ☐ Flow Battery with 1 active electrolyte methods ☐ Others:
Description of method used to fail cells if other than external thin film heater with thermal ramp: N/A

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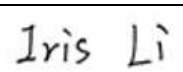
Summary of test results
Compliance with performance criteria in accordance with Clause 7.8 and Figure 1.1 ~~[was]~~[was not] achieved. ~~**[No further testing (i.e. module level, unit level and installation level) is required.]**~~ [ ] Thermal runaway was not induced in the cell; and [ ] The cell vent gas did not present a flammability hazard when mixed with any volume of air, as determined in accordance with ASTM E918 at both ambient and vent temperatures.

Test laboratory information		
Test laboratory and location(s)		
Test laboratory	UL(Changzhou) Quality Technical Service Co., LTD	
Test location/ address	21 Longmen Rd, National High-Tech Industrial Development District, Wujin, Changzhou, Jiangsu, China	
Tested by (name)	Zhang Wei /Vic Zhang	
Witnessed by (for 3rd Party Lab Test Location) (Name, signature)	N/A	N/A
Project Handler (name, signature)	Arui Zhou	
Reviewer (name, signature)	Iris Q Li	

List of Attachments (including a total number of pages in each attachment)

Attachment	Description	Pages
A	Cell conditioning (charge/discharge) profiles	***18*** *through* ***22***
B	Cell instrumentation photos	***21*** *through* **23**
C	Cell temperature profiles during test	***22*** *through* ***24***
D	Cell test photos	***25*** *through* **34**
E	Cell Vent Gas Test Chamber Photo and Profile of Chamber Gas Analysis (O_2 and Pressure)	***35*** *through* ***37***

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Test Verdicts	
Clause Requirement Does Not Apply to the Test Item:	N/A (Not Applicable)
Clause Requirement Met**:**	M (Met)
Clause Requirement Not Met:	NM (Not Met)
Clause Requirement Completed:	C (Completed)
Clause Requirement Completed with Modification	Mod (Modified)
Test Dates	
Date of Receipt of Test Item	2024-04-28
Date(s) of Performance of Tests	2024-05-07~2024-05-14

General remarks

"(See Attachment #)" refers to additional information appended to the report.

Throughout this report a point is used as the decimal separator.

Name and address of factory(ies) supplying samples for test:	Factory_1: Guangdong Ruiqing Contemporary Amperex Technology Limited Factory_1 address: No.1 Shidai Street,High-tech Industrial Development Zone, Zhaoqing City，Guangdong Province Factory_2: Jiangxi Yichun Contemporary Amperex Technology Limited Factory_2 address: No. 1, Chunfeng Road, Yichun Economic and Technological Development Zone, Jiangxi Province Factory_3: Fuding Contemporary Amperex Technology Limited Factory_3 address: No. 1, Shidai Road, Xueqiao Village, Qianqi Town, Fuding City, 355200 Ningde City, Fujian Province, PEOPLE'S REPUBLIC OF CHINA

General product information and other remarks:

The tested cell is a Lithium-ion battery cell, Model CBDC0. Each cell has a capacity of 285 Ah and nominal voltage 3.2 Vdc.

The overall dimensions of cell are 71.55±0.8mm (Width) by 174.3±0.8mm (Length) by 207.3±0.8mm (Height).

The weight of cell is 5460g±300g.

The test samples were produced in Factory 1.

This report is reissued from UL 9540A:2019, Fourth Edition, revised November 12, 2019, to UL 9540A, Fifth Edition, revised on March 12, 2025, based on the original report UL Project No. 4791281615 issued on July 23, 2024.

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No test was conducted for this reissue investigation as all the new requirements were addressed in the UL Project No. 4791281615 taking account the requirements of UL CRD i9540A- 20200520.

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UL 9540A, Edition 5			
Clause	**Requirement + Test**	**Remark**	**Verdict**
PERFORMANCE			
7.2	**Sample**		
7.2.1	Samples conditioned through charge discharge cycling a minimum of 2 cycles	See Attachment A for profiles	C
7.2.2	100% SOC and stabilize a minimum of 1 h before tests	See Table 1 for specifications	
7.2.3	Cell voltage measured and recorded before test		C
7.2.4	Cells with flexible laminate casings and prismatic cells constrained per end use during tests	See Attachment D	C
7.3	**Determination of thermal runaway methodology**		
7.3.1	General		
7.3.1.1	Ambient indoor laboratory conditions: 25 ±5°C (77 ±9°F) 50 ±25% RH at the initiation of the test	See Table 2	C
7.3.1.2	Heat the cell to thermal runaway by externally applied flexible film heaters	See Attachment B	C
	Heater Dimension, L x W, mm	152.4 mm by 203.2 mm, two pieces provided, attached on the two largest surfaces of the cell.	C
	A surface heating rate of 4°C (7.2°F) to 7° C (12.6°F) per minute was applied to the cell	See Attachment C and Table 3	C
	A thermocouple shall be placed in a representative position to ensure measurement of the cell surface which is least influenced by the heater.		C
	In cases where flexible film heaters do not cause the thermal runaway. The following method(s) was employed to cause thermal runaway: ☐ Mechanical (e.g., nail penetration), ☐ Electrical stress in the form of overcharging, ☐ Electrical stress in the form of over discharging ☐ Electrical stress in the form of external short-circuiting ☐ Use of alternate heating sources (e.g., oven), ☐ Other	Only external heating in the form of using flexible thin film heaters to cause thermal runaway	N/A
7.3.1.3	Detail of test method when using another cell abuse method to initiate thermal runaway		N/A
7.3.1.4	Monobloc batteries such as a lead acid or nickel cadmium batteries may be treated as an individual cell		N/A

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UL 9540A, Edition 5			
Clause	**Requirement + Test**	**Remark**	**Verdict**
7.3.1.5	Estimated surface temperature at which internal short circuiting within the cell will occur that could lead to a thermal runaway condition		N/A
7.3.1.6	The cell was heated until thermal runaway has occurred	See Attachment C	C
	Another external heating method was used to cause cell thermal runaway		N/A
7.3.1.7	The cell's exterior surface temperature was measured. a) Under the heater b) Cell surface near the heater c) Cell vent area	See Attachments B and C	C
7.3.1.8	Additional or alternate thermocouple locations may be utilized		C
7.3.1.9	Thermocouple locations did not interfere with cell operation or thermal runaway behaviour		C
7.3.1.10	The temperature at which the cell case vents due to internal pressure rise was documented	See Table 3 and Attachments B and C	C
7.3.1.11	The temperature at the onset of thermal runaway was documented	See Table 3 and Attachment C	C
	If cell venting occurs first, the cell was heated continuously until thermal runaway occurs	See Attachment C	C
7.3.1.12	When using methods other than the heater method, the stresses were applied to the cell until thermal runaway occurs		N/A
7.3.1.13	Three additional samples were tested using the same method and exhibited thermal runaway	See Tables 3 and 4 and Attachment C	C
7.3.2	Flow Battery Thermal Runaway Determination Tests		
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	Size of pressure vessel used, L:100 See Attachment E	C
	The test was initiated with an initial condition of atmospheric pressure and less than 1% oxygen by volume	See Attachment E Atmospheric pressure, psig: 0.26	C
		Oxygen concentration measured, % volume: 0.04	
		Inert gas used: Nitrogen	

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UL 9540A, Edition 5			
Clause	**Requirement + Test**	**Remark**	**Verdict**
7.4.2	Cell vent gas composition was determined using Gas Chromatography (GC)	See Table 7 and Attachment E	C
	Hydrogen gas was measured	See Table 7	C
	The initial atmospheric conditions prior to testing were noted	See Table 2	C
7.4.3	The lower flammability limit of the cell vent gas was determined on samples of the synthetically replicated gas mixture in accordance with ASTM E918, testing at both ambient and cell vent temperatures	See Tables 8 and 9	C
7.4.4	The gas burning velocity of the synthetically replicated cell vent gas was determined in accordance with the Method of Test for Burning Velocity Measurement of Flammable Gases Annex in ISO 817	See Tables 8 and 9	C
7.4.5	P_{max} of the synthetically replicated cell vent gas was determined in accordance with EN 15967	See Tables 8 and 9	C
7.7	**Cell Level Test Report Information**		
7.7.1	Minimum information provided in the report for items a) through l)		C
7.8	**Performance – Cell Level Test**		
7.8.1	a) Thermal runaway cannot be induced in the cell; and	Thermal runaway can be induced in the cell with external heater during the test	NM
	b) The cell vent gas does not present a flammability hazard when mixed with any volume of air, at both ambient and vent temperatures	As a result of gas analysis, the gas generated from the cell were identified flammable	NM

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Table 1 – Specified conditioning parameters			
Charging:		Discharging	
Current, A	285	Current, A	285
Power (CP), W	912	Power (CP), W	912
Standard full charge voltage, Vdc	3.65	Voltage at start of discharge, Vdc	3.65
End of charge voltage, Vdc	3.65	End of discharge voltage, Vdc	2.5
Charging Test Ambient, °C	0~60	Discharging Test Ambient, °C	-20~60
Refer to Attachment A for charge/discharge profiles for each cell.			

Note: The charge and discharge cycle of the cell is carried out in accordance with 912W constant power.

Table 2 - Test initiation details					
	Cell test 1	Cell test 2	Cell test 3	Cell test 4	Cell test 5
Cell sample number	7152957-S001	7152957-S002	7152957-S003	7152957-S004	7152957-S007
Charge completion date,	2024-05-07	2024-05-08	2024-05-08	2024-05-09	2024-05-14
Charge completion time,	15:21:37	07:18:33	11:58:24	08:35:21	09:51:49
Test date,	2024-05-07	2024-05-08	2024-05-08	2024-05-09	2024-05-14
Test start time,	17:01:26	10:44:16	15:47:23	10:12:33	16:13:24
Initial lab temperature, °C	22.3°C	22.0°C	22.0°C	22.3°C	23.0°C
Initial relative humidity, %RH	62.0%RH	74.6%RH	74.6%RH	62.0%RH	60.5%RH

Table 3 - Thermal runaway results					
	Cell test 1	Cell test 2	Cell test 3	Cell test 4	Cell test 5
OCV at start of test, Vdc	3.375	3.365	3.380	3.391	3.353
Average heating rate, °C/min	4.5	4.5	4.5	4.5	4.5
Venting time, hh:mm:ss	0:39:01	0:40:32	0:38:09	0:37:25	0:40:13
Venting temperature, °C	159	164	161	159	173
Thermal runaway time, hh:mm:ss	0:53:06	0:52:53	0:52:04	0:51:34	0:52:30
Thermal runaway temperature, °C	217	216	223	222	226
See Attachment C for surface temperature profiles during testing.					

Table 4 – Average vent and thermal runaway temperatures	
Average of cell vent temperatures, °C	161
Average of cell thermal runaway temperatures, °C	220
Values above are averages of cell tests other than the gas analysis test	

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Table 5 – Flow battery parameters
N/A

Table 6 – Results of flammability tests of flow battery electrolyte
N/A

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Table 7 – Results of Gas Analysis (Excluding O_2 and N_2)			
Gas		**Measured %**	**Component LFL[1]**
Carbon Monoxide	CO	10.610	10.9
Carbon Dioxide	CO2	30.116	N/A
Hydrogen	H2	43.569	4.0
Methane	CH4	6.625	4.4
Acetylene	C2H2	0.188	2.3
Ethylene	C2H4	4.159	2.4
Ethane	C2H6	1.245	2.4
Propadiene (Allene)	C3H4	0.005	1.9
Propylene	C3H6	1.056	1.8
Propane	C3H8	0.292	1.7
-	C4 (Total)	0.443	N/A
-	C5 (Total)	0.089	N/A
-	C6 (Total)	0.034	N/A
Benzene	C6H6	0.015	1.2
Toluene	C7H8	0.002	1.0
Dimethyl Carbonate	C3H6O3	1.477	N/A
Ethyl Methyl Carbonate	C4H8O3	0.077	N/A
Total	-	100	-

[1] Extracted LFL values from ISO 10156-2017

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Table 8 – Gas composition excluding the constituents with boiling points higher than 60°C[2]			
Gas		**Measured %**	**Component LFL**
Carbon Monoxide	CO	10.783	10.9
Carbon Dioxide	CO2	30.607	N/A
Hydrogen	H2	44.279	4.0
Methane	CH4	6.733	4.4
Acetylene	C2H2	0.191	2.3
Ethylene	C2H4	4.226	2.4
Ethane	C2H6	1.265	2.4
Propylene	C3H6	1.073	1.8
Propane	C3H8	0.297	1.7
Propadiene	C3H4	0.005	1.9
-	C4 (Total)	0.450	N/A
-	C5 (Total)	0.090	N/A
Total	-	100.0	10.9

[2] The constituents with a higher boiling point were excluded for the flammability characteristic analysis as these components will turn into a liquid state at room temperature and will not release from the gas bottle as a homogenous mixture.

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Table 9 – Properties of Vent Gas Analysis	
Lower flammability limit at ambient temperature, 25°C, % vol in air	8.05
Lower flammability limit at vent temperature, 161°C, % vol in air	7.545
Burning velocity measurement (S_u), cm/sec	64.13
Maximum pressure (P_{max}), psig	94.29

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	TABLE: Critical components information				
Object / part No.	**Manufacturer/ trademark**	**Type / model**	**Technical data**	**Standard**	**Mark(s) of conformity**
Cell Model	Contemporary Amperex Technology Co.,Limited	CBDC0	Nominal voltage：3.2V Rated capacity：285Ah	UL 1973	MH62898
Separator	Contemporary Amperex Technology Co.,Limited	SBM	Material: PE Internal code: SBM	—	—
Electrolyte	Contemporary Amperex Technology Co.,Limited	ESN	Composition: LiPF6, DMC, EMC, EC, PC, DEC;	—	—
Case	Contemporary Amperex Technology Co.,Limited	PPA	Material: Al 3003 Minimum thickness: 0.5-0.7mm	—	—
Insulators/ location in cell	Contemporary Amperex Technology Co.,Limited	PTA XBG PAP	Up-Plate Material: PC Mylar Material: PP Down-Plate Material: PP	—	—
Vent	Contemporary Amperex Technology Co.,Limited	PTA	Length: (25.3-30.3) mm, Width: (13.7-16.7) mm Pressure: 0.4Mpa~1.2Mpa	—	—

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Attachment A: Cell Conditioning (Charge/discharge) Profiles - (*Pages **18** through **22***)

Note: The charge and discharge cycle of the cell is carried out in accordance with 912W constant power.

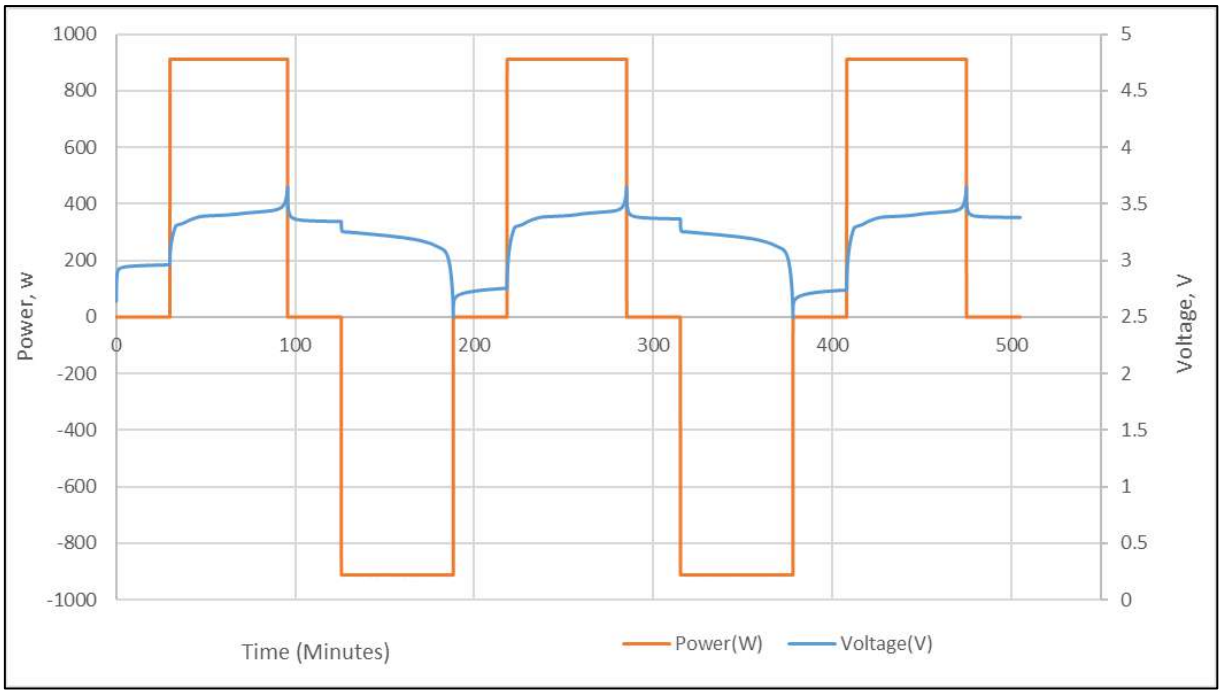

Figure 1: Cell 1 Conditioning (Charge/discharge) Profiles

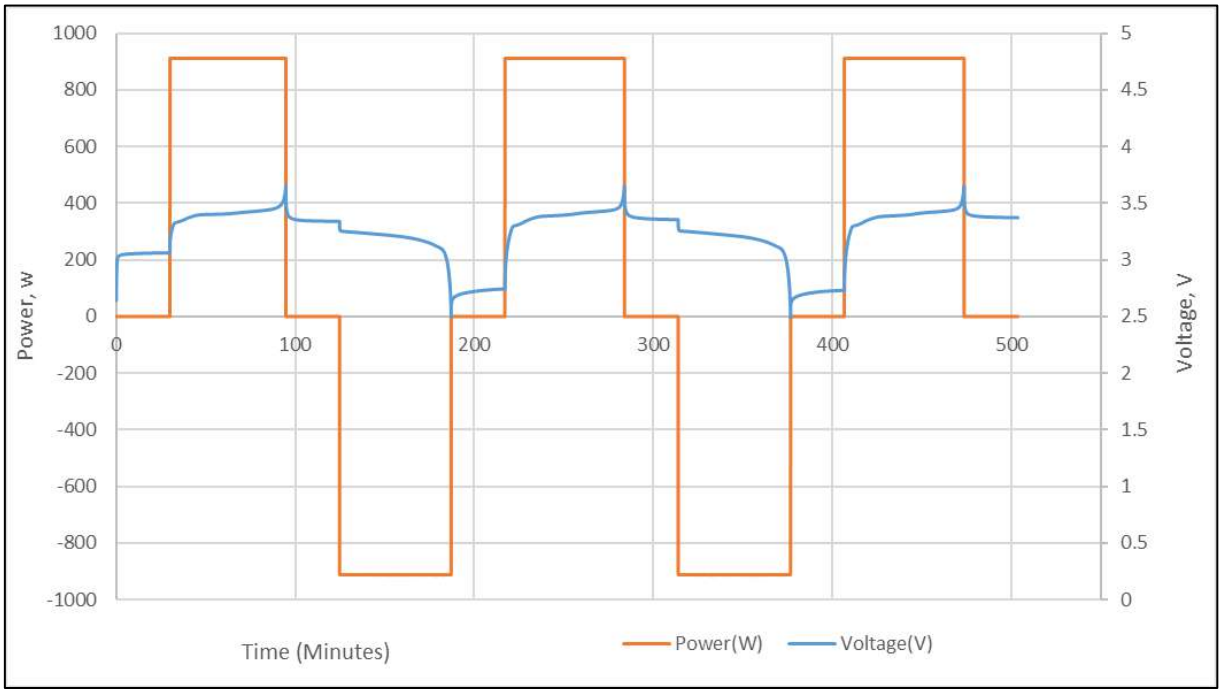

Figure 2: Cell 2 Conditioning (Charge/discharge) Profiles

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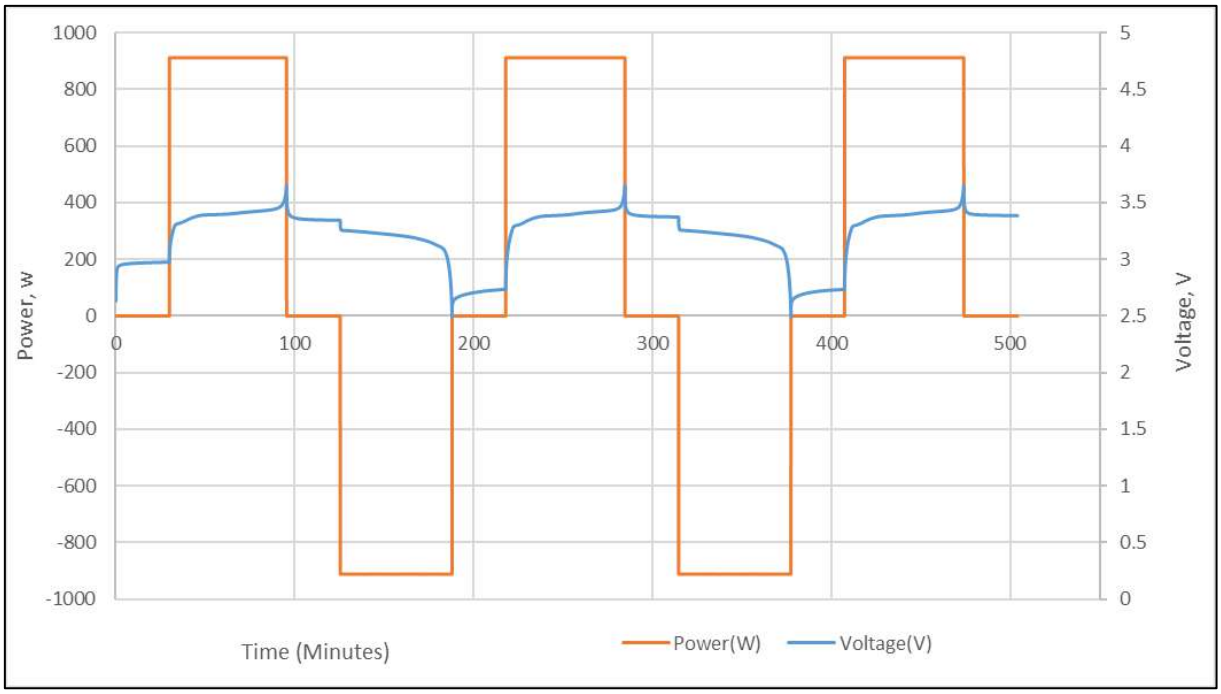

Figure 3: Cell 3 Conditioning (Charge/discharge) Profiles

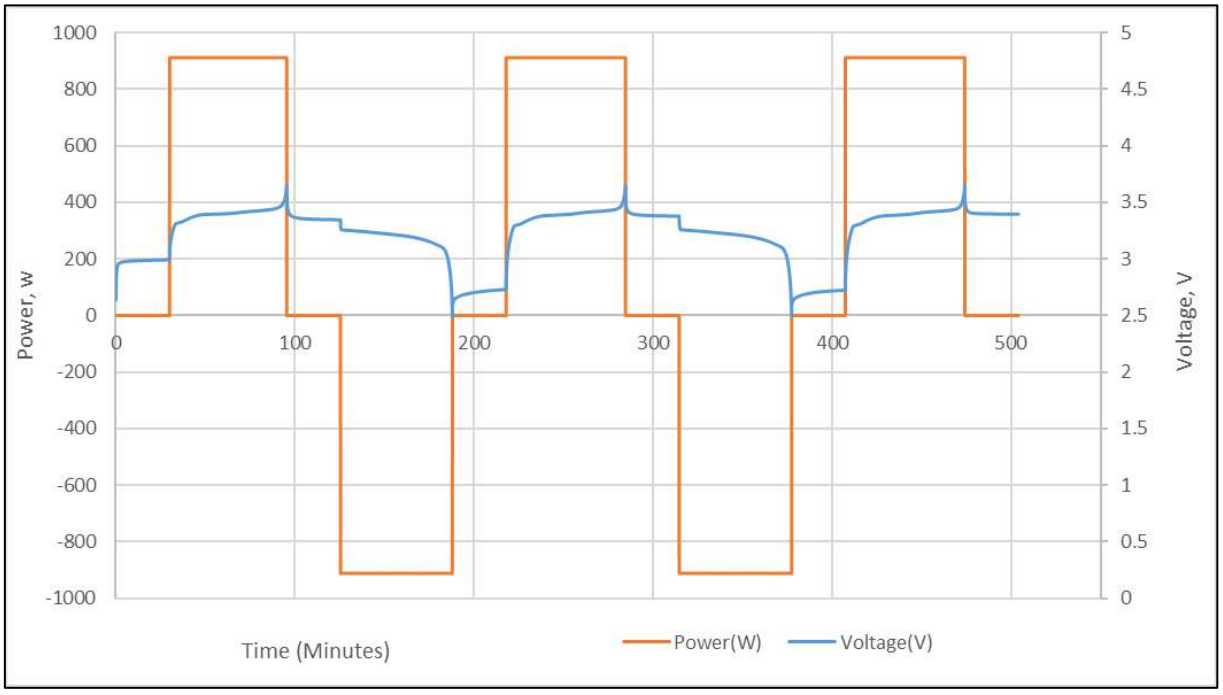

Figure 4: Cell 4 Conditioning (Charge/discharge) Profiles

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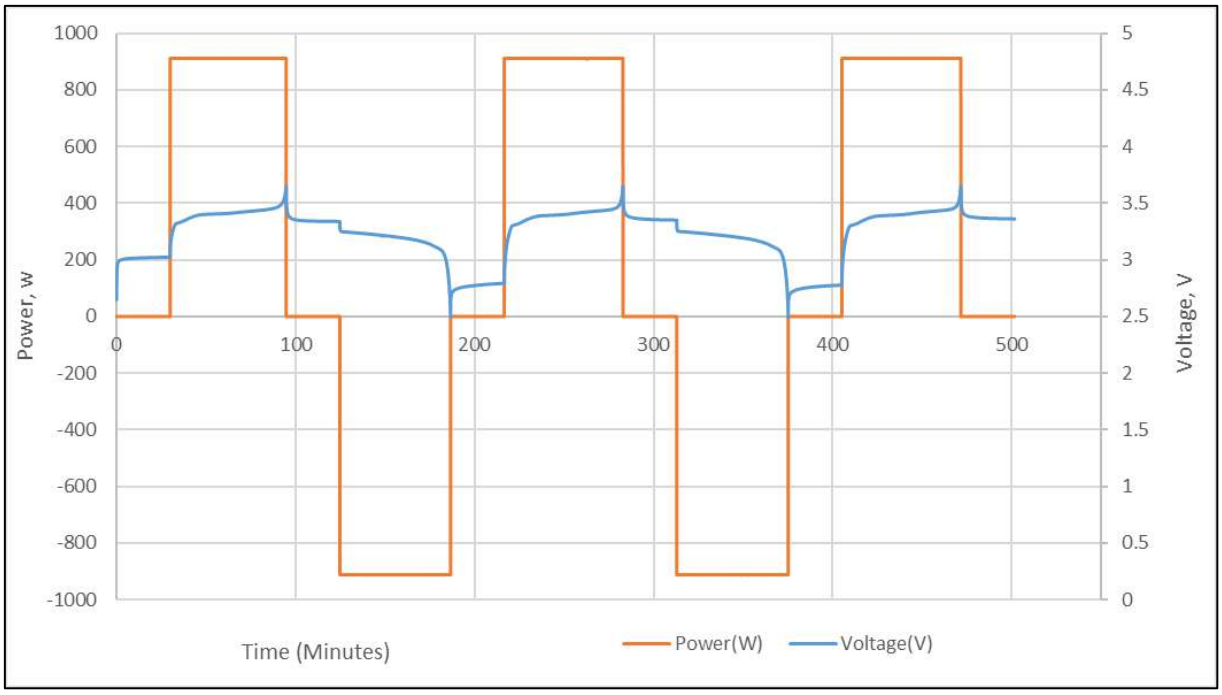

Figure 5: Cell 5 Conditioning (Charge/discharge) Profiles

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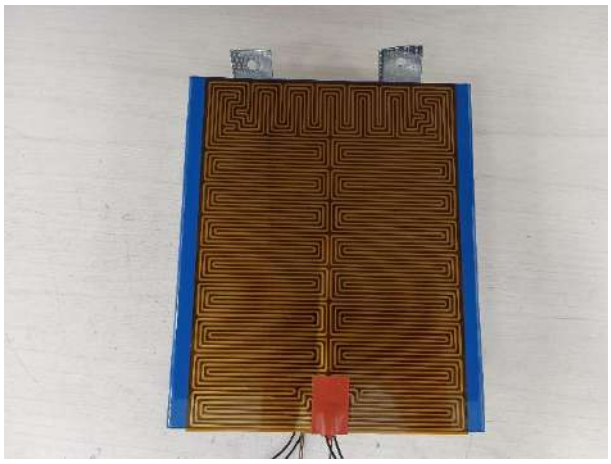
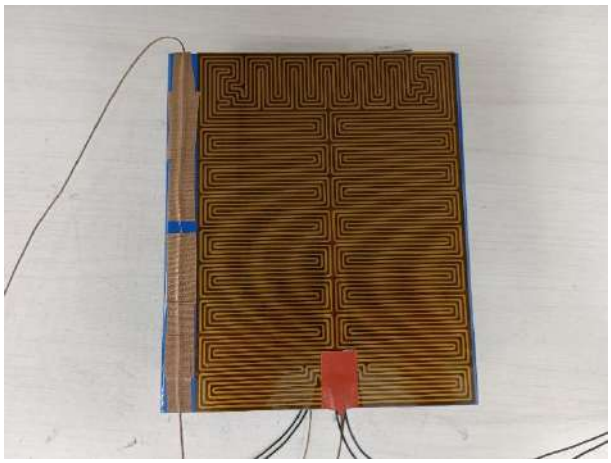
Attachment B: Cell Instrumentation Photos - (*Pages **21** through **21***)







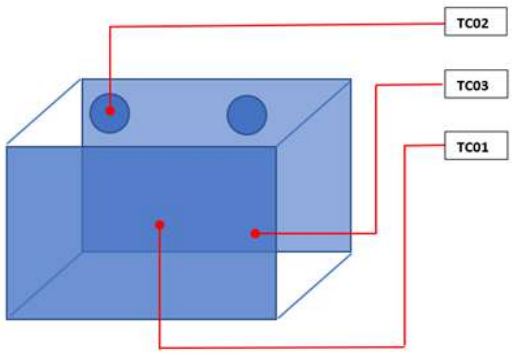


Figure 6: Sample Instrumentation Prior to Test

Note: heaters were placed on two sides of the cell after thermocouples were instrumented.

Note: TC01 between cell body and heater; TC02 on the cell positive; TC03 on the cell body not covered by heater; TC04 Ambient temperature; V1 cell voltage.

Note: TC03 also indicates the timing of cell venting based on the product structure and test phenomena.

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Attachment C: Cell Temperature Profiles - (*Pages **22** through **24***)

Note: TC01 between cell body and heater; TC02 on the cell positive; TC03 on the cell body not covered by heater; TC04 Ambient temperature; V1 cell voltage.
TC01 was used to control the temperature at 4 to 7°C/min and TC03 temperatures were reported herein for the surface temperature at the onset of vent and thermal runaway.

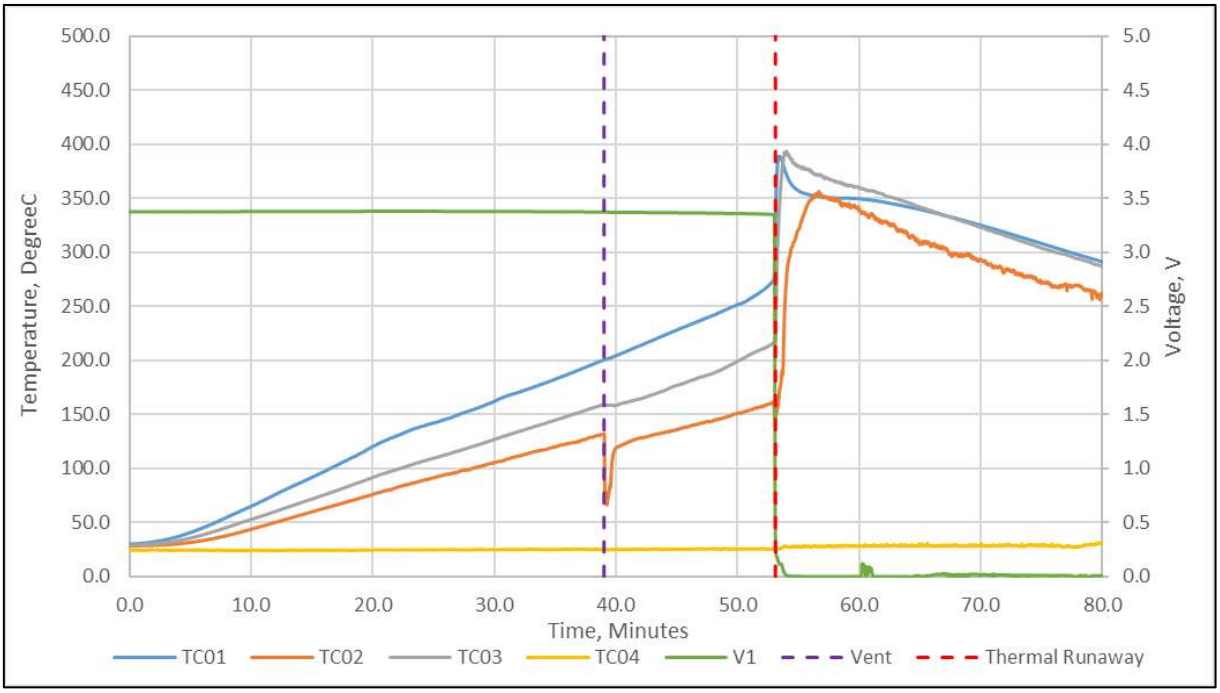

Figure 7: Cell 1 – External Heating 4.5°C per minute

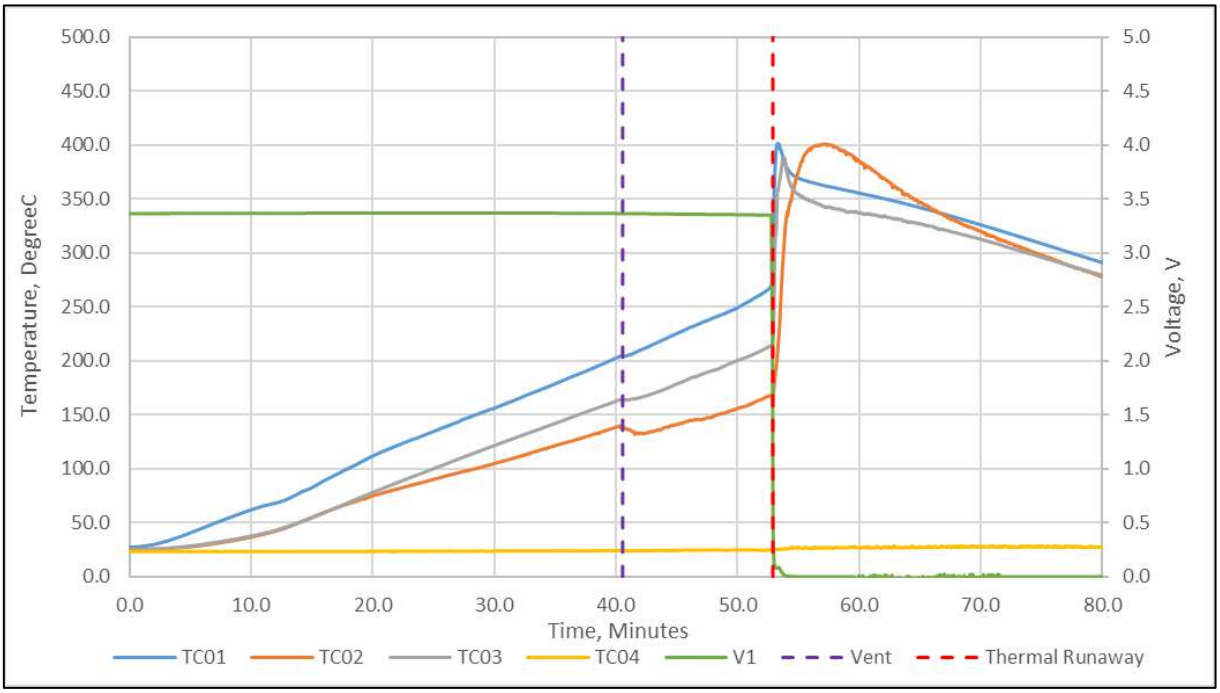

Figure 8: Cell 2 – External Heating 4.5°C per minute

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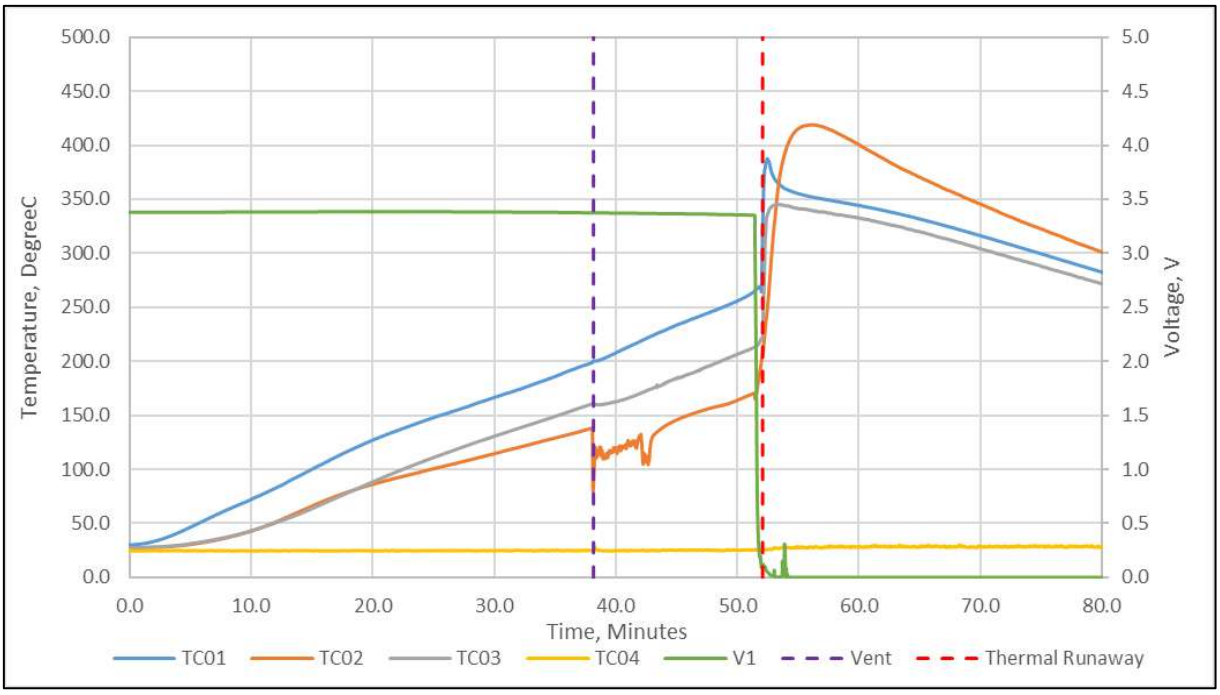

Figure 9: Cell 3 – External Heating 4.5°C per minute

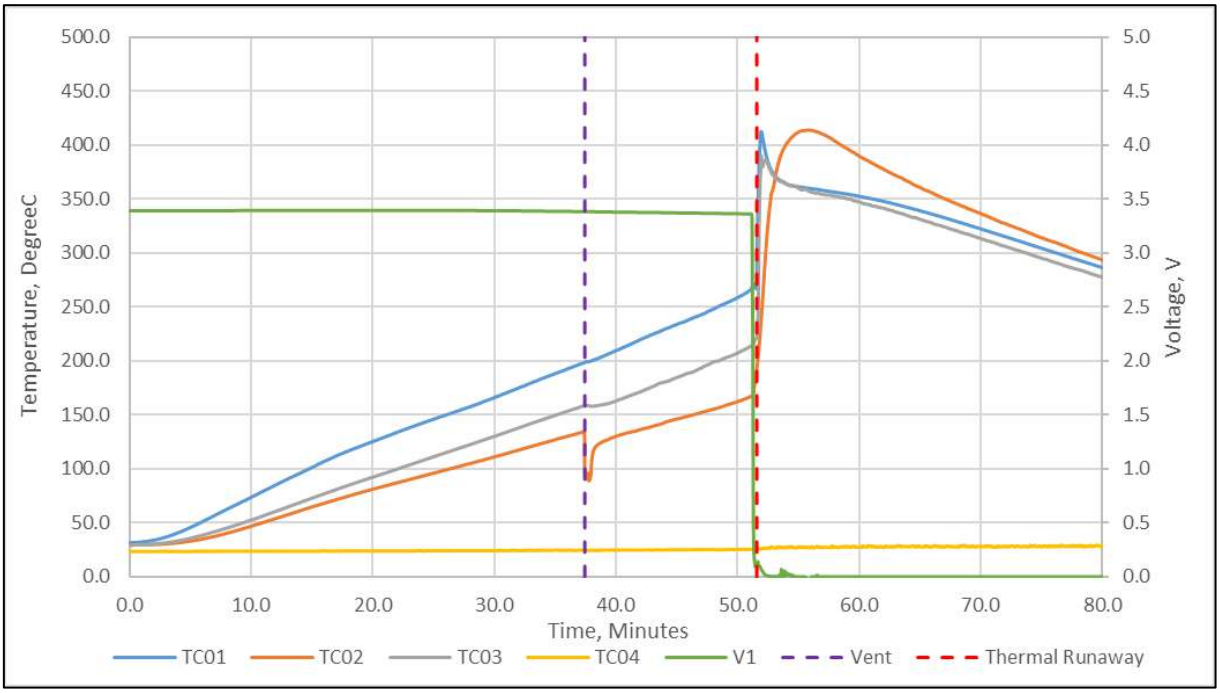

Figure 10: Cell 4 – External Heating 4.5°C per minute

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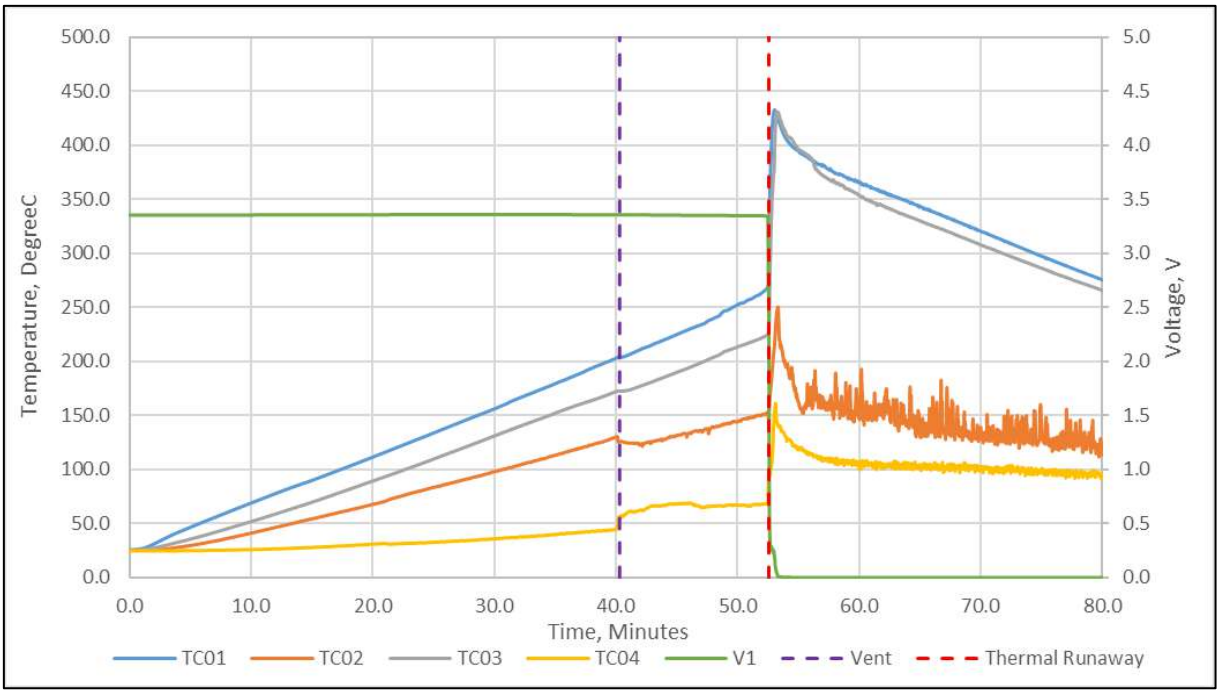

Figure 11: Cell 5 – External Heating 4.5°C per minute

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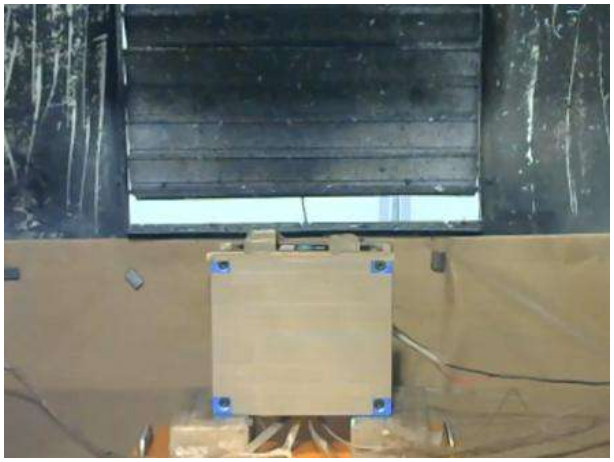
Attachment D: Cell Test Photos - (*Pages **25** through **34***)

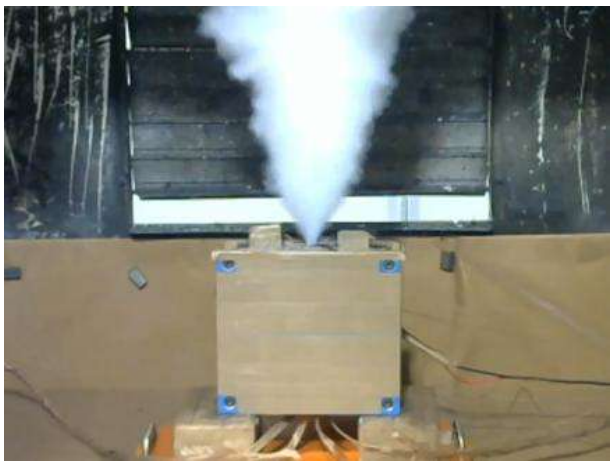
Cell Sample 1 – below figure shows highlights of cell testing. Cell venting and thermal runaway were observed, however no evidence of fire. Figure on next page shows photos of cell after testing.



(a) Test Start
[00:00]



(b) Cell Venting
[39:01]



(c) Thermal runaway behavior
[53:06]

Figure 12: Highlights of Cell 1 Testing

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Figure 13: Sample 1 Post Test Photos

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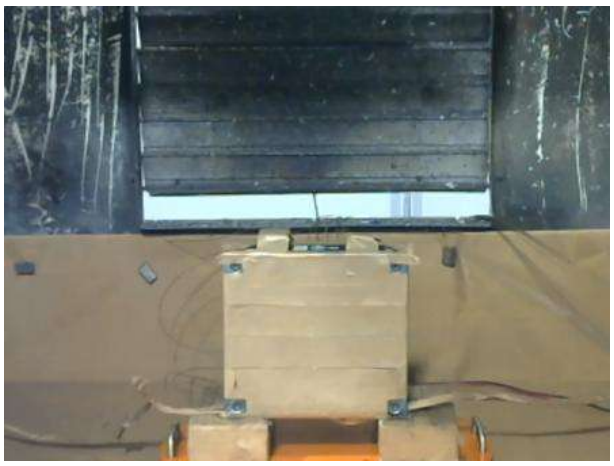
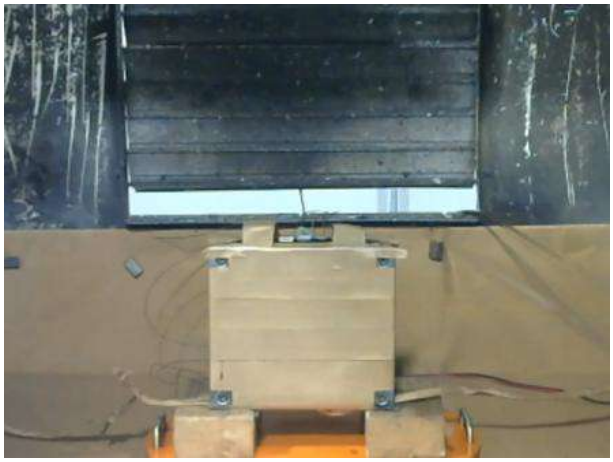
Cell Sample 2 – below figure shows highlights of cell testing. Cell venting and thermal runaway were observed, however no evidence of fire. Figure on next page shows photos of cell after testing.



(a) Test Start
[00:00]



(b) Cell Venting
[40:32]



(c) Thermal runaway behavior
[52:53]

Figure 14: Highlights of Cell 2 Testing

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Figure 15: Sample 2 Post Test Photos

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Cell Sample 3 – below figure shows highlights of cell testing. Cell venting and thermal runaway were observed, however no evidence of fire. Figure on next page shows photos of cell after testing.



(a) Test Start
[00:00]



(b) Cell Venting
[38:09]



(c) Thermal runaway behavior
[52:04]

Figure 16: Highlights of Cell 3 Testing

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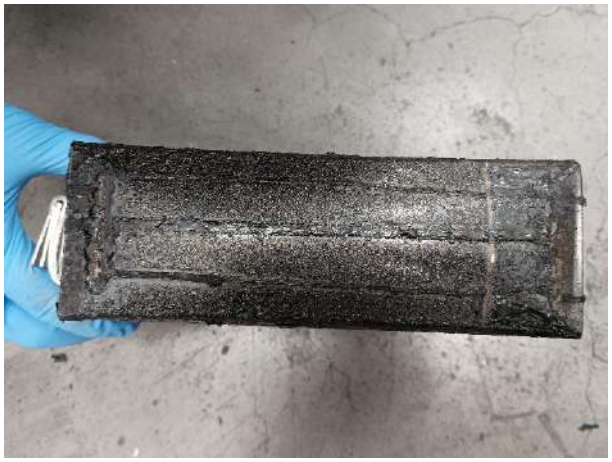


Figure 17: Sample 3 Post Test Photos

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Cell Sample 4 – below figure shows highlights of cell testing. Cell venting and thermal runaway were observed, however no evidence of fire. Figure on next page shows photos of cell after testing.



(a) Test Start
[00:00]



(b) Cell Venting
[37:25]



(c) Thermal runaway behavior
[55:34]

Figure 18: Highlights of Cell 4 Testing

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Figure 19 Sample 4 Post Test Photos

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Cell Sample 5 – below figure shows highlights of cell testing. Cell venting and thermal runaway were observed, however no evidence of fire. Figure on next page shows photos of cell after testing.



(a) Test Start
[00:00]



(b) Cell Venting
[40:13]



(c) Thermal runaway behavior
[52:30]

Figure 20: Highlights of Cell 5 Testing

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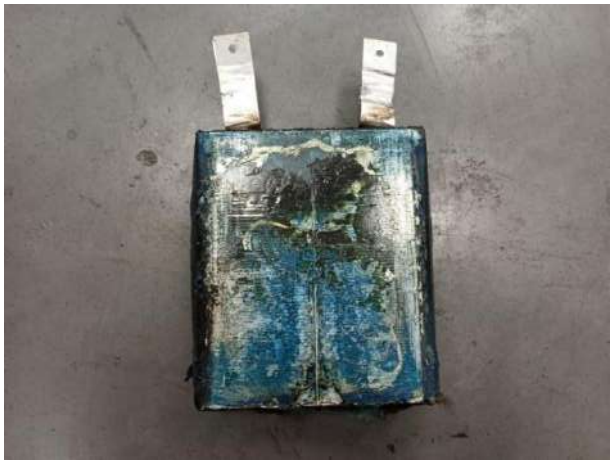




Figure 21: Sample 5 Post Test Photos

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Attachment E: Cell Vent Gas Test Chamber Photo and Profile of Chamber Gas Analysis (O_2 and Pressure) - (*Pages **35** through **37***)

The gas composition test was conducted with the battery inserted into the battery gas composition test chamber and the chamber was sealed. The battery gas composition test chamber is a 100 L pressure vessel and is shown in figure below.

Prior to initiating thermal runaway, the chamber's atmosphere was purged until a condition of less than 1% oxygen by volume (actual 0.04%, with initial pressure 0.26psig).



Figure 22: Sample 5 instrumented and inside gas test chamber

$\phi_{O2,\ chamber}$=	0.04	%

Pinitial,chamber=	0.26	psig

Figure 23: Profile of gas test chamber (O2 and Pressure)

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Table Re-normalized Gas Quantification, excluding N_2 and O_2, and unknown compounds.			
Item	**Measure**	**Chemical formula**	**Conc.(%)**
1	Carbon Monoxide	CO	10.610
2	Carbon Dioxide	CO_2	30.116
3	Hydrogen	H_2	43.569
4	Methane	CH_4	6.625
5	Ethylene	C_2H_4	4.159
6	Acetylene	C_2H_2	0.188
7	Ethane	C_2H_6	1.245
8	Propane	$CH_3CH_2CH_3$	0.292
9	Propylene	C_3H_6	1.056
10	Propadiene (Allene)	C_3H_4	0.005
11	Isobutane	$CH_3CH(CH_3)CH_3$	0.014
12	Butane	C_4H_{10}	0.059
13	Isobutylene	C_4H_8	0.239
14	1-Butene	C_4H_8	0.061
15	trans-2-Butene	C_4H_8	0.027
16	cis-2-Butene	C_4H_8	0.042
17	Pentane	C_5H_{12}	0.064
18	trans-2-Pentene	C_5H_{10}	0.023
19	cis-2-Pentene	C_5H_{10}	0.002
20	1,4-Pentadiene	C_5H_8	0.000
21	Hexane	C_6H_{14}	0.006
22	1-Hexene	C_6H_{12}	0.027
23	Benzene	C_6H_6	0.015
24	1-Heptene	C_7H_{14}	0.000
25	Toluene	C_7H_8	0.002
26	Styrene	C_8H_8	0.000
27	Dimethyl Carbonate	$C_3H_6O_3$	1.477
28	Ethyl Methyl Carbonate	$C_4H_8O_3$	0.077
29	Diethyl Carbonate	$C_5H_{10}O_3$	0.000
	Total	Measurement result	100.000

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Appendix of Report

The tested cell model is CBDC0, with PN number FC-FY5-71H4L4-XXXX.

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MODULE LEVEL TEST REPORT
UL 9540A
Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems (AACD)

Project number	4791943679
File number	N/A
Date of issue	2025-10-29
Total number of pages	26
UL report office	**UL(Changzhou) Quality Technical Service Co., LTD**
Applicant name	**Contemporary Amperex Technology Co., Limited**
Applicant address	**No.2 Xiangang Road, Zhangwan Town, Jiaocheng Distict Nindde, Fujian, 352100 CN**
Standard	UL 9540A:2025, Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems, 5th Edition, March 12, 2025
Test procedure	Section 8
Non-standard test method	N/A

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General disclaimer:

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

UL Solutions did not select the sample(s), determine whether the sample(s) were representative of production samples, witness the production of the test sample(s), nor were we provided with information relative to the formulation used in the test sample(s).

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Photo(s) of module:



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Cell information	
Model number	CBDC0
Rating, Vdc	3.2 Vdc
Rating, Ah	285 Ah
Chemistry of test item	Lithium iron phosphate
Format	Prismatic
Overall dimensions, mm	174.3±0.8mm (depth) by 71.55±0.8mm (width) by 207.3±0.8mm (height)
Cell weight, g	5460±300g
Original equipment manufacturer (OEM)	Contemporary Amperex Technology Co., Limited
Branding manufacturer (if not OEM)	N/A
Standard test item certified to	UL 1973
Organization that certified test item	UL Solutions, MH62898
Summary of cell level test results	
Specific method used to initiate thermal runaway	External heating using thin film with 4°C to 7°C thermal ramp
Average cell surface temperature at gas venting, °C	161
Average surface temperature at thermal runaway, °C	220
Gas volume, L	176.3
Lower flammability limit (LFL), % volume in air at the ambient temperature	8.05
Lower flammability limit (LFL), % volume in air at the venting temperature	7.545
Burning velocity, (S_u) cm/s	64.13
Maximum pressure, (P_{max}) psig	94.29

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Cell gas composition

Gas		Measured %
Carbon Monoxide	CO	10.610
Carbon Dioxide	CO2	30.116
Hydrogen	H2	43.569
Methane	CH4	6.625
Acetylene	C2H2	0.188
Ethylene	C2H4	4.159
Ethane	C2H6	1.245
Propadiene (Allene)	C3H4	0.005
Propylene	C3H6	1.056
Propane	C3H8	0.292
-	C4 (Total)	0.443
-	C5 (Total)	0.089
-	C6 (Total)	0.034
Benzene	C6H6	0.015
Toluene	C7H8	0.002
Dimethyl Carbonate	C3H6O3	1.477
Ethyl Methyl Carbonate	C4H8O3	0.077
Total	**-**	100

Module Information	
Module Manufacturer	Contemporary Amperex Technology Co., Limited
Model number	M01285P10L01
Rating, Vdc	166.4
Rating, Ah	285
Module cell configuration, xS/yP	52S/1P
Module dimensions (W x D x H), mm	1150±5*810±5*241.5±5
Module weight, kg	325±10
Standard test item certified to	N/A
Organization that certified test item	N/A

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Cell failure test method performed for the module level
☒ External heating using thin film heater(s) ☐ Nail Penetration ☐ Overcharge ☐ External short circuit ☐ Overdischarge ☐ Others:
Description of method used to fail cells if other than external thin film heater with thermal ramp: N/A
Description of components employed within the module that serve to suppress thermal runaway propagation (fire protection features): N/A

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Summary of module level test
Performance criteria in accordance with Clause 8.5 [X] Vent gas **[** ~~was~~ **] [** was not **]** nonflammable as determined by the cell level test; [X] There **[** ~~was~~ **] [** was no **]** spread of flame outside of the module; and [X] The module exterior surface temperature **[** ~~did~~ **] [** did not **]** exceed the cell venting temperature. [ ] All the performance criteria of the module level test as indicated in 8.5 of UL 9540A, 5th edition have been met, therefore, the unit level test in accordance with Section 9 of UL 9540A was not required to be conducted. [X] All the performance criteria of the module level test as indicated in 8.5 of UL 9540A, 5th edition have not been met, therefore, the unit level test in accordance with Section 9 of UL 9540A is required to be conducted on a complete unit employing this module..
Performance criteria in accordance with Clause 8.6 [X] Thermal runaway was contained by module design; and [X] There was no leakage of hazardous materials, rupture of the module casing, or explosion with flying debris
[ ] All the performance criteria of the module level test as indicated in 8.6 of UL 9540A, 5th edition have been met, therefore, the unit level test in accordance with Section 9 of UL 9540A is not required to be conducted. [X] All the performance criteria of the module level test as indicated in 8.6 of UL 9540A, 5th edition have not been met, therefore, the unit level test in accordance with Section 9 of UL 9540A is required to be conducted on a complete unit employing this module.

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Testing Laboratory information		
Testing Laboratory and testing location(s)		
Testing Laboratory	Beijing Building Materials Testing Academy	
Testing location/ address	Block 1, B15 Yaxin Road, Doudian Town, Fangshan district, Beijing 102402, CN PSN: 3369533	
Tested by (name)	Zhang Qi, Huang Fei	
Witnessed by (for 3rd Party Lab Test Location) (name, signature)	N/A	N/A
Project Handler (name, signature)	Roy Shi	
Reviewer (name, signature)	Arui Zhou	

List of Attachments (including a total number of pages in each attachment)		
Attachment	**Description**	**Pages**
A	Module Conditioning (Charge/discharge) Profiles	***18** through **18***
B	Module Construction Photos	***19*** through ***19***
C	Module Instrumentation Photos	***20** through **20***
D	Module and Initiating Cell(s) Temperature Profiles [for High Temperature Batteries]	***21** through **21***
E	Module Testing Photos	***22** through **23***
F	Module Gas Flow Rate, Chemical Heat Release Rate Profile, Smoke Release Rate Profile	***24** through **26***

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Test Verdicts	
Clause Requirement Does Not Apply to the Test Item:	N/A (Not Applicable)
Clause Requirement Met**:**	M (Met)
Clause Requirement Not Met:	NM (Not Met)
Clause Requirement Completed:	C (Completed)
Clause Requirement Completed with Modification	Mod (Modified)
Test Dates	
Date of Receipt of Test Item	2024-06-19
Date(s) of Performance of Tests	2024-06-22
General remarks	
"(See Attachment #)" refers to additional information appended to the report. Throughout this report a point is used as the decimal separator.	
Manufacturer's Declaration of samples submitted for test:	
The module can be manufactured at more than one location. The manufacturer provided a written declaration stating that the manufacturing process at all manufacturing locations is identical and product from one manufacturing location is representative of all manufacturing locations listed below.	☒ **Yes** ☐ **Not applicable**
Name and address of factory(ies) supplying samples for test:	Factory 1: Contemporary Amperex Technology Co Limited Factory address1: No.2 Xingang Road Zhangwan Town, Jiaocheng District, Ningde, 352100 Ningde, Fujian, P.R.CHINA Factory 2: Guangdong Ruiqing Contemporary Amperex Technology Limited Factory address 2: No1, Shidai steet, Dawang HightechZone, Sihui, 526200 Zhaoqing, PEOPLE'S REPUBLIC OF CHINA Factory 3: Jiangxi Yichun Contemporary Amperex Technology Limited Factory address 3: No. 1, Chunfeng Road, YichunEconomic and Technological Development Zone, 336000Yichun, Jiangxi Province, PEOPLE'S REPUBLIC OFCHINA
General product information and other remarks: Battery module model M01285P10L01 employs cell Models CBDC0 manufactured by Contemporary Amperex Technology Co Limited, rated 166.4V, 285Ah. The test samples were produced in Factory 1.	

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This report is reissued from UL 9540A:2019, Fourth Edition, revised November 12, 2019 to UL 9540A, Fifth Edition, revised on March 12, 2025, based on the original report UL Project No. 4791324742 issued on July 30, 2024.
This update also updated the description of module size from 1155±5*810±5*243.5±5 to 1150±5*810±5*241.5±5. Page 4.

No test was conducted for this reissue investigation as all the new requirements were addressed in the UL Project No. 4791324742 taking account the requirements of UL CRD i9540A-4-20200110.

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UL 9540A, Edition 5			
Clause	**Requirement + Test**	**Remark**	**Verdict**
PERFORMANCE			
8.1	**Samples**		
8.1.1	Samples conditioned through charge discharge cycling a minimum of 2 cycles	See Attachment A for profiles See Table 1 for specifications See also Table 2 The module voltage was checked before the test, and the voltage did not drop further compared to 1h to 8h after cycles, which was judged acceptable.	Mod
8.1.2	100% SOC and allowed to rest for a minimum of 1h before testing		
8.1.3	The module voltage was measured and recorded before testing.		C
8.1.4	Electronic controls such as BMS not relied upon during testing		C
8.2	**Test Method**		
8.2.1	Ambient indoor laboratory conditions: 25 ±5°C (77 ±9°F) ≤50 ±25% RH at the initiation of the test.	See Table 2	C
8.2.2	Test conducted under a smoke collection hood appropriately sized for the module		C
8.2.3	The weight of the module was recorded before and after testing, kg, unless consumed by fire	See Table 9	C
8.2.4	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 and the design of the module. The location of the cell(s) forced into thermal runaway were selected to present the greatest thermal exposure to adjacent cells	See Attachment C for figures showing location within the module of the cell(s) forced into thermal runaway	C
8.2.5	A sufficient number of cells were forced into thermal runaway to create a condition of cell to cell thermal runaway propagation within the module		C
8.2.6	Temperatures were measured on • initiating cells, • nearby non-initiating cells, and • exterior surface of module enclosure closest to initiating cell locations		C
8.2.7	The method used to initiate thermal runaway in the cell(s) were in accordance with 7.3	See Summary of Cell Testing at the beginning of this report.	C

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UL 9540A, Edition 5			
Clause	**Requirement + Test**	**Remark**	**Verdict**
8.2.8	The occurrence of thermal runaway was verified	See Test Results from Cell Level Test from the beginning of this report See Attachment D	C
8.2.9	The module was placed on top of a non-combustible horizontal surface with the module orientation representative of its intended final installation.	See Attachment E	C
8.2.10	The chemical heat release rate of the module was measured with oxygen consumption calorimetry	See Table 8 See Attachment F	C
8.2.11	The chemical heat relate rate was measured for the duration of the test	See Attachment F	C
8.2.12	The chemical heat release rate was measured using the following equipment: ● Paramagnetic oxygen analyser ● Non-dispersive infrared carbon dioxide and carbon monoxide analyser ● Velocity probe ● Type K thermocouple	See Attachment F	C
	The instrumentation was located in the exhaust duct of the heat release rate calorimeter at a location that minimizes the influences of bends or exhaust devices.		C
8.2.13	The chemical heat release rate at each of the flows was calculated in accordance with 8.2.11.	See Attachment F	C
8.2.14	The hydrocarbon content of the vent gas was measured using flame ionization detection.	See Table 5	C
	Hydrogen gas shall be measured with an appropriate sensor for the anticipated range of gas as well as for exposure to anticipated contaminants, such as a palladium-nickel thin-film solid state sensor.	See Table 5	C
8.2.15	At the request of the BESS manufacturer, the hydrocarbon content of the vent gas may be measured using a Fourier-Transform Infrared Spectrometer with a minimum resolution of 1 cm-1 and a path length of at least 2 m (6.6 ft), or equivalent gas analyzer.	FTIR analysis was not used in accordance with the Certification Requirement Decision: Corrections to gas measurement methods to make FTIR as an option for measuring hydrocarbon contents of gas emissions and to include Hydrogen measurements during the Unit Level Test. FTIR was considered redundant to the other gas measurement methods used.	N/A

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UL 9540A, Edition 5			
Clause	**Requirement + Test**	**Remark**	**Verdict**
	Vent gas velocity and temperature measurements respectively were obtained in the exhaust duct of the heat release rate calorimeter using equipment specified in 8.2.10.		C
8.2.16	The light transmission in the exhaust duct of the heat release rate calorimeter was measured using a white light source and photo detector for the duration of the test.		C
8.2.17	Smoke release rate was calculated as outlined in 8.2.15	See Table 8 See Attachment F	C
8.4	**Module level test report**		
8.4.1	Module level report includes the following:		
	a. Module manufacturer and model number and whether UL 1973 compliant; b. Number of cells in module; c. Module configuration;	See Test Item Description at start of this report.	C
	d. Module construction features;	See Attachment C See Critical Components Table See Also “Description of components employed within the module that impact propagation (fire protection features)” at the beginning of this report.	C
	e. Module voltage corresponding to the tested SOC;	See Table 2	C
	f. Thermal runaway initiation method used;	See Attachment C	C
	g. Heat release rate versus time data;	See Table 8 See Attachment F	C
	h. Flammable gas generation and composition data;	See Attachment F See Table 7	C
	i. Peak smoke release rate and total smoke release data.	See Table 8 See Attachment F	C
	j. Observation(s) of flying debris or explosive discharge of gases;	See Attachment E and Table 10	C
	k. Observation(s) of sparks, electrical arcs, or other electrical events;	See Attachment E and Table 10	C
	l. Identification/location of cells(s) that exhibited thermal runaway within the module;	See Table 3	C
	m. Locations and visual estimations of flame extension and duration from the module;	See Attachments E See Table 10	C
	n. Module weight loss;	See Table 9	C

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UL 9540A, Edition 5			
Clause	**Requirement + Test**	**Remark**	**Verdict**
	o. Module exterior maximum temperature		C
	p. Video of the test.		C
	q. Cell level test report summary		C
8.5	**Performance – Module level**		
8.5.1	Unit level testing is not required if all the following performance conditions are met during the module level test:		
	a. Cell vent gas is nonflammable as determined by the cell level test	Cell gas report show the cell gases are flammable. See Cell Gas Composition Table.	NM
	b. There is no spread of flame outside of module;		M
	c. Module exterior temperature does not exceed the cell venting temperature as measured adjacent to the initiating cell where the greatest thermal exposure is anticipated		M

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Table 1 – Specified conditioning parameters			
Charging:		**Discharging:**	
Power (CP), kW	47.424	Power (CP), kW	47.424
Standard full Charge Voltage, Vdc	Any cell reaches of 3.65V or total voltage reach 189.8V	End of discharge voltage, Vdc	Any cell reaches of 2.5V or total voltage reach 130V
Cutoff Voltage, V	Any cell reaches of 3.65V or total voltage reach 189.8V	Cutoff Voltage, V	Any cell reaches of 2.5V or total voltage reach 130V
Charging Test Ambient, °C	0~57	Discharging Test Ambient, °C	-20~57
Refer to Attachment A for charge/discharge profiles for the module.			

Table 2 Test Initiation Details	
Charge completion date, YYYY-MM-DD	2024-06-20
Charge completion time, hh:mm	15:13
Test Date, YYYY-MM-DD	2024-06-22
Test Start Time, hh:mm	12:32
Initial Lab Temperature, °C	28.6
Initial Relative Humidity, %RH	65
Module OCV at Start of Test, Vdc	173.3
Method used to force cell into thermal runaway, details of failure methods (such as overcharge parameters)	External heating using thin film heaters

Table 3 – Approximate time of thermal runaway propagation through module	
Time to thermal runaway, hh:mm:ss	**Location**
0:50:30	Cell(20)
0:53:33	Cell(19)
0:54:23	Cell(21)

Table 4 – Test overview timeline		
Time, hh:mm:ss	**Event**	**Description**
00:00:00	Test Start	The test was started and the heater was turned on to heat the initiating cell (Cell 20) at a ratio of 4 ~ 7 °C/min.
00:49:26	Venting of initiating Cell	Initiating cell (Cell 20) vented at around 176°C measured through T2-2 by an indication of sudden dip in cell's temperature curve. See Figure (b)
00:50:30	Thermal runaway of initiating cell	Initiating cell (cell 20) was at around 170°C measured through T2-2. Smoke was continuously released from the vent and the temperature of cell 20 began to increase in an uncontrollable manner. See Figure (c)
00:53:33	Thermal runaway of initiating cell	Thermal runaway propagated to nearby cell (cell 19). Observation of enclosure breaching, more smoke released from the enclosure. See Figure (d)
00:54:23	Thermal runaway of initiating cell	Thermal runaway propagated to nearby cell (cell 21). More smoke released from the enclosure. See Figure (f)
01:30:00	Test Termination	Data acquisition was stopped. The module was left in the test overnight and with video monitored. See Figure (g)

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Table 5 – Gases measured and measurement methods used in unit level testing			
Measurement Method	**Gases Measured**	**Chemical Formula**	**Gas Type**
Flame Ionization Detection (FID)	Total Hydrocarbons	-	Hydrocarbons
Solid-state Hydrogen Sensor	Hydrogen	H_2	-
Non-dispersive infrared spectroscopy (NDIR)	Carbon Dioxide	CO_2	Carbon Containing
	Carbon Monoxide	CO	Carbon Containing
# - This table was modified to reflect the gases measured during testing.			

Table 6 - Gas generation periods	
Time, hh:mm:ss to hh:mm:ss	**Condition**
0:49:26 to 01:30:00	Pre-Flaming
No flaming	Flaming
External Flaming of Gas	
Condition	**Duration (hh:mm:ss)**
External Flaming of Vent Gases:	No flaming

Table 7– Summary of battery gas volumes for deflagration hazard calculations				
Gas Component	Gas Type	During Pre-flaming, L	During Flaming, L	Minimum detectable flow rate, LPM
Total Hydrocarbons (Propane Equivalent)	Hydrocarbons	80.77	No flaming	0.30
Carbon Dioxide	Carbon Containing	134.88	No flaming	0.49
Carbon Monoxide	Carbon Containing	38.37	No flaming	0.29
Hydrogen	Hydrogen	143.29	No flaming	5.86

Table 8 – Chemical heat and smoke release rates			
Chemical Heat Release Rate (HRR)		**Smoke Release Rate (SRR)**	
Peak Chemical HRR, kW	No flaming	Maximum SRR, m^2/s	1.73
		Total Smoke Released, m^2	138.92

Table 9 – Module Weight Loss and Temperature	
Module weight Before Test, kg:	327.5kg
Module weight After Test, kg:	326.0kg
Weight Loss, kg:	1.5kg
Maximum measured temperature on module enclosure, °C	144°C

Table 10 – Other Observations		
	Observed, Yes/No	**Location**
Flying debris	No	N/A
Enclosure rupture	No	N/A
Explosive discharge of gas	No	N/A
Sparks or electrical arcs	No	N/A
Flaming outside of module	No	N/A

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Table 11 – Critical Component Information					
Component / part number	**Manufacturer/ trademark**	**Type / model**	**Technical data**	**Standard**	**Mark(s) of conformity**
Cells	CATL	CBDC0	Nominal voltage: 3.2V Rated capacity: 285Ah	UL 1973:2022	UL MH62898
Module Model	CATL	-	Nominal voltage: 166.4V Rated capacity: 285Ah	--	--
Metal enclosure(Bottom)	CATL	-	Material: AL3003, Minimum thickness: 1.4mm/1.0mm Size: 1145*810*59.5mm	--	--
Plastic enclosure(Top)	0000005701	PP	V-0, 85°C, THK: 1.1mm Size: L*W*H(mm) 1145*803.6*197.5	UL 94	Intertek 20890002-MT-3
Battery connector	0000007975	REA4-WTAB-95-A	1500Vdc, 350A, RTI:105°C ,V-0, Min THK: 1.7mm	UL 4188	UL E526230
CSC PCB material	0000007727	SH10	V-0, 130°C, CTI>600, 1.6mm	UL 94 UL 796 UL 746A	UL E248779
Internal connecting wires for HV	0000009966	3932	2000V, -40°C ~125°C, 95mm^2	UL 758	UL E214184
Voltage sampling wire	0000009966	3666	32awg, XLPE, 105°C, 600 Vac.	UL 758	UL E214184
Temperature sampling wire	0000008559	4484	32 - 16 AWG 150°C ,300 Vac.	UL 758	UL E237675
NTC Sensor	0000008559	103AP-2	10kΩ±0.5%/1%, -50°C to 110°C	UL1581	UL E92669
Mica paper	0000014138	GM-S	5600VDC@60s, 1mA; 500MΩ@1000V D	UL 94	SCH21070294-02B
Plastic material for sampling connector	0000013562	PA66 GF25	V-0, THK: 0.35mm, -40°C to 125°C	UL 94	EG190813001R02Zver.1
cushion	0000021179 0000032408	MPP-15	size:201*169*3.3mm 1000VDC,60S,R≥500MΩ 2700VDC,60S,I≤1mA	--	--
Heat insulating pad	0000003940 0000009455	FNF-G	size:200*164*2.3mm 1000VDC,60S,R≥500MΩ 2700VDC,60S,I≤1mA	UL 94	SGS GZMR220400910201_CN

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Explosion relief valve	13358	PDA3K-50G	Discharge pressure: 3kPa Plastic material: PC+GF10/PC Aluminum alloy materia: AL 6063 Sealing ring material: silicon rubber Membrane material: e-PTFE	--	--

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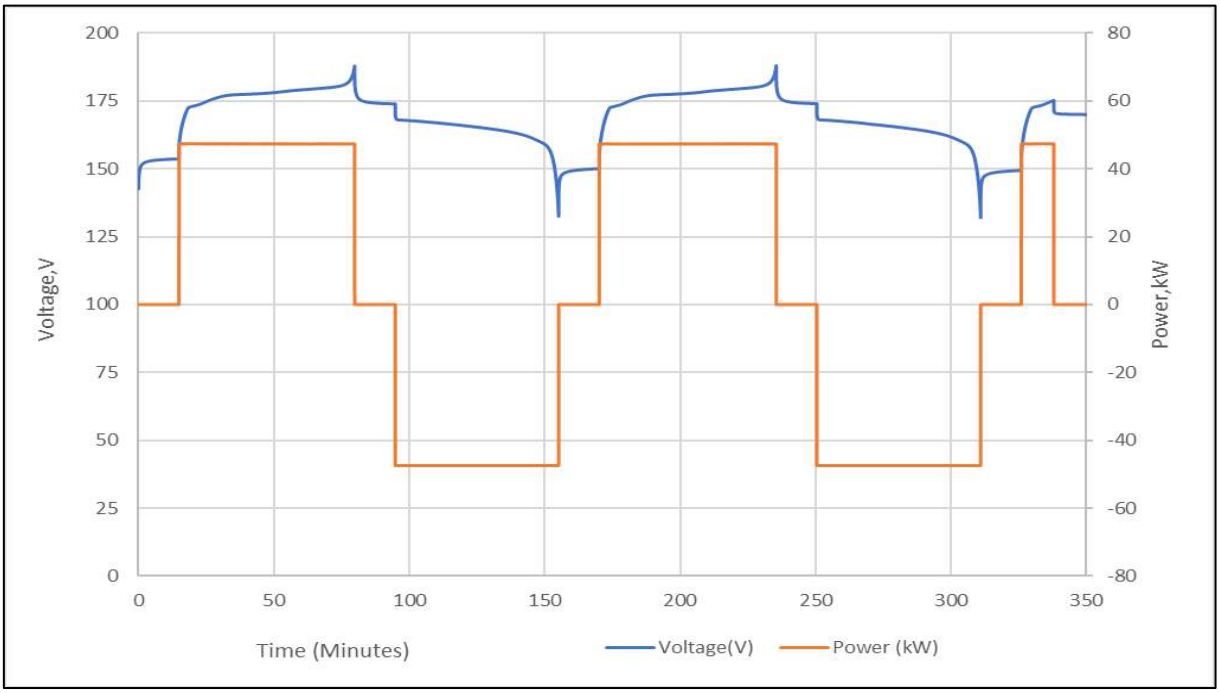
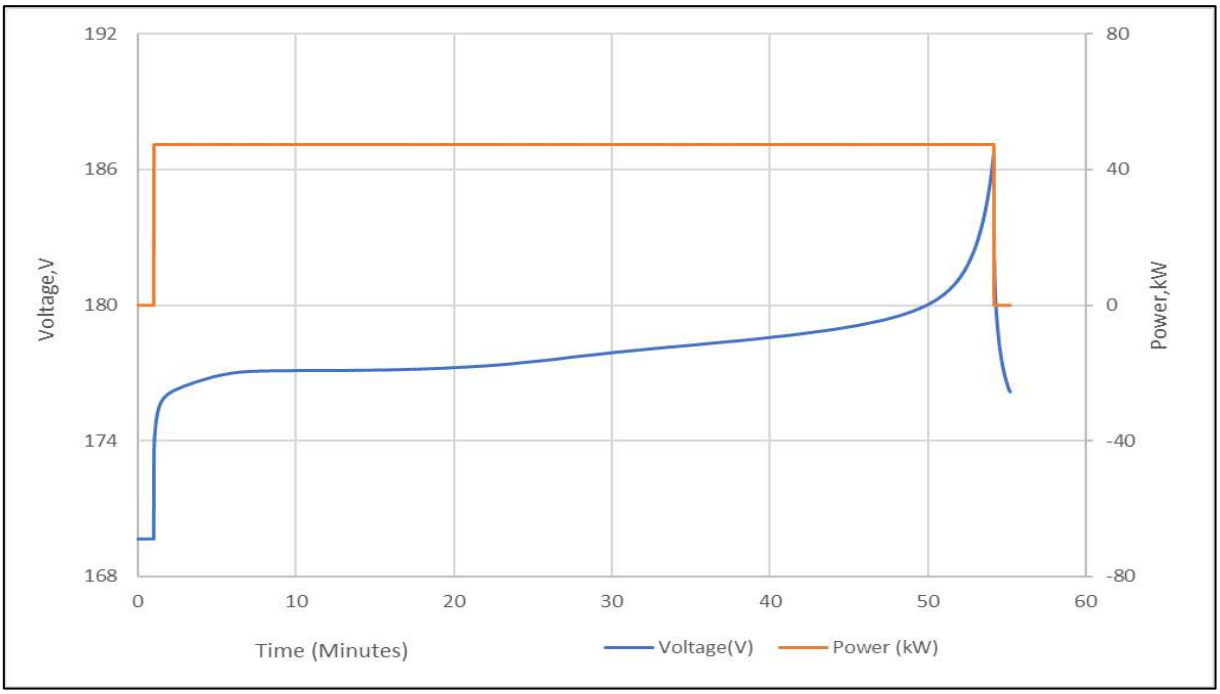
Attachment A: Module Conditioning (Charge/discharge) Profiles - (*Pages **18** through **18***)



Charge/Discharge Cycle



Module charge to 100% SOC

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Attachment B: Module Construction Photos - (Pages ***19*** through ***19***)



Figure 1: Photo of cell – large side

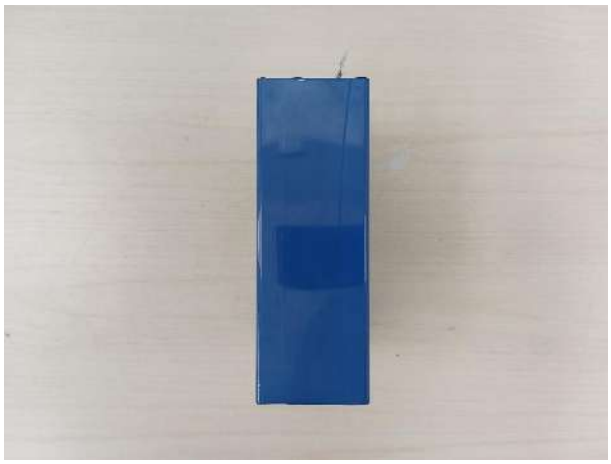

Figure 2: Photo of cell – Narrow side view

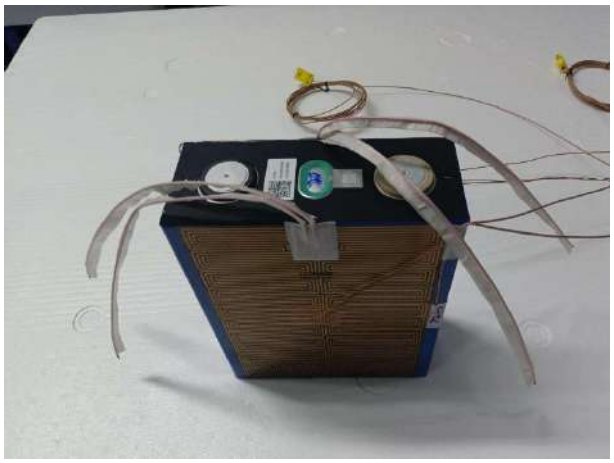

Figure 3: Cell with heater. two pieces of 203.0 mm by 152.4 mm for each sample.



Figure 4: Photo of module – Internal view

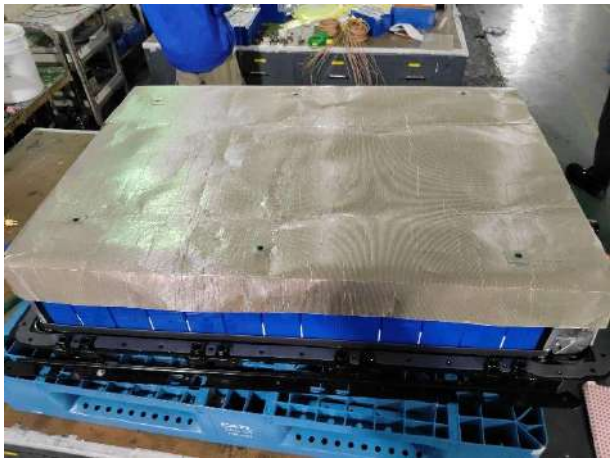

Figure 5: Mica sheet in the module



Figure 6: Photo of module

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Attachment C: Module Instrumentation Photos - (*Pages **20** through **20***)

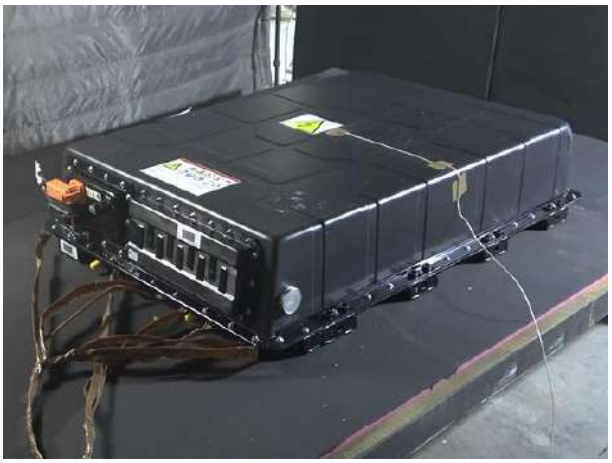

Figure 7: Module on the test platform-side view-1



Figure 8: Module on the test platform- side view-2

Note: The thermocouple T1-1 was used to control the supply power to the heater to keep the heating rate at 4 ~ 7 °C/min. T2-1 and T2-2 were used to represent the temperature of initiating cell.
T1-1, on the wide side surface center of cell 20, between the cell and heater.
T1-2 on the other wide side surface center of cell 20, between the cell and heater.
T2-1, T2-2, on each wide side surface center of cell 20, not covered by heater.
V1, V2, V3, V4, V5 was the voltage of cell 20, 19, 21, 7, 33 separately.
T3-1, T3-2, T4-1, T4-2, T5, T6, T7, T8 were attached on the wide side surface center of cells shown in below illustration.

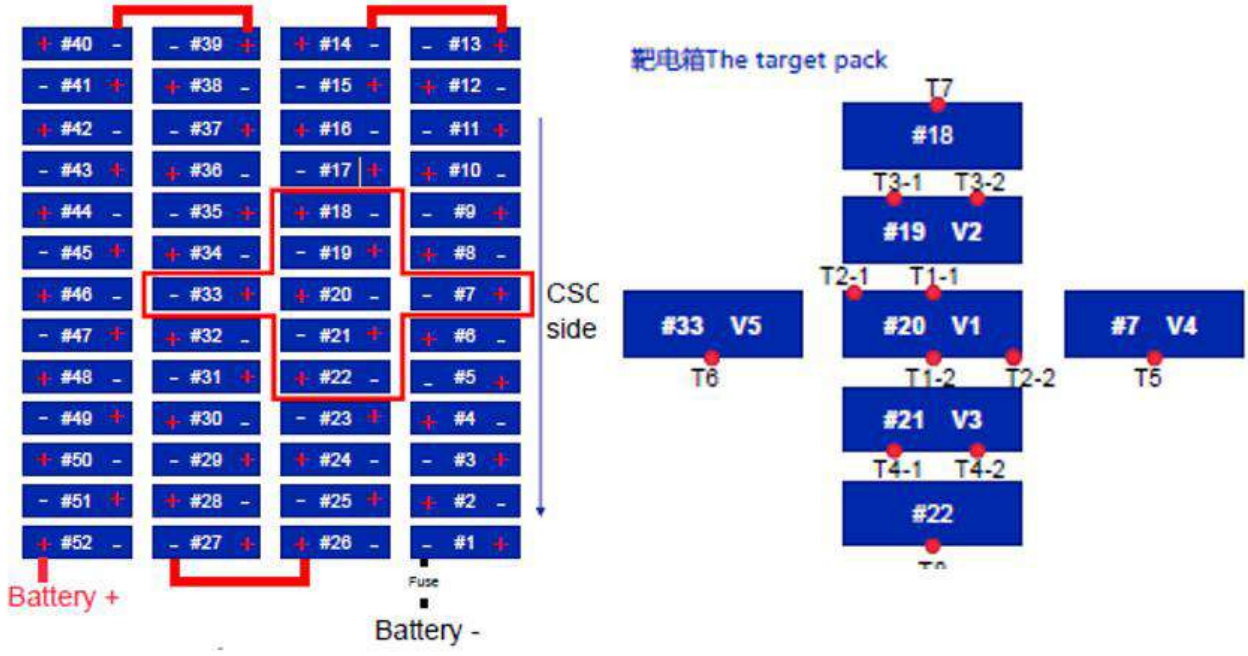

Figure 9: Location of TCs

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Attachment D: Module and Initiating Cell(s) Temperature Profiles [for High Temperature Batteries - (*Pages* **21** *through* **21**)

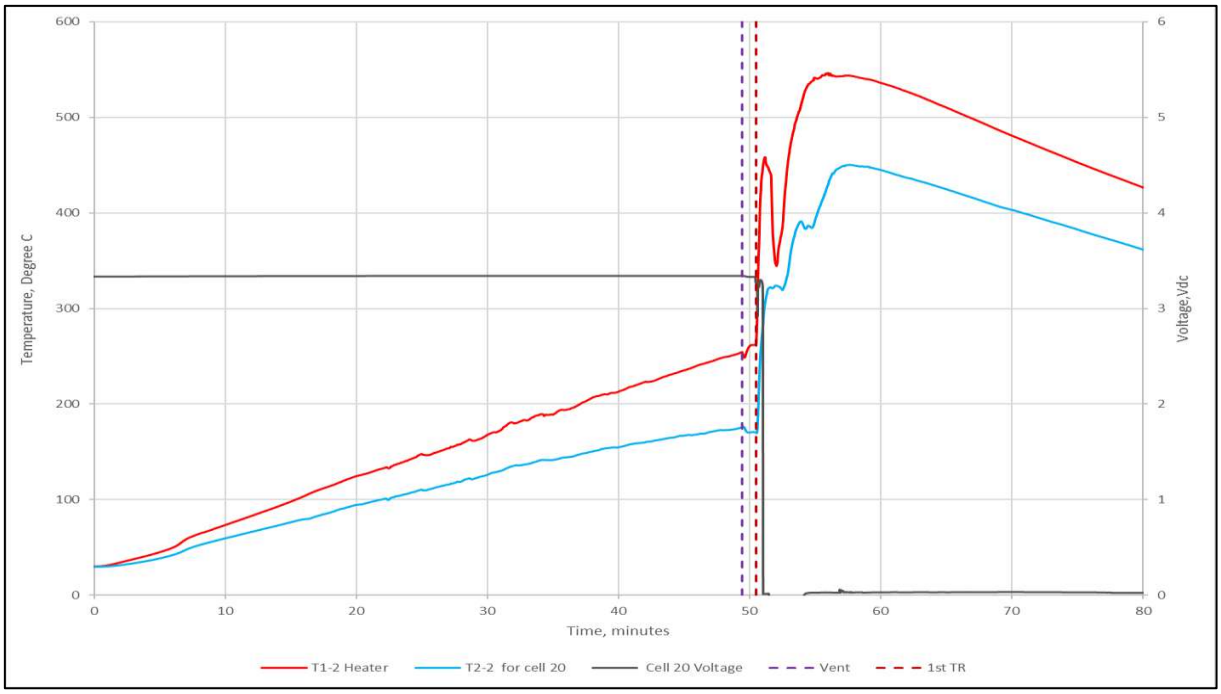

Figure 10: Initiating cell Temperature and Voltage Profiles During Testing

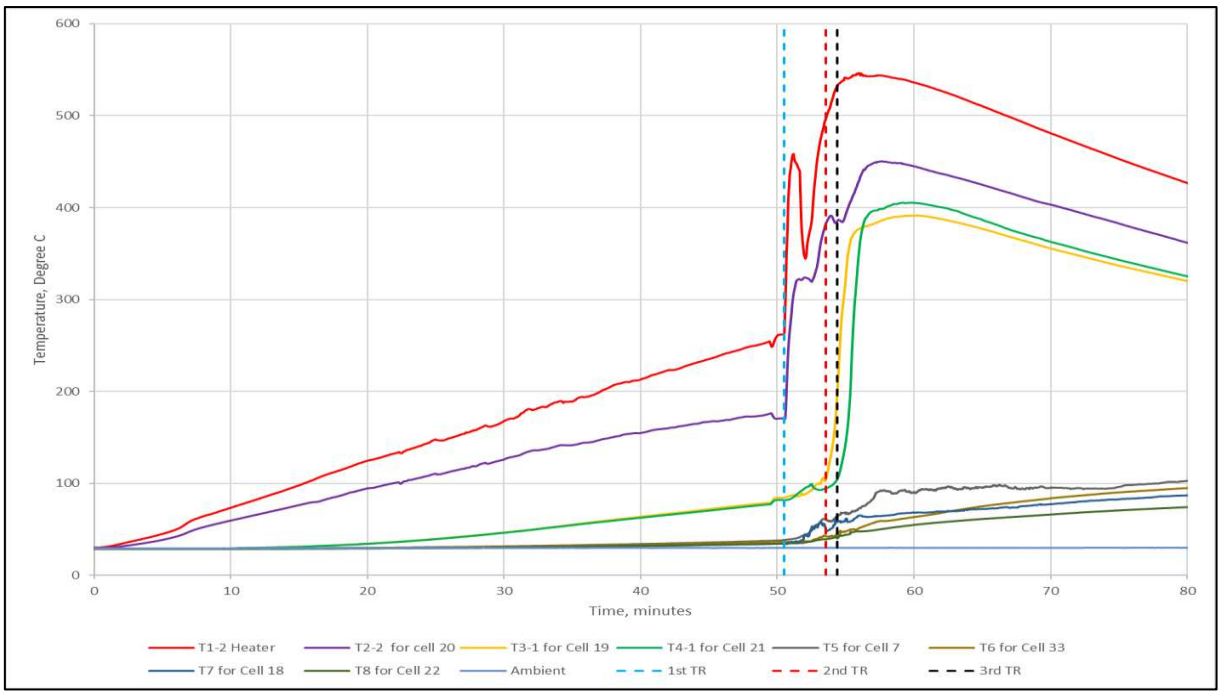

Figure 11: Temperature Profiles Describing Cell to Cell Propagation

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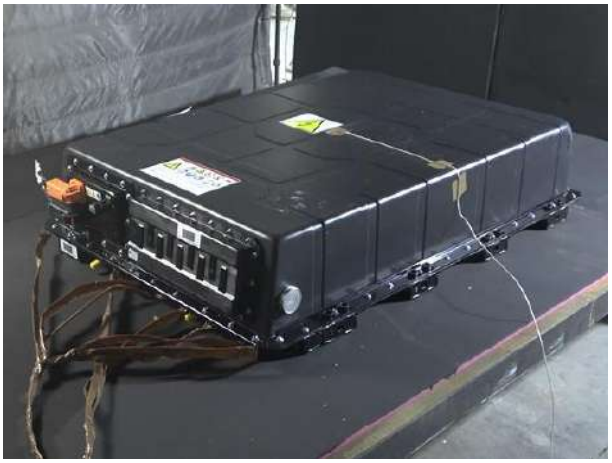
Attachment E: Module Testing Photos - (*Pages **22** through **23***)

	
(a) Test start [00:00:00]	(b) Initiating cell 20 Venting [00:49:26]
	
(c) Thermal runaway of initiating Cell 20 [00:50:30]	(d) Thermal runaway of adjacent Cell 19 [00:53:33]

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(e) Thermal runaway of adjacent Cell 21 [00:54:23]



(f) Test Termination [01:30:00]









Figure 12: Post-test photo

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Attachment F: Module Gas Flow Rate, Chemical Heat Release Rate Profile, Smoke Release Rate Profile - (*Pages **24** through **26***)

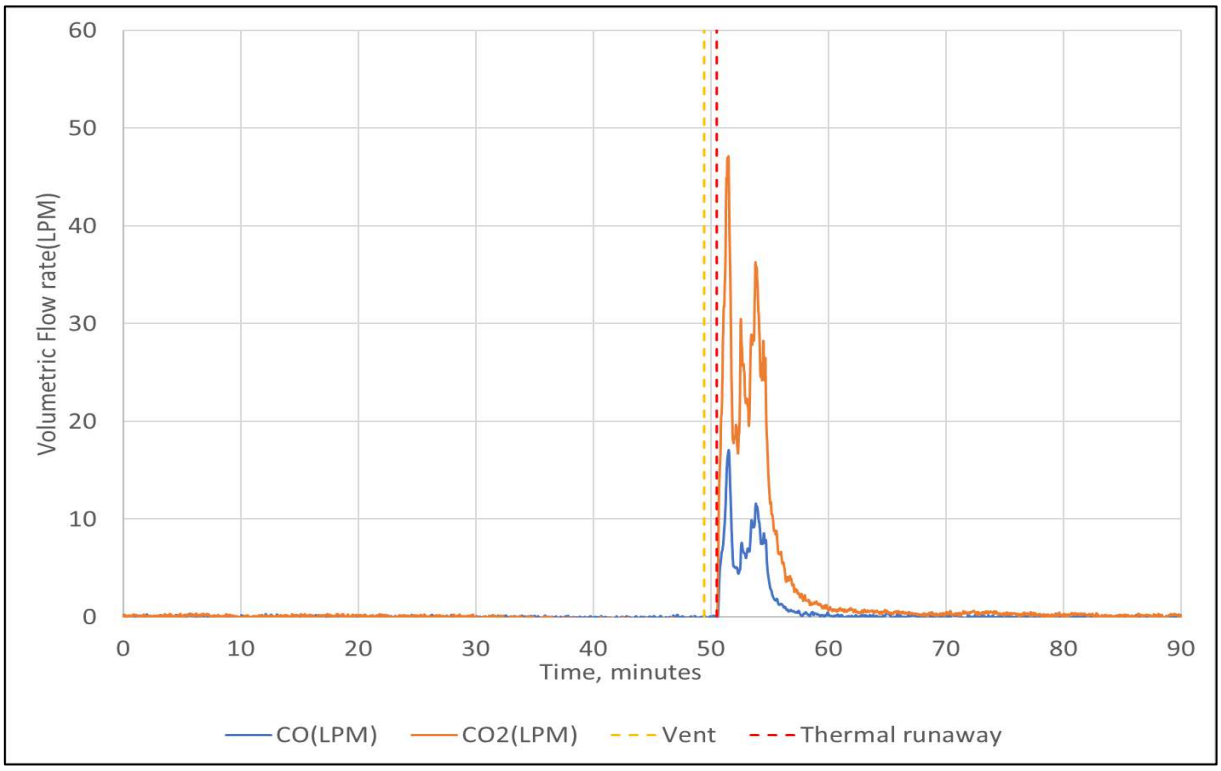

Figure 13 - CO, CO2 Volumetric flow rates

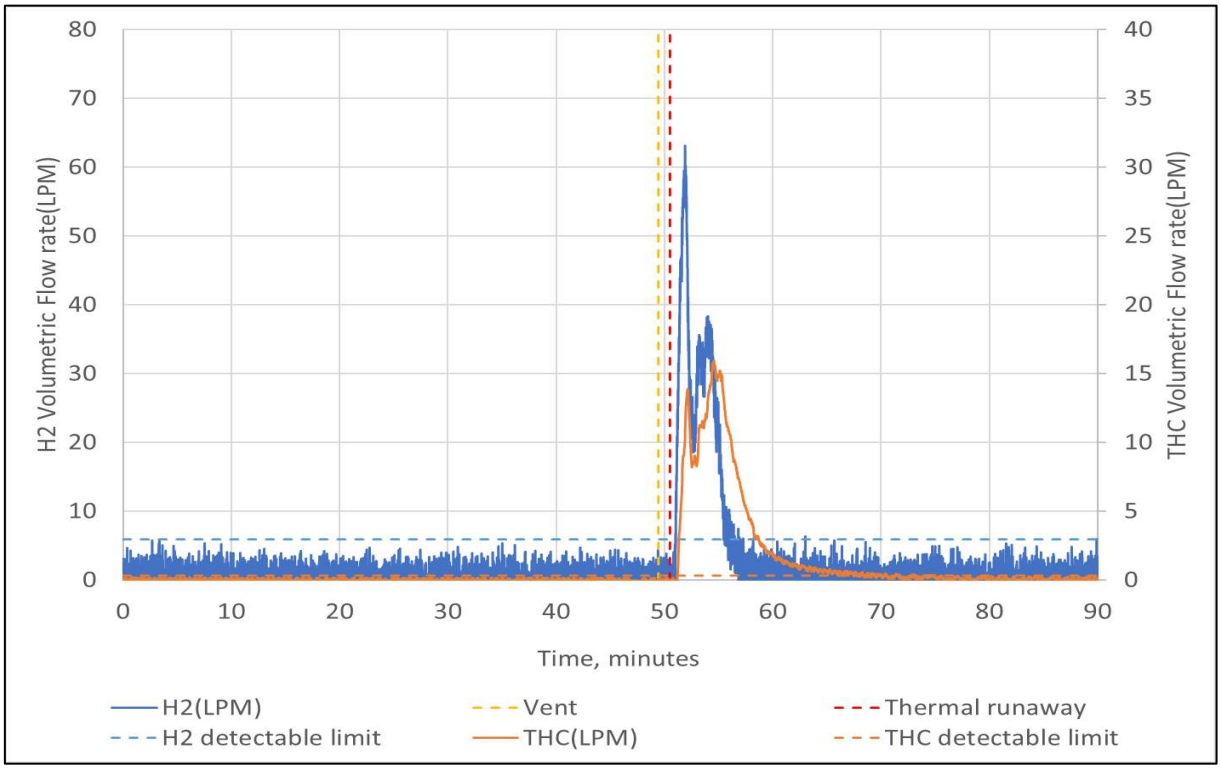

Figure 14 - THC, H2 Volumetric flow rates

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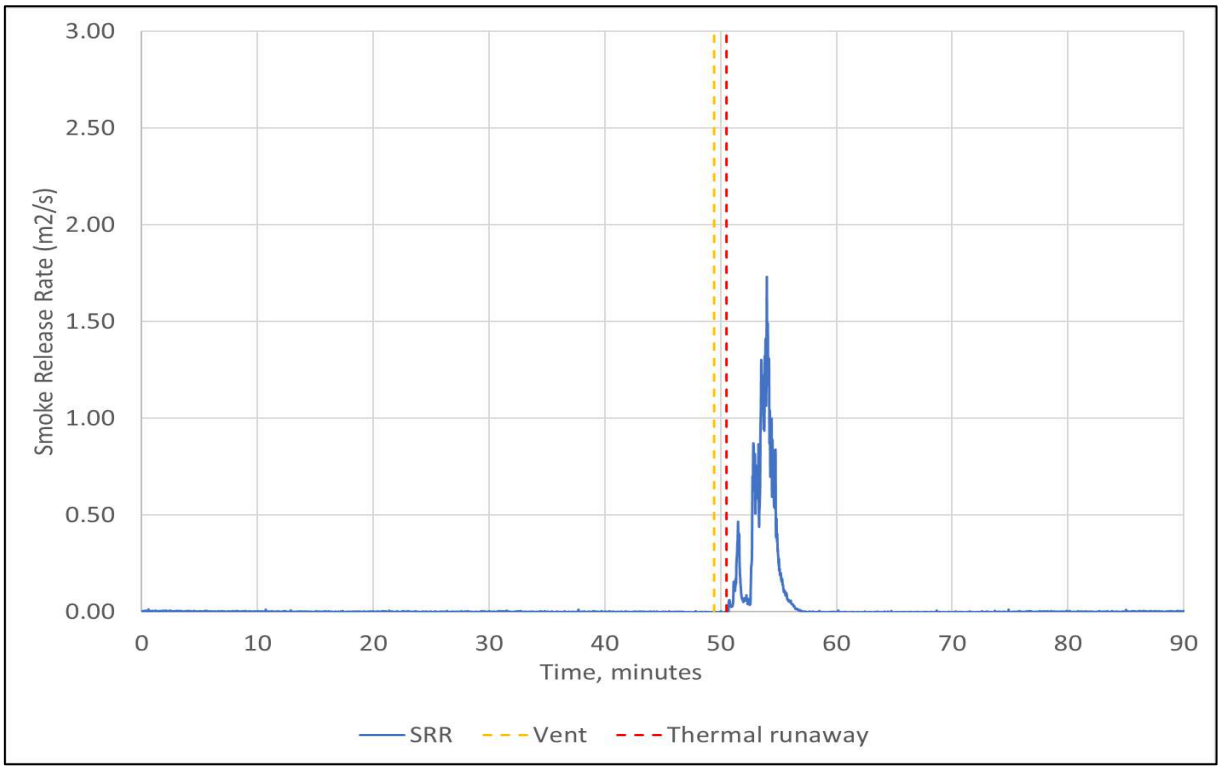

Figure 15: Smoke release rate

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Appendix of Report

The tested cell model is CBDC0, with PN number FC-FY5-71H4L4-XXXX.

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UNIT LEVEL TEST REPORT
UL 9540A
Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems (AACD)

Project number	4791943683
File number	N/A
Date of issue	2025-10-28
Total number of pages	47
UL report office	UL(Changzhou) Quality Technical Service Co., LTD
Applicant name	Contemporary Amperex Technology Co., Limited
Applicant address	No.2 Xingang Road, Zhangwan Town, Jiaocheng District 352100 Ningde, Fujian, PEOPLE'S REPUBLIC OF CHINA
Standard	UL 9540A:2025, Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems, 5th Edition, March 12, 2025
Test procedure	Section 9
Non-standard test method	N/A

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General disclaimer:

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

UL Solutions did not select the sample(s), determine whether the sample(s) were representative of production samples, witness the production of the test sample(s), nor were we provided with information relative to the formulation used in the test sample(s).

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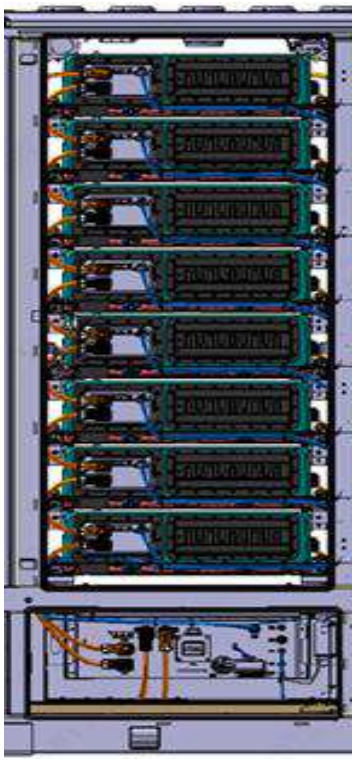



Layout and unit photo

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Cell information	
Model number	CBDC0
Rating, Vdc	3.2
Rating, Ah	285
Chemistry of test item	Lithium iron phosphate
Format	Prismatic
Overall dimensions, mm	174.3±0.8 (depth) by 71.55±0.8 (width) by 207.3±0.8 (height)
Cell weight, g	5460±300
Original equipment manufacturer (OEM)	Contemporary Amperex Technology Co., Limited
Branding manufacturer (if not OEM)	N/A
Standard test item certified to	UL 1973
Organization that certified test item	UL Solutions, MH62898
Summary of cell level test results	
Average cell surface temperature at gas venting, °C	161
Average surface temperature at thermal runaway, °C	220
Gas volume, L	176.3
Lower flammability limit (LFL), % volume in air at the ambient temperature	8.05
Lower flammability limit (LFL), % volume in air at the venting temperature	7.545
Burning velocity, (S_u) cm/s	64.13
Maximum pressure, (P_{max}) psig	94.29

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Cell gas composition

Gas		Measured %
Carbon Monoxide	CO	10.610
Carbon Dioxide	CO2	30.116
Hydrogen	H2	43.569
Methane	CH4	6.625
Acetylene	C2H2	0.188
Ethylene	C2H4	4.159
Ethane	C2H6	1.245
Propadiene (Allene)	C3H4	0.005
Propylene	C3H6	1.056
Propane	C3H8	0.292
-	C4 (Total)	0.443
-	C5 (Total)	0.089
-	C6 (Total)	0.034
Benzene	C6H6	0.015
Toluene	C7H8	0.002
Dimethyl Carbonate	C3H6O3	1.477
Ethyl Methyl Carbonate	C4H8O3	0.077
Total	-	100

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Module Information	
Module Manufacturer	Contemporary Amperex Technology Co., Limited
Model number	M01285P10L01
Rating, Vdc	166.4
Rating, Ah	285
Module cell configuration, xS/yP	52S/1P
Module dimensions (W x D x H), mm	1150±5*810±5*241.5±5
Module weight, kg	325±10
Standard test item certified to	N/A
Organization that certified test item	N/A
Summary of module level test results	
Number of initiating cells	1
Thermal runaway propagation	Initiating cell went into thermal runaway and propagated to two adjacent cells
Maximum smoke release rate, m^2/s	1.73
Total smoke released, m^2	138.92
Total smoke released duration	0:49:26 to 01:30:00
Peak chemical heat release rate, kW	No flaming occurred
External flaming	No external flaming occurred
Location(s) of flame venting and length, m	No flaming occurred
Flying debris	No flying debris occurred
Re-ignitions	No further re-ignitions were observed during post test observation
Maximum temperature measured on module case, C:	144

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Summary of module level test gas analysis data

Gas analysis method:

☒ 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)

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

Gas Compound	Gas Type	Pre-Flaming, L	Flaming, L	Minimum detectable flow rate, LPM
Total Hydrocarbons (Propane Equivalent)	Hydrocarbons	80.77	No flaming	0.30
Carbon Dioxide	Carbon Containing	134.88	No flaming	0.49
Carbon Monoxide	Carbon Containing	38.37	No flaming	0.29
Hydrogen	Hydrogen	143.29	No flaming	5.86

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Unit Information	
Model number	C04285P10L01-R
Rating, Vdc	1331.2
Rating, Ah	285
BESS dimensions (W x D x H, mm)	1231*832*2108
BESS module configuration	1P8S
Number of modules in BESS	8
Module cell configuration, xS/yP	52S1P
Number of cells in module	52
BESS weight, kg	2600±40
BESS enclosure material	No enclosure provided for BESS unit, racks are directly mounted on the container frames
BESS Intended Installation: a) Indoor floor mounted non-residential b) Indoor floor mounted residential c) Outdoor ground mounted non-residential d) Outdoor ground mounted residential e) Indoor wall mounted non-residential f) Indoor wall mounted residential g) Outdoor wall mounted non-residential h) Outdoor wall mounted residential i) Rooftop residential j) Open parking garage non-residential	c) Outdoor ground mounted non-residential For a container system BESS including those intended for outdoor installation only, the unit level test shall be in accordance with the indoor floor mounted unit level test using the battery system racks as the test units and with the test installation set up in accordance with the installation layout within the container.
Residential Indoor Use: Smallest volume room installations specified.	N/A
Original Equipment Manufacturer (OEM)	Contemporary Amperex Technology Co., Limited
Branding Manufacturer (if not OEM)	N/A
Was the unit certified?	No
Standard the unit was certified to	N/A
Organization that certified the unit	N/A

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Summary of unit level test results	
Number of initiating cell(s)	1
Number of initiating modules	1
Thermal Runaway Propagation:	Initiating cell went into thermal runaway and propagated to two adjacent cells.
External Flaming from BESS:	No external flaming occurred
Location(s) of Flame Venting:	No external flaming occurred
Maximum Temperature[1], °C - Target BESS	44.4
Maximum Temperature[1], °C - Wall Surface	32.7
Peak Chemical Heat Release Rate, kW	No flaming occurred
Peak Convective Heat Release Rate, kW	No flaming occurred
Maximum Smoke Heat Release Rate, m^2/s	0.40
Maximum Heat Flux[1] - Instrumented Walls, kW/m^2	0
Maximum Heat Flux[1] - Ceiling or Soffit, kW/m^2	N/A
Maximum Heat Flux[1] - Target Modules, kW/m^2	0.54
Maximum Heat Flux[1] - Egress Path, kW/m^2	0
Flying Debris:	No flying debris occurred
Re-ignitions:	No further re-ignitions were observed during post test observation

Cell failure test method performed for the unit level

☒ External heating using thin film heater

☐ Nail Penetration

☐ Overcharge

☐ External short circuit

☐ Overdischarge

☐ Others:

Description of method used to fail cells if other than external thin film heater with thermal ramp:

N/A

Description of components employed within the BESS that serve to supress propagation (fire protection features):

N/A

Deviation from the module level test:

N/A

[1] Averaged over 60 seconds.

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Summary of unit level test gas analysis data

Gas analysis method:

☒ Non-Dispersive Infrared Spectrometer (NDIR)☐ 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)

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

Gas Compound	Gas Type	Pre-Flaming, L	Flaming, L	Minimum detectable flow rate, LPM
Total Hydrocarbons (Propane Equivalent)	Hydrocarbons	164.23	No flaming	0.36
Carbon Dioxide	Carbon Containing	226.46	No flaming	3.24
Carbon Monoxide	Carbon Containing	41.87	No flaming	2.70
Hydrogen	Hydrogen	30.26	No flaming	83.78

Summary of test results

Compliance with performance criteria in accordance with Table 9.1 for outdoor ground mounted non-residential unit [was] [~~was not~~] achieved.

Installation level testing [~~is~~] [is not] required.

[X] Surface temperatures of modules within the target BESS units adjacent to the initiating BESS unit did not exceed the temperature at which thermally initiated cell venting occurs, as determined in 7.3.1.10;

[X] For BESS units intended for installation near exposures, surface temperature measurements on wall surfaces did not exceed 97°C (175°F) of temperature rise above ambient;

[X] Explosion hazards were not observed, including deflagration or detonation

[X] Heat flux measured at the minimum distance to a means of egress specified by the manufacturer did not exceed 1.3 kW/m².

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Testing Laboratory information		
Testing Laboratory and testing location(s)		
Testing Laboratory	Beijing Building Materials Testing Academy	
Testing location/ address	Block 1, B15 Yaxin Road, Doudian Town, Fangshan district, Beijing 102402, CN	
Tested by (name)	Zhang Qi, Oliver Zhao	
Witnessed by (for 3rd Party Lab Test Location) (name, signature)	N/A	N/A
Project Handler (name, signature)	Qianqian Yang	
Reviewer (name, signature)	Arui Zhou	

List of Attachments (including a total number of pages in each attachment)

Attachment	Description	Pages
A	BESS Charge Profiles	30 through 33
B	BESS Construction Photos	34 through 34
C	BESS Instrumentation Photos	35 through 37
D	Temperature Profiles and Heat Flux Measurements	38 through 41
E	BESS Testing Photos	42 through 43
F	BESS Gas Flow Rate, Heat Release Rates, Smoke Release Rate Profiles	44 through 46

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Test Verdicts	
Clause Requirement Does Not Apply to the Test Item:	N/A (Not Applicable)
Clause Requirement Met**:**	M (Met)
Clause Requirement Not Met:	NM (Not Met)
Clause Requirement Completed:	C (Completed)
Clause Requirement Completed with Modification	Mod (Modified)
Test Dates	
Date of Receipt of Test Item	2024-08-10
Date(s) of Performance of Tests	2024-08-23
General remarks	
"(See Attachment #)" refers to additional information appended to the report. Throughout this report a point is used as the decimal separator.	
The unit can be manufactured at more than one location. The manufacturer provided a written declaration stating that the manufacturing process at all manufacturing locations is identical and product from one manufacturing location is representative of all manufacturing locations listed below.	☐ **Yes** ☒ **Not applicable**
Name and address of factory(ies) supplying samples for test:	Contemporary Amperex Technology Co Limited No.2 Xingang Road Zhangwan Town, Jiaocheng District, Ningde, 352100 Ningde, Fujian, PEOPLE'S REPUBLIC OF CHINA

General product information and other remarks:

Battery Unit Model C04285P10L01-R is lithium-ion racks manufacturer by Contemporary Amperex Technology Co., Limited. The rack consists of 8 battery modules Model M01285P10L01 connected in series with a control box. The rack frame is part of the container frame and test was conducted with initiating rack and target racks installed in the container enclosure.

In the test, 3 racks were placed inside the container. Container size: 6058mm(D)*2462mm(W)*2896mm(H).

Battery Module Model M01285P10L01 employs cell Models CBDC0 manufactured by Contemporary Amperex Technology Co., Limited, rated 166.4V, 285Ah.

This report is reissued from UL 9540A:2019, Fourth Edition, revised November 12, 2019 to UL 9540A, Fifth Edition, revised on March 12, 2025, based on the original report UL Project No. 4791320298 issued on September 24, 2024.

No test was conducted for this reissue investigation as all the new requirements were addressed in the UL Project No. 4791320298 taking account the requirements of UL CRD i9540A-20210326, i9540A-20220104, i9540A-20220519, i9540A-20220721, i9540a_4_20200110.

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UL 9540A, Edition 5			
Clause	**Requirement + Test**	**Result – Remark**	**Verdict**
PERFORMANCE			
9.1	**Sample and test configuration**		
9.1.1	The unit level test conducted with BESS units installed as described in the manufacturer's instructions.	See Attachment C for test installations Installation type: outdoor ground mounted in a container, non- residential use	C
9.1.2	The unit level test required one initiating BESS unit in which a thermal runaway condition resulting in cell to cell thermal runaway propagation in accordance with the module level test is initiated and target adjacent BESS units representative of an installation.	See Attachment C for test installations	C
	Tests conducted for indoor floor mounted installations for residential BESS are representative of both indoor floor mounted and outdoor ground mounted installations.		N/A
	Tests conducted indoors with fire propagation hazards and separation distances between initiating and target units representative of the installation.		C
	Testing conducted outdoors for outdoor only installations with following in place: a) Wind screens with wind speed of ≤ 12 mph; b) Temperature range is 10°C to 40°C (50°F to 104°F); c) Humidity is < 90% RH; d) Sufficient light to observe the testing; e) There is no precipitation; f) There is control of vegetation and combustibles in the test area; and g) There are protection mechanisms in place to prevent inadvertent access by unauthorized persons in the test area.		N/A
9.1.3	For outdoor non-residential high temperature batteries installed in a container, the unit level test is waived.		N/A
9.1.4	For installations where the high temperature battery modules are not installed on racks but rather within separate compartments within the container, the modules is considered the test unit.		N/A

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UL 9540A, Edition 5			
Clause	**Requirement + Test**	**Result – Remark**	**Verdict**
9.1.5	Testing to determine fire characterization was done at the battery system level rather than a complete BESS	One initiating unit sample and three target unit samples were used for test. Power Conversion System was not involved in the test. See Attachment C.	C
9.1.6	For outdoor and open parking garages where egress is less than 3 m (10 feet) from the BESS, testing will be conducted as described in this section (Section 9.2).		C
9.1.7	The initiating BESS contained components representative of a BESS unit in a complete installation.		C
	Combustible components that interconnect the initiating and target BESS units was included.		C
9.1.8	Target BESS units include the outer cabinet (if part of the design), racking, module enclosures, and components that retain cells components. The target BESS may also include one live, populated module at the location of the highest anticipated temperature of the enclosure.		C
9.1.9	The initiating BESS was at the maximum operating state of charge (MOSOC),	See Table 1&2 and Attachment A	C
	After charging and prior to testing, the initiating BESS was at rest for a minimum period of 1 hour at room ambient.	See Table 2	C
9.1.10	Voltage shall be measured prior to initiating the test. If less than 0.1% of the fully charged voltage, the initiating BESS shall be charged again.	See Table 13	C
9.1.11	The BESS unit included an integral fire suppression system.	No include integral fire suppression system.	N/A
9.1.12	Electronics and software controls such as the battery management system (BMS) are not relied upon for this testing.		C
	Included a fire suppression control in accordance with UL 864 that is external to the BESS.		N/A
9.2	**Test method – Indoor floor mounted BESS units**		
9.2.1	Test room ambient temperature within 10°C (50°F) to 32°C (90°F).	See Table 2	C
9.2.2	Access door(s) or panels on the initiating BESS unit and adjacent target BESS units were closed, latched and locked duration of the test.	There are no doors or panels for racks.	N/A
9.2.3	The initiating BESS unit was positioned adjacent to two instrumented wall sections.	See Attachment C	C

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UL 9540A, Edition 5			
Clause	**Requirement + Test**	**Result – Remark**	**Verdict**
9.2.4	Instrumented wall sections extend not less than 0.49 m (1.6 ft) horizontally beyond the exterior of target BESS units.	Front wall was 7.2m length, side wall was 9.6m length,	C
9.2.5	Instrumented wall sections were at least 0.61-m (2-ft) taller than the BESS unit height, and not less than 2.13 m (7 ft) in height above the floor.	Front wall and side wall were 3.7m high.	C
9.2.6	The surface of the instrumented wall sections were covered with gypsum wall board and painted flat black. An incremental visual reference shall be provided on the instrumented wall sections for scale so that flame extension can be accurately measured if applicable. The gypsum wall board shall be 13-mm (1/2-inch) thick at minimum.	See Attachment C	C
9.2.7	The initiating BESS unit was centered underneath an appropriately sized smoke collection hood of an oxygen consumption calorimeter.		C
9.2.8	The light transmission in the calorimeter's exhaust duct was measured using a white light source and photo detector. The smoke release rate was calculated.	See Table 11 See Attachment F	C
9.2.9	The chemical and convective heat release rates were measured for the duration of the test.	See Table 11 See Attachment F	C
9.2.10	The heat release rate measurement system was calibrated using an atomized heptane diffusion burner. The calibration was performed using flows of 3.8, 7.6, 11.4 and 15.2 L/min (1, 2, 3 and 4 gpm) of heptane.		C
9.2.11	The chemical heat release rate was measured using the following equipment: ● Paramagnetic oxygen analyser ● Non-dispersive infrared carbon dioxide and carbon monoxide analyser ● Velocity probe ● Type K thermocouple		C
9.2.12	The chemical heat release rate at each of the flows was calculated.		C
9.2.13	The physical spacing between BESS units (both initiating and target) and adjacent walls was representative of the intended installation.	See Attachment C	C

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UL 9540A, Edition 5			
Clause	**Requirement + Test**	**Result – Remark**	**Verdict**
9.2.14	Separation distances were specified by the manufacturer for distance between: a) The BESS units and the instrumented wall sections; and b) Adjacent BESS units.	See Attachment C Racks were installed inside container frame. The spacing between the initiating rack and adjacent target racks (left, right and behind of initiating unit) was 0 mm. The spacing from the front wall or side wall to the container frame was 2000 mm.	C
9.2.15	Wall surface temperatures were measured in vertical array(s) at 152-mm (6-in) intervals for the full height of the instrumented wall sections using No. 24-gauge or smaller, Type-K exposed junction thermocouples.	See Table 6.1&6.2 See Attachment C&D	C
	The thermocouples for measuring the temperature on wall surfaces were horizontally positioned in the wall locations to receive greatest thermal exposure from the initiating BESS unit. Temperatures shall be measured continuously, averaging over every 60-second interval. The maximum of these averages shall be documented for each thermocouple location.		C
9.2.16	Thermocouples were secured to gypsum surfaces and the thermocouple tip was depressed into the gypsum so as to be flush with the gypsum surface at the point of measurement .		C
9.2.17	Heat flux was measured with at least two water-cooled Schmidt-Boelter or Gardon gauges at the surface of each instrumented wall. Heat flux shall be measured continuously, averaging over every 60-second interval. The maximum of these averages shall be documented for each gauge location. a) Both are collinear with the vertical thermocouple array; b) One is positioned to receive the greatest heat from the initiating module; and c) One is positioned to receive the greatest heat flux during potential propagation within the initiating BESS unit.	See Table 7	C
	Exception: If (b) and (c) are deemed to be at the same location based on a construction review, only one gauge is required.		N/A

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Clause	**Requirement + Test**	**Result – Remark**	**Verdict**
9.2.18	Heat flux was measured with 2 water-cooled Schmidt-Boelter or Gardon gauges at the surface of each adjacent target BESS units facing initiating BESS unit. Heat flux shall be measured continuously, averaging over every 60-second interval. The maximum of these averages shall be documented for each gauge location: a) One is positioned at the elevation estimated to receive the greatest heat flux from the initiating module; and b) One is positioned at the elevation estimated to receive the greatest surface heat flux due to initiating BESS.	See Table 7	C
	Exception: If (a) and (b) are deemed to be at the same location based on a construction review, only one gauge may be installed on the target unit for the measurement.		N/A
9.2.19	For BESS intended for installation outdoors or in open parking garages, heat flux shall be measured with the sensing element of at least one water-cooled Schmidt-Boelter or Gardon gauge positioned at the mid height of the initiating unit at the minimum horizontal distance from the BESS specified by the manufacturer or the point where the majority of off-gas venting is expected from the initiating unit. Heat flux shall be measured continuously, averaging over every 60-second interval.	See Table 7	C
9.2.20	No. 24-gauge or smaller, Type-K exposed junction thermocouples were installed to measure the temperature of the surface proximate to the cells and between the cells and exposed face of the initiating module.	See Attachment C&D	C
	Each non-initiating module enclosure within the initiating BESS unit was instrumented with at least one No. 24-gauge or smaller Type-K thermocouple(s) within non-initiating modules.	See Attachment C	C
	Additional thermocouples were placed to account for convoluted geometries. Temperatures shall be measured continuously, averaging over every 60-second interval. The maximum of these averages shall be documented for each thermocouple location.		N/A
9.2.21	For residential use, the DUT was covered with a single layer of cheese cloth ignition indicator. The cheesecloth was untreated cotton cloth running 26 – 28 m2/kg with a count of 28 – 32 threads in either direction within a 6.45 cm^2 (1 in^2) area.	Non-residential use.	N/A

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UL 9540A, Edition 5			
Clause	**Requirement + Test**	**Result – Remark**	**Verdict**
9.2.22	Cell to cell thermal runaway propagation in accordance with the module level test was created within a single module in the initiating BESS unit: a) The position selected to present the greatest thermal exposure to adjacent modules; and b) The setup was the same as that used to initiate and propagate thermal runaway within the module level test.	See Attachment C	C
9.2.23	Composition, velocity and temperature instrumentation shall be collocated with heat release rate calorimetry instrumentation.	See Attachment C	C
	The hydrocarbon content of the vent gas shall be measured using flame ionization detection. Hydrogen gas shall be measured with a palladium-nickel thin-film solid state analyzer. Composition, velocity and temperature instrumentation shall be collocated with heat release rate calorimetry instrumentation.	See Table 8	C
9.2.24	At the request of the manufacturer, the hydrocarbon content of the vent gas may also be measured using a Fourier-Transform Infrared Spectrometer with a minimum resolution of 1 cm-1 and a path length of at least 2 m (6.6 ft), or equivalent gas analyzer.	FTIR analysis was not used as no request of the manufacturer.	N/A
9.2.25	The test shall be terminated if: a) There are three consecutive temperature readings measured inside each module within the initiating BESS unit that are determined to be falling over 15-minute intervals; b) The modules return to a temperature less than 60°C (140°F) c) The fire propagates to adjacent units or to adjacent walls d) A condition hazardous to test staff or the test facility requires mitigation, or e) Flaming outside the test room is observed	Test temperature recording was terminated until no noticeable phenomenon observed and all measured temperatures of the initiating unit return to ambient temperature.	C
9.2.26	For residential use systems, the gas collection data gathered shall be compared to the smallest room installation specified by the manufacturer to determine if the flammable gas collected exceeds 25 % LFL in air.	Non-residential unit.	N/A
9.3	**Test method – Outdoor ground mounted units**		
9.3.1	Outdoor ground mounted non-residential use BESS for installation: test method described in Section 9.2 was used.		C

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

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Clause	**Requirement + Test**	**Result – Remark**	**Verdict**
9.7.1	Installation type tested:	Outdoor ground mounted, non-Residential, container type For a container system BESS including those intended for outdoor installation only, the unit level test shall be in accordance with the indoor floor mounted unit level test using the battery system racks as the test units and with the test installation set up in accordance with the installation layout within the container.	C
9.7.2	Testing is intended to represent more than one installation type.	See Test Item Description at the beginning of this report.	C
9.7.3	a. Unit manufacturer name and model number (and whether UL 9540 compliant);		C
	b. Number of modules in the initiating BESS unit		C
	c. BESS construction features;	See Attachment C See Critical Components Table	C
	d. Fire protection features/ detection/ suppression systems within unit		N/A
	e. Module voltages corresponding to the tested SOC;	See Table 13	C
	f. Thermal runaway initiation method used;	See Attachment C	C
	g. Location of the initiating module within the BESS unit;	See Attachment C	C
	h. Diagram and dimensions of the test setup including mounting location of the initiating and target BESS units, and the locations of walls, ceilings, soffits as applicable, and thermocouples;	See Attachment C	C
	i. Observation of any flaming outside the initiating BESS enclosure and the maximum flame extension;	See Table 14	C
	j. Chemical and convective heat release rate versus time data;	See Table 11 See Attachment F	C
	k. Separation distances from the initiating BESS unit to target walls and target heat flux gauges	See Attachment C	C
	l. Separation distances from the initiating BESS unit to target BESS units	See Attachment C	C
	m. The maximum wall surface and target BESS temperatures achieved during the test and the location of the measuring thermocouple;	Tables 5，6.1 & 6.2	C

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Clause	**Requirement + Test**	**Result – Remark**	**Verdict**
	n. The maximum ceiling or soffit surface temperatures achieved during the indoor or outdoor wall mounted test and the location of the measuring thermocouple;		N/A
	o) The maximum incident heat flux on target wall surfaces and target BESS units;	Table 7	C
	p) The maximum incident heat flux on target ceiling or soffit surfaces achieved during the indoor or outdoor wall mounted test;		N/A
	q. Flammable gas generation and composition data if conducted indoors;	See Tables 8, 9, and 10 See Attachment F	C
	r. Peak smoke release rate and total smoke release data if conducted indoors.	See Table 11 See Attachments F	C
	s. Indication of the activation of integral fire protection systems and if activated the time into the test at which activation occurred;	Table 12 No fire protection systems	N/A
	t. Observation(s) of flying debris or explosive discharge of gases unless mitigated by an engineered deflagration protection system;	See Table 14	C
	u. Observation of re-ignition(s) from thermal runaway events	See Table 15	C
	v. Observation(s) of sparks, electrical arcs, or other electrical events;	See Table 14	C
	w. Observations of the damage to: 1) The initiating BESS unit; 2) Target BESS units; 3) Adjacent walls, ceilings, or soffits;	See Attachment E	C
	x. Video of the test.		C
	y. Circumstances of test termination, when terminated in accordance with 9.2.25		C
	z. Module level test report summary and cell level test report summary		C
9.8	**Performance at Unit level testing**		
9.8.1	Installation level testing in Section 10 was not required if the following performance conditions outlined in Table 9.1 are met during the unit level test.		M
Non-Residential Installations – Outdoor ground mounted:			
	a) Surface temperatures of modules within target BESS units do not exceed the temperature at which thermally initiated cell venting occurs;	Max surface temperature 44.4°C didn't exceed the cell venting temperature 161°C	M
	b) For BESS units intended for installation near exposures, surface temperature measurements on wall surfaces do not exceed 97°C (175°F) rise above ambient;	Max wall surface temperature 32.7°C didn't exceed 97°C rise above ambient	M

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Clause	**Requirement + Test**	**Result – Remark**	**Verdict**
	c) Explosion hazards are not observed, including deflagration or detonation;	No explosion observed	M
	d) Heat flux measured at the minimum distance to a means of egress specified by the manufacturer did not exceed 1.3 kW/m^2.	Measured heat flux was 0 kW/m^2, which didn't exceed 1.3 kW/m^2	M

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Table 1 – Specified conditioning parameters			
Charging		Discharging	
Power (CP), kW	47.424*8	Power (CP), kW	47.424*8
Standard Full Charge Voltage ,Vdc	Any cell reaches of 3.65V or total voltage reach 189.8V for module Any cell reaches of 3.65V or total voltage reach 1518.4V for rack	End of discharge voltage, Vdc	Any cell reaches of 2.5V or total voltage reach 130V for module Any cell reaches of 2.5V or total voltage reach 1040V for rack
Charging Test Ambient, °C	0~57	Discharging Test Ambient, °C	-20~55
See Attachment A for charge/discharge profiles for each cell.			

Table 2 - Test Initiation Details	
Charge completion date,	2024-08-20
Charge completion time,	17:12:16
Test Date,	2024-08-23
Test Start Time,	14:33:32
Initial Lab Temperature, °C	31.8
Initial Relative Humidity, %RH	66
Module OCV at Start of Test, Vdc	173.5

Table 3 – Approximate time of thermal runaway propagation through module		
Locations (Cell #)	**Event**	**Time, hh:mm:ss**
Cell 20	Vent	0:49:08
Cell 20	Thermal runaway	0:52:00
Cell 19	Thermal runaway	0:54:46
Cell 21	Thermal runaway	0:56:33

Table 4 – Test overview timeline		
Time (hh:mm:ss)	**Event**	**Description**
00:00:00	Test Start	The test was started and the heater was turned on to heat the initiating cell (Cell 20) at a ratio of 4 ~ 7 °C/min.
00:49:08	Venting of initiating Cell	Initiating cell (Cell 20) vented at around 180.3°C measured through T2-2 by an indication of sudden dip in cell's temperature curve. See Figure (b) in Attachment E
00:52:00	Thermal runaway of initiating cell	Initiating cell (Cell 20) was at around 184.5°C measured through TC 2-2. The temperature of cell (cell20) began to increase in an uncontrollable manner. Small amount of smoke release observed. See Figure (c) in Attachment E
00:54:46	Thermal runaway of initiating cell	Thermal runaway propagated to nearby cell (cell19) with more smoke released See Figure (d) in Attachment E
00:56:33	Thermal runaway of initiating cell	Thermal runaway propagated to nearby cell (cell21) with more smoke released See Figure (e) in Attachment E
01:50:00	Test Termination	Data acquisition was stopped. The module was left in the test overnight and with video monitored See Figure (f) in Attachment E

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Table 5 - Maximum Temperatures in Target Units					
Cell vent temperature from cell test data, °C		161°C			
Target Unit 1		**Target Unit 2**		**Target Unit 3**	
Module Location No.	Temperature (°C)	Module Location No.	Temperature (°C)	Module Location No.	Temperature (°C)
Module-1	31.0	Module-1	31.1	Module-1	31.4
Module-2	31.9	Module-2	31.8	Module-2	33.3
Module-3	44.4	Module-3	32.7	Module-3	30.7
Module-4	34.0	Module-4	31.7	Module-4	33.6
Module-5	31.7	Module-5	31.3	Module-5	31.8
Module-6	31.3	Module-6	31.3	Module-6	31.4
Module-7	31.4	Module-7	31.5	Module-7	31.5
Module-8	31.7	Module-8	31.6	Module-8	31.7
Note: Temperatures were measured constantly and then averaged every 60-seconds.					

Table 6.1- Maximum Temperatures on Instrumented Wall – Front Wall					
Ambient Temperature: 31.8°C					
UL 9540A performance criteria, Ambient + 97°C: 128.8°C					
Height, mm	Maximum Temperature (°C)	Height, mm	Maximum Temperature (°C)	Height	Maximum Temperature (°C)
152	30.7	1368	31.8	2584	31.7
304	31.4	1520	32.1	2736	32.5
456	31.3	1672	32.4	2888	32.1
608	31.3	1824	31.9	3040	32.3
760	31.9	1976	31.1	3192	32.4
912	32.1	2128	31.8	3344	32.5
1064	32.1	2280	31.8	3496	32.3
1216	32.1	2432	31.6	3648	32.6
Note: Temperatures were measured constantly and then averaged every 60-seconds.					

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Table 6.2- Maximum Temperatures on Instrumented Wall – Side Wall					
Ambient Temperature: 31.8°C					
UL 9540A performance criteria, Ambient + 97°C: 128.8°C					
Height, mm	Maximum Temperature (°C)	Height, mm	Maximum Temperature (°C)	Height	Maximum Temperature (°C)
152	30.9	1368	31.6	2584	32.3
304	31.2	1520	31.7	2736	32.2
456	31.2	1672	32.0	2888	32.6
608	31.1	1824	32.1	3040	32.7
760	31.7	1976	32.2	3192	32.2
912	31.4	2128	30.1	3344	32.1
1064	31.5	2280	32.1	3496	32.2
1216	31.6	2432	32.4	3648	32.3
Note: Temperatures were measured constantly and then averaged every 60-seconds.					

Table 7 – Heat Flux Measurements			
Summary of maximum heat flux in target units		Summary of maximum heat flux measured on instrumented wall	
Maximum Heat Flux, kW/m^2			
Target Unit 1 Module No.3: 8#	0.16	Heat Flux Gauge No.	kW/m^2
Target Unit 1 Module No.4: 2#	0.28	Front wall 1400 mm high, 4#	0
Target Unit 2 Module No.3: 3#	0.54	Front wall 1600 mm high, 10#	0
Target Unit 2 Module No.4: 6#	0.03	Side wall 1400 mm high, 5#	0
Target Unit 3 Module No.3: 3#	0	Side wall 1600 mm high, 7#	0
Target Unit 3 Module No.4: 11#	0.24	-	-
Egress path measurement: 9#		0	
Note: Heat fluxes were measured constantly and then averaged every 60-seconds.			

Table 8 – Gases measured and measurement methods used in unit level testing			
Measurement Method	**Gases Measured**	**Chemical Formula**	**Gas Type**
Flame Ionization Detection (FID)	Total Hydrocarbons	-	Hydrocarbons
Solid-state Hydrogen Sensor	Hydrogen	H_2	
Non-dispersive infrared spectroscopy (NDIR)	Carbon Dioxide	CO_2	Carbon Containing
	Carbon Monoxide	CO	Carbon Containing
# - This table was modified to reflect the gases measured during testing.			

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Table 9 - Gas generation periods	
Time	**Condition**
From the venting point 0:49:08 to the end of test 01:50:00	Pre-Flaming
Flaming was not observed during the test.	Flaming
External Flaming of Gas	
Condition	**Duration (hh:mm:ss)**
External Flaming of Vent Gases:	Flaming was not observed during the test.

Table 10 – Summary of battery gas volumes for deflagration hazard calculations				
Gas Component	Gas Type	During Pre-flaming, L	During Flaming, L	Minimum detectable flow rate, LPM
Total Hydrocarbons (Propane Equivalent)	Hydrocarbons	164.23	No flaming	0.36
Carbon Dioxide	Carbon Containing	226.46	No flaming	3.24
Carbon Monoxide	Carbon Containing	41.87	No flaming	2.70
Hydrogen	Hydrogen	30.26	No flaming	83.78

Table 11 – Smoke and heat release rate			
Heat Release Rate (HRR)		**Smoke Release Rate (SRR)**	
Peak Chemical HRR, kW	No flaming observed	Maximum SRR, m^2/s	0.40
Peak Convective HRR, kW	No flaming observed	Total Smoke Released, m^2	59.06

Table 12 – Integral Fire suppression system Details of Operation
N/A

Table 13 - Module OCV voltage measurement comparison before and after testing			
Module Location In Rack	OCV Prior to Test, V	OCV Post Test, V	Difference, V
Module-1	173.5	173.4	0.1
Module-2	173.5	173.5	0
Module-3 (Initiating Module)	173.5	163.4	10.1
Module-4	173.5	173.4	0.1
Module-5	173.5	173.5	0
Module-6	173.5	173.5	0
Module-7	173.5	173.5	0
Module-8	173.5	173.4	0.1

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

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

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Critical components information					
Component / part number	**Manufacturer/ trademark**	**Type / model**	**Technical data**	**Standard**	**Mark(s) of conformity**
Module construction					
Cells	CATL	CBDC0	Nominal voltage: 3.2V Rated capacity: 285Ah	UL 1973:2022	UL MH62898
Module	CATL	M01285P10 L01	166.4V, 285Ah	--	--
Metal enclosure(Bottom)	CATL	-	Material: AL3003, Minimum thickness: 1.4mm/1.0mm Size: 1145*810*59.5mm	--	--
Plastic enclosure(Top)	0000005701	PP	V-0, 85°C, THK: 1.1mm Size: L*W*H(mm) 1145*803.6*197.5	UL 94	Intertek 20890002-MT-3
Battery connector	0000007975	REA4-WTAB-95-A	1500Vdc, 350A, RTI:105°C ,V-0, Min THK: 1.7mm	UL 4188	UL E526230
CSC PCB material	0000007727	SH10	V-0, 130°C, CTI>600, 1.6mm	UL 94 UL 796 UL 746A	UL E248779
Internal connecting wires for HV	0000009966	3932	2000V, -40°C ~125°C, 95mm^2	UL 758	UL E214184
Voltage sampling wire	0000009966	3666	32awg, XLPE, 105°C, 600 Vac.	UL 758	UL E214184
Temperature sampling wire	0000008559	4484	32 - 16 AWG 150°C ,300 Vac.	UL 758	UL E237675
NTC Sensor	0000008559	103AP-2	10kΩ±0.5%/1%, -50°C to 110°C	UL1581	UL E92669
Mica paper	0000014138	GM-S	5600VDC@60s, 1mA; 500MΩ@1000V D	UL 94	SCH21070294-02B
Plastic material for sampling connector	0000013562	PA66 GF25	V-0, THK: 0.35mm, -40°C to 125°C	UL 94	EG190813001R02Zver.1
cushion	0000021179 0000032408	MPP-15	size:201*169*3.3mm 1000VDC,60S,R≥500 MΩ 2700VDC,60S,I≤1mA	--	--

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Heat insulating pad	0000003940 0000009455	FNF-G	size:200*164*2.3mm 1000VDC,60S,R≥500 MΩ 2700VDC,60S,I≤1mA	UL 94	SGS GZMR220400910201_CN
Explosion relief valve	13358	PDA3K-50G	Discharge pressure: 3kPa Plastic material: PC+GF10/PC Aluminum alloy materia: AL 6063 Sealing ring material: silicon rubber Membrane material: e-PTFE	--	--
Container					
Enclosure	CIMC	NT-S-2596G	Material: high weather resistance rolled steel, THK: 1.6mm to 12mm, Size: 6058mm(D)* 2462mm(W)* 2896mm(H)	--	--
Sealing strip on containers	-	EPDM-2015	Tensile Str: 2606.7psi, Min Service Temperature: -40°C, Max Service Temperature: 70°C	UL 157	UL MH60816
Connecting wire for HV	0000009966	3932	2000V, 125°C, 95mm^2	UL 758	UL E214184
Material of Insulator	0000007989	SB6040M10	Size:40mm(D)*60mm(H), 2400V Materials:Unsaturated Polyester (UP) RTI: 130°C CTI: 600V, V-0	UL 94 UL 746A UL 746B	UL E240680
Insulating sheet	0000011523	KLX FRPC-1880B	THK: 0.75mm, V-0, 125°C	UL94 UL746C	UL E315185
Main control box					
Enclosure	CATL	--	Material: steel DC01, Min. THK: 1mm Size:741.4(D)*711.5 (W)*239.3(H)	--	--
Connector	0000004160	ES095	1500Vdc,310A,-40°C to 125°C	IEC 61984 UL 1977	TUV report 50331326 001 TUV report 50331326 002

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External cable	0000009966	3932	2000V, 125°C, 95mm^2	UL 758	UL E214184
Sealing strip	-	EPDM-2015	Tensile Str: 2606.7psi, Min Service Temperature: -40°C, Max Service Temperature: 70°C	UL 157	UL MH60816

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Attachment A: BESS Charge Profiles - (*Pages* 30 *through* 33)

Note: 1. There were 8 modules in the initiating unit. Due to the voltage limitation of the charging device, the modules in the unit were divided into 8 groups and were then fully charged separately. The charging power of each module is 47.424kW and the charging ends when any cell reaches of 3.65V or 189.8V for module.

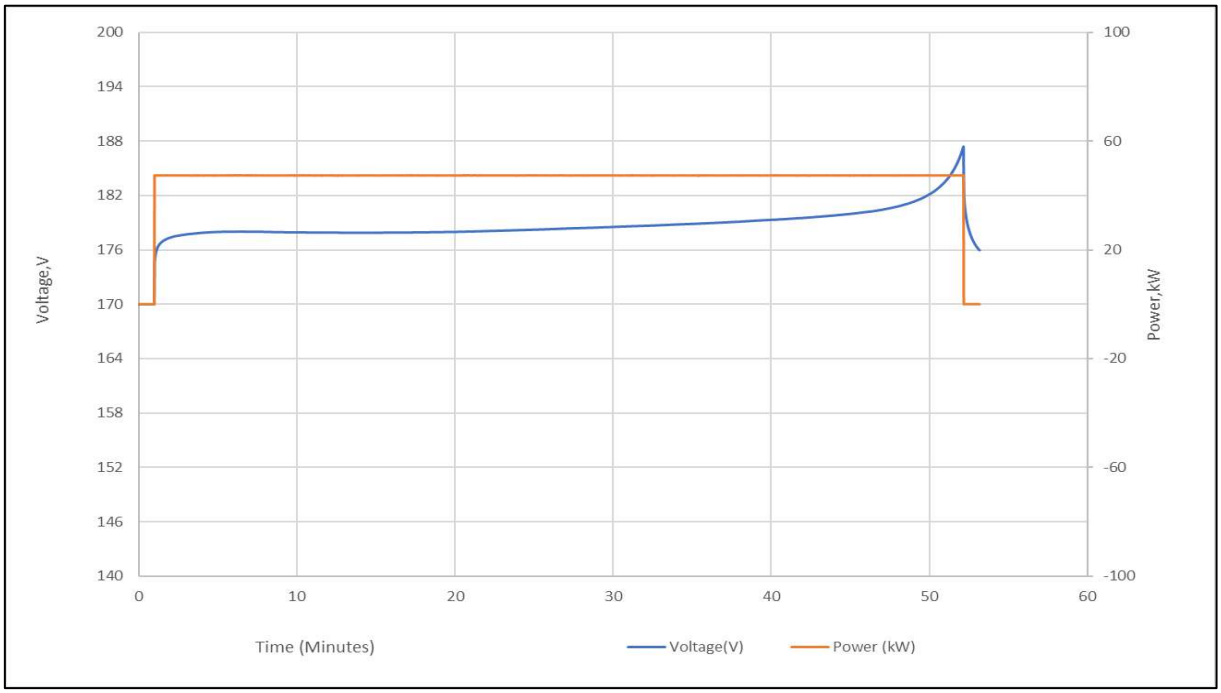

Figure 1: Initiating unit, module 1 charge to 100% SOC

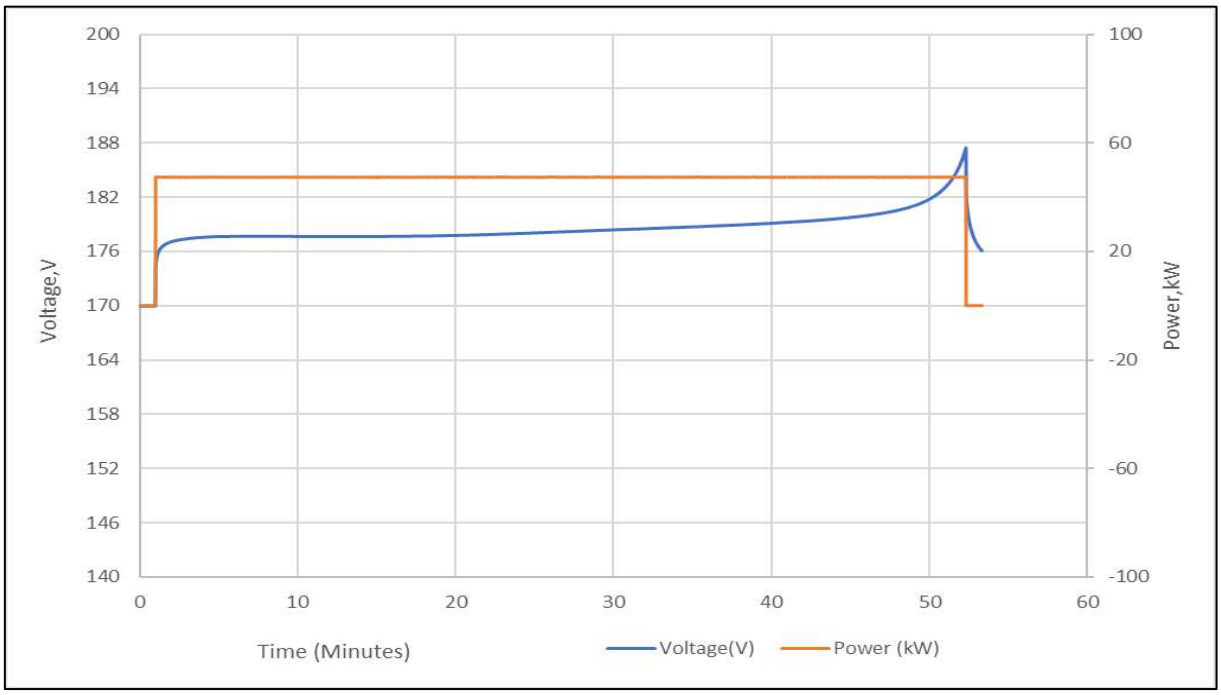

Figure 2: Initiating unit, module 2 charge to 100% SOC

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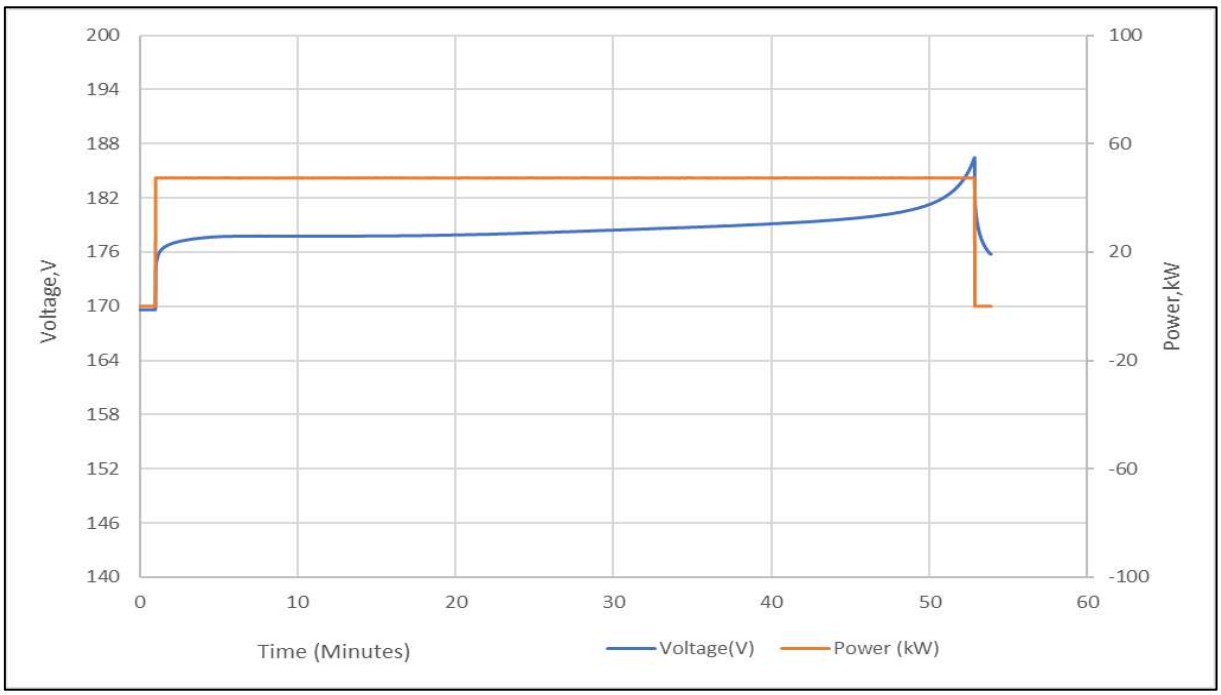

Figure 3: Initiating unit, module 3 charge to 100% SOC

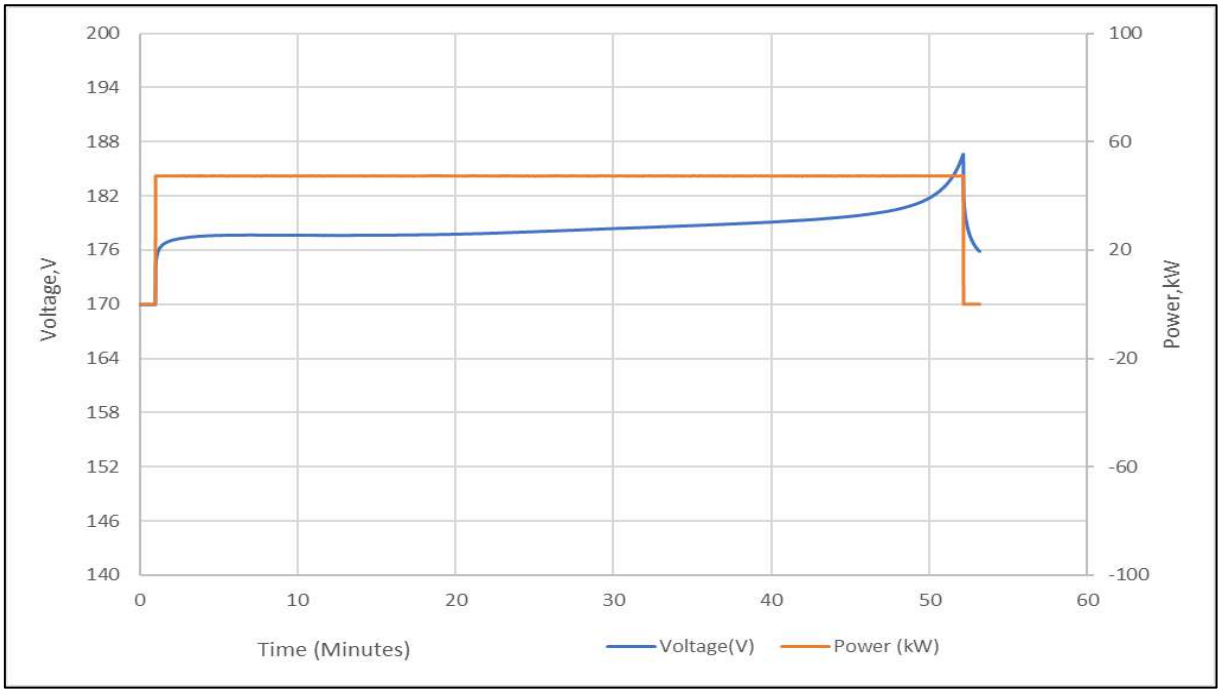

Figure 4: Initiating unit, module 4 charge to 100% SOC

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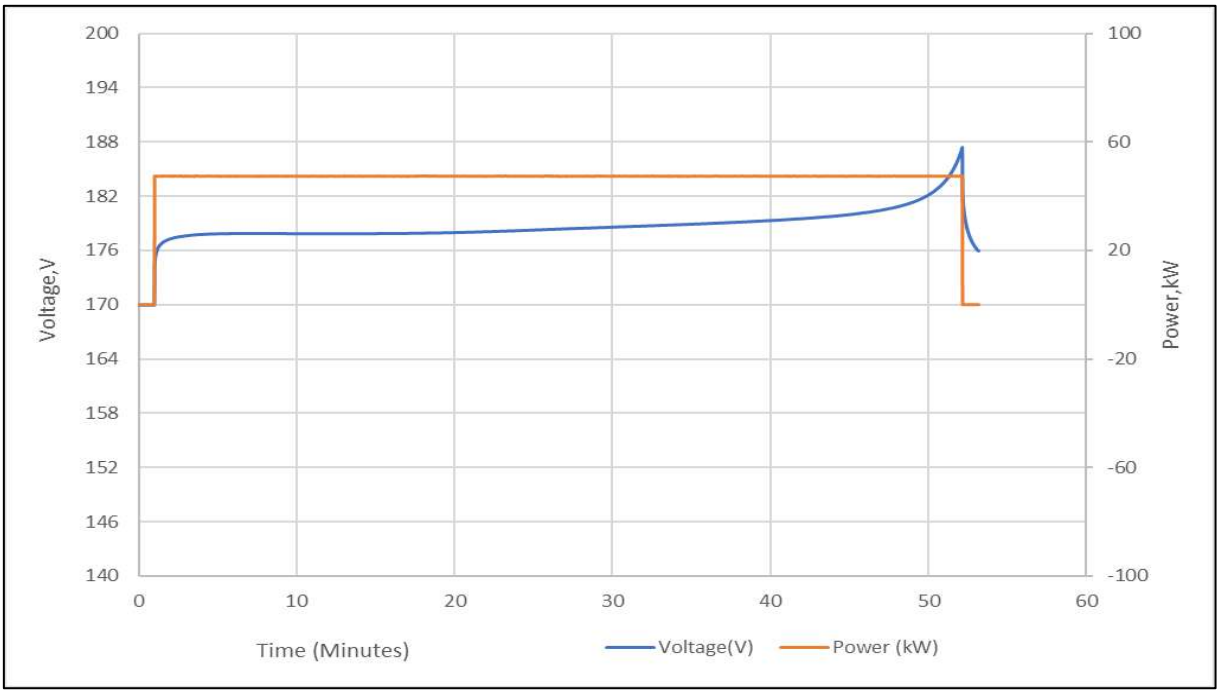

Figure 5: Initiating unit, module 5 charge to 100% SOC

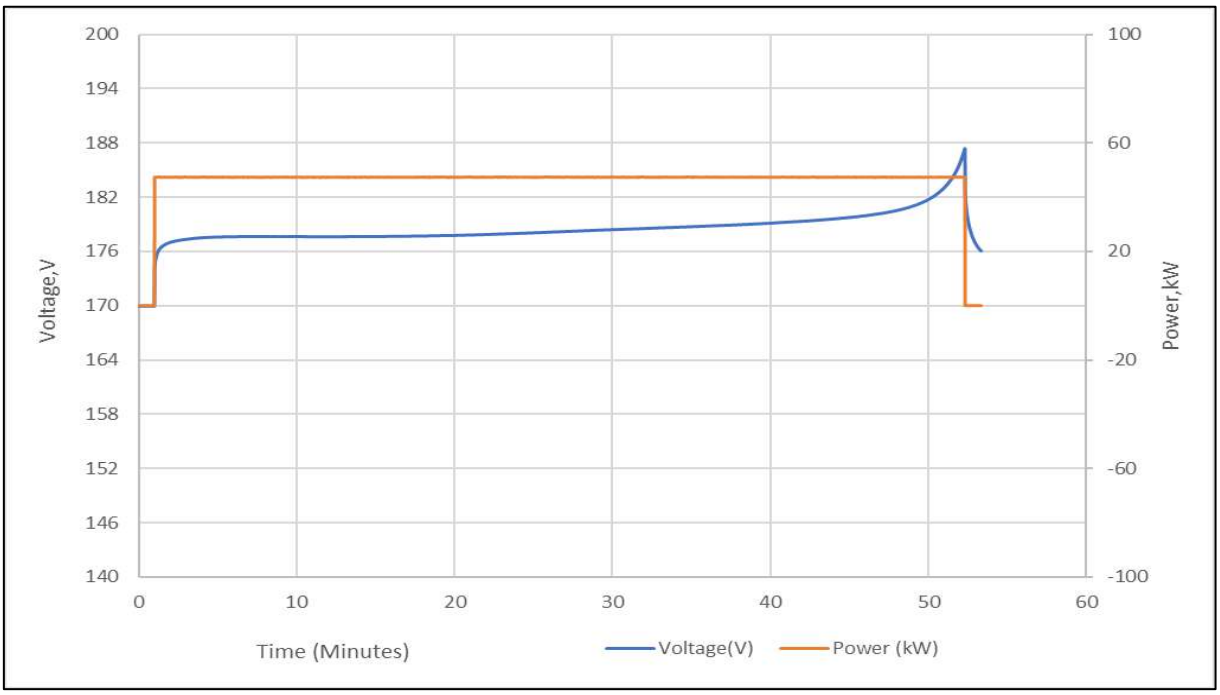

Figure 6: Initiating unit, module 6 charge to 100% SOC

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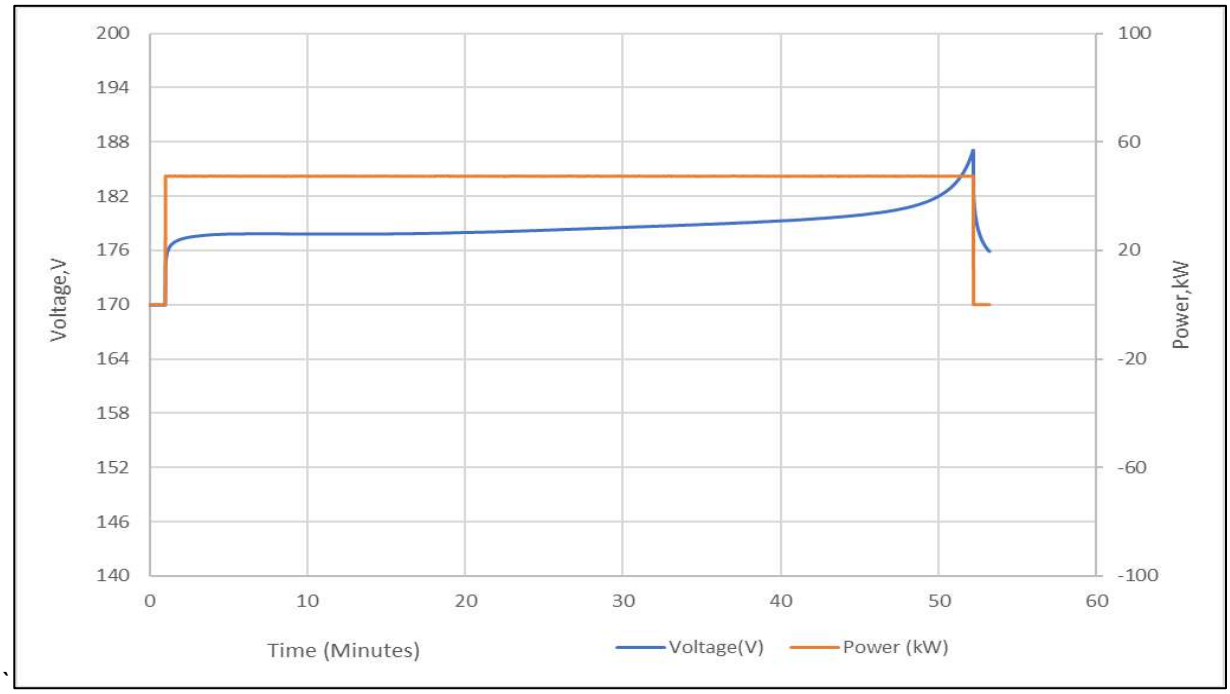

Figure 7: Initiating unit, module 7 charge to 100% SOC

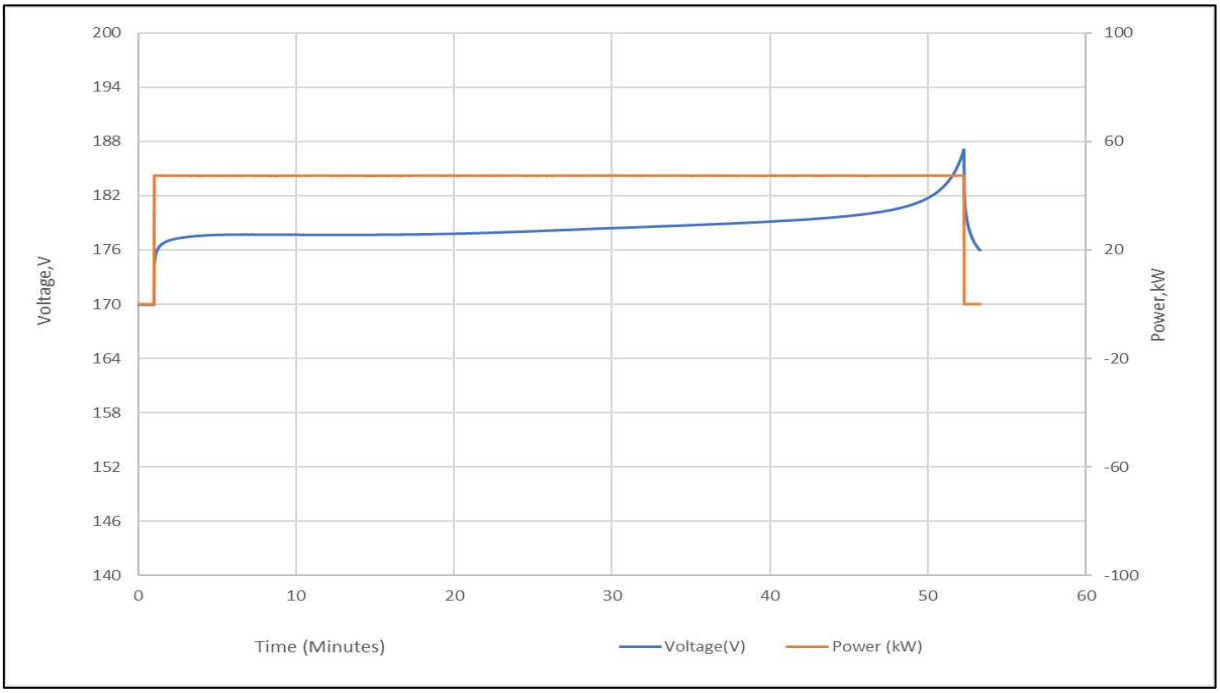

Figure 8: Initiating unit, module 8 charge to 100% SOC

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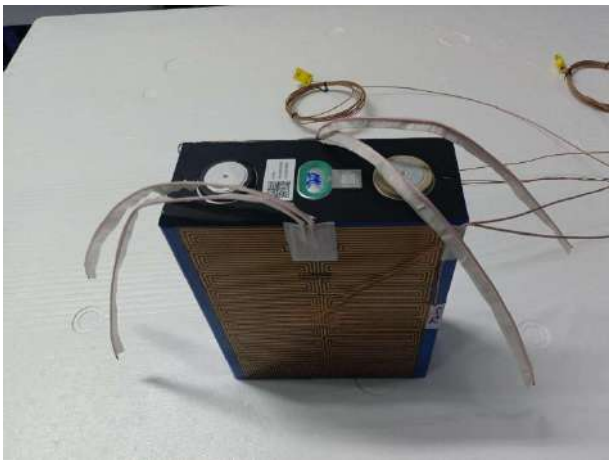
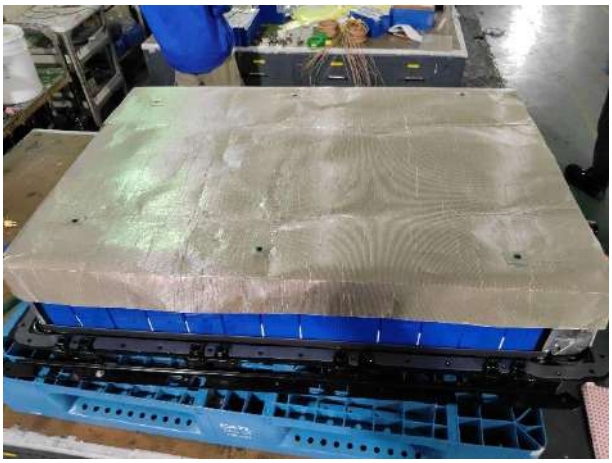
Attachment B: BESS Construction Photos - (*Pages* 34 *through* 34)





BESS unit and module Construction Photos

Note: There is no fire detection and suppression system in the Unit BESS.

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Attachment C: : BESS Instrumentation Photos - (*Pages* 35 *through* 37)

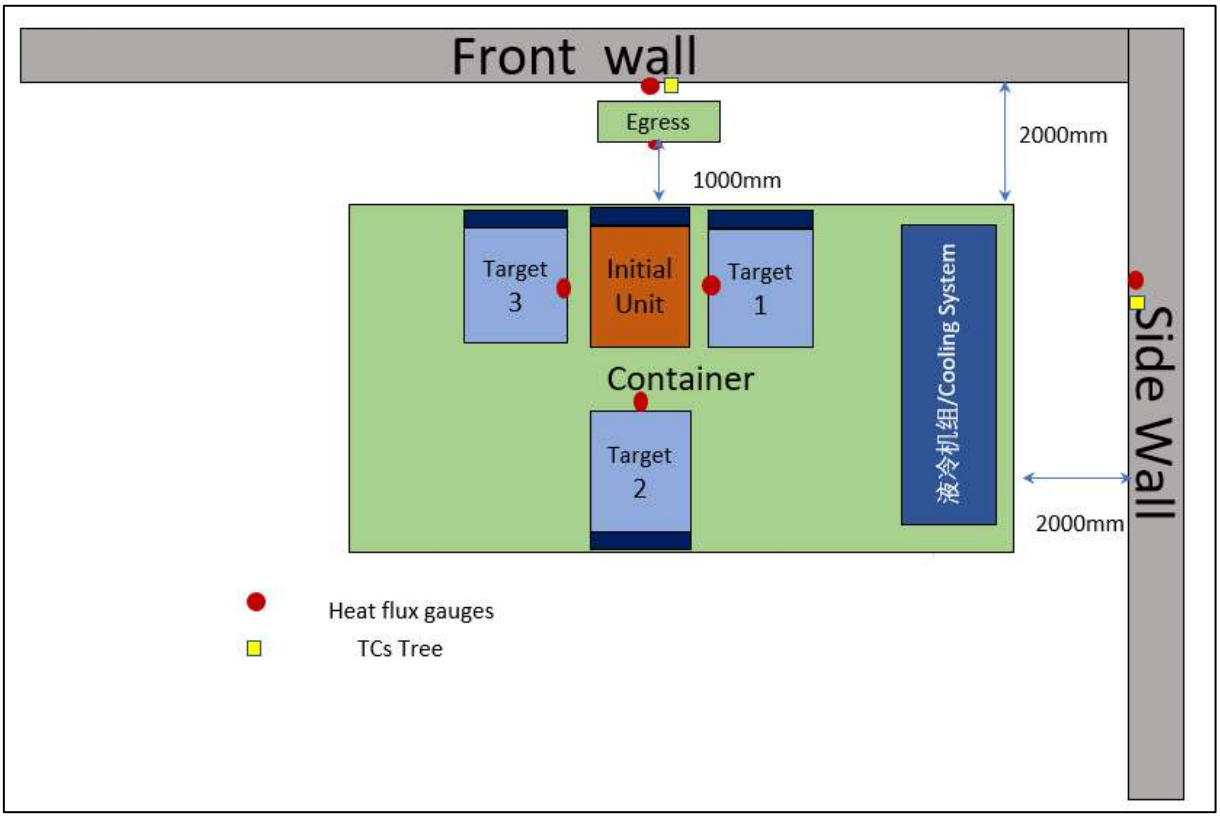

Figure 9: Test area layout-1





Figure 10: Test area layout-2

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Note: The thermocouple T1-1 was used to control the supply power to the heater to keep the heating rate at 4 ~ 7 °C/min. T2-1 and T2-2 were used to represent the temperature of initiating cell.
T1-1, on the wide side surface center of cell 20, between the cell and heater.
T1-2 on the other wide side surface center of cell 20, between the cell and heater.
T2-1, T2-2, on each wide side surface center of cell 20, not covered by heater.
V1, V2, V3, V4, V5 was the voltage of cell 20, 19, 21, 7, 33 separately.
T3-1, T3-2, T4-1, T4-2, T5, T6, T7, T8, were attached on the wide side surface center of cells shown in below illustration.

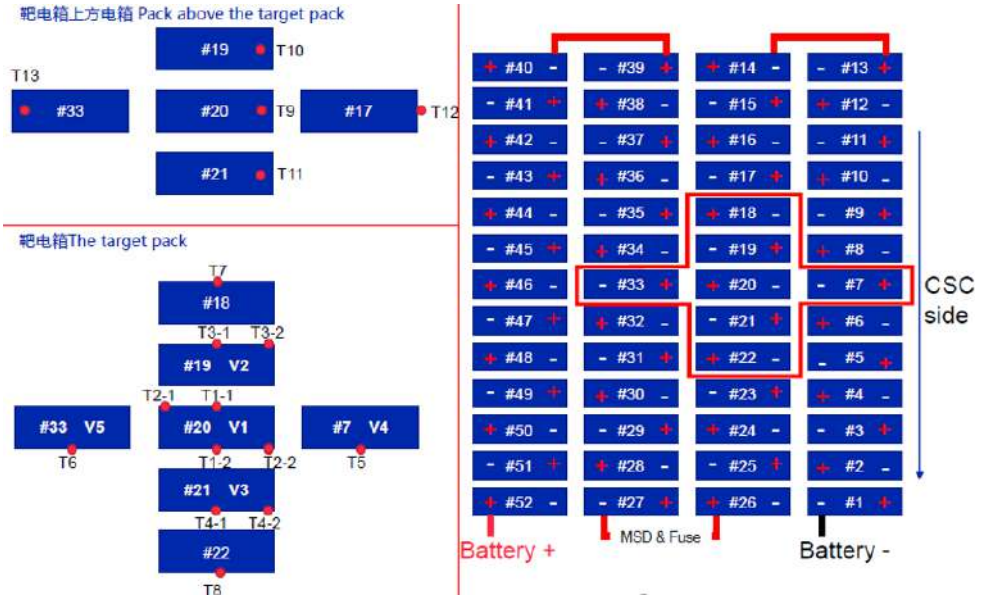

Figure 11: TC Location in the initiating module and above module. TCs were on the cells' large side body

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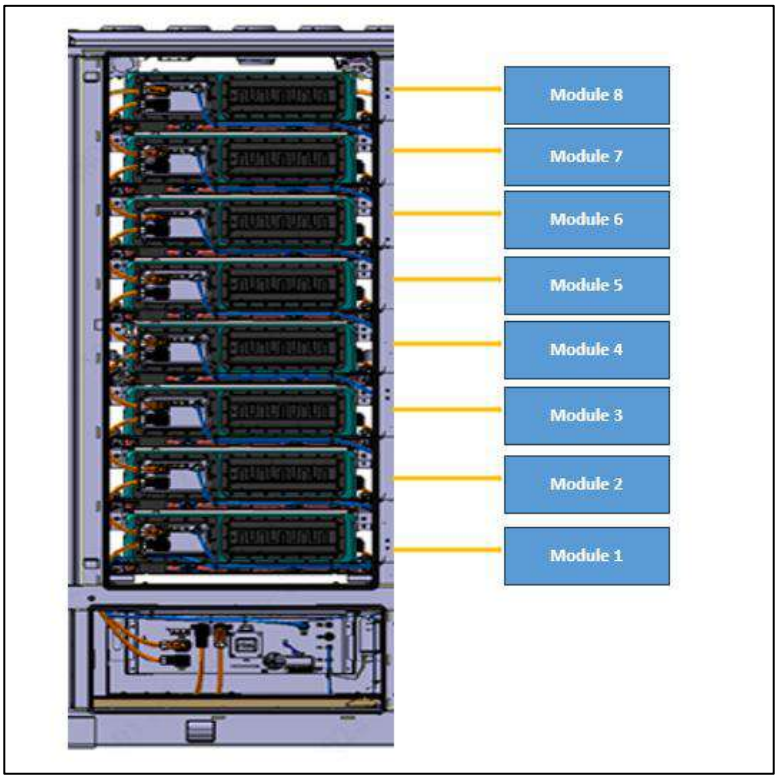
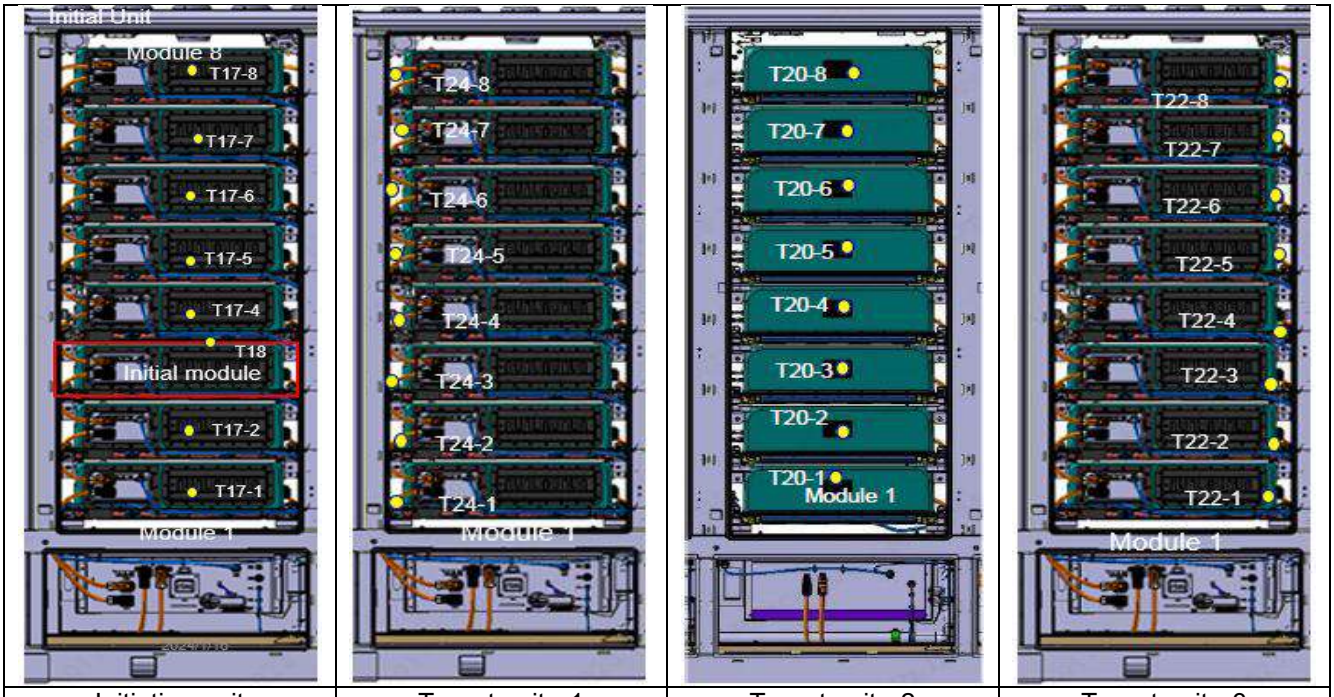


Figure 12: The initiating module 3 location in the initiating unit



Initiating unit	Target unit - 1	Target unit - 2	Target unit - 3

Figure 13: TC location in the initiating and target units, TC24 series for target unit-1, TC20 series for target unit-2, TC22 series for target unit-3, TC17 series for Initiating unit.

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Attachment D: Temperature Profiles and Heat Flux Measurements - (Pages 38 through 41)

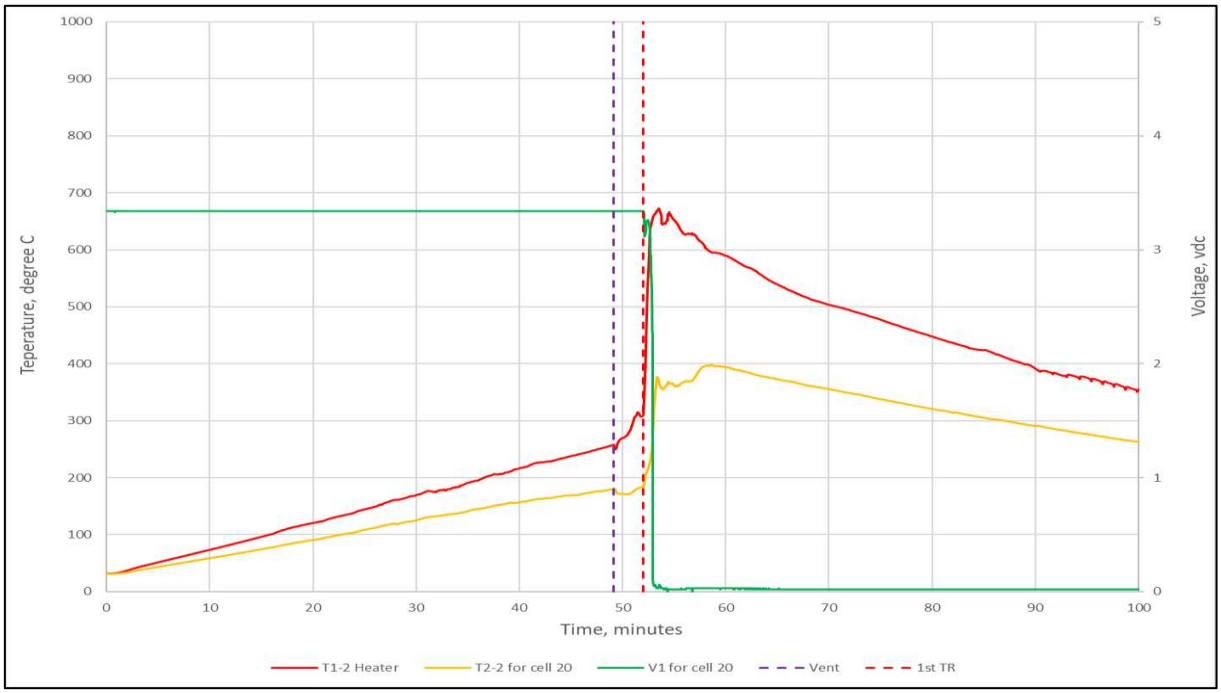

Figure 14: Initiating cells vent, Thermal runaway Initiating cell Temperature Profile During Testing

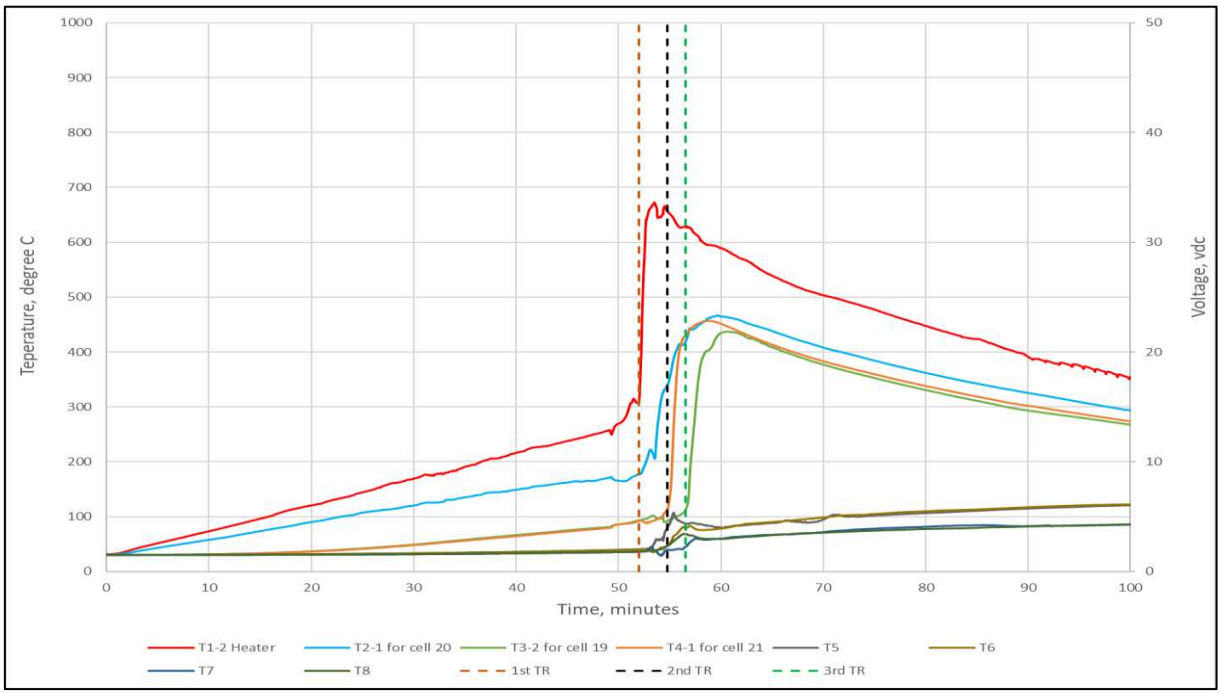

Figure 15: Initiating module temperature

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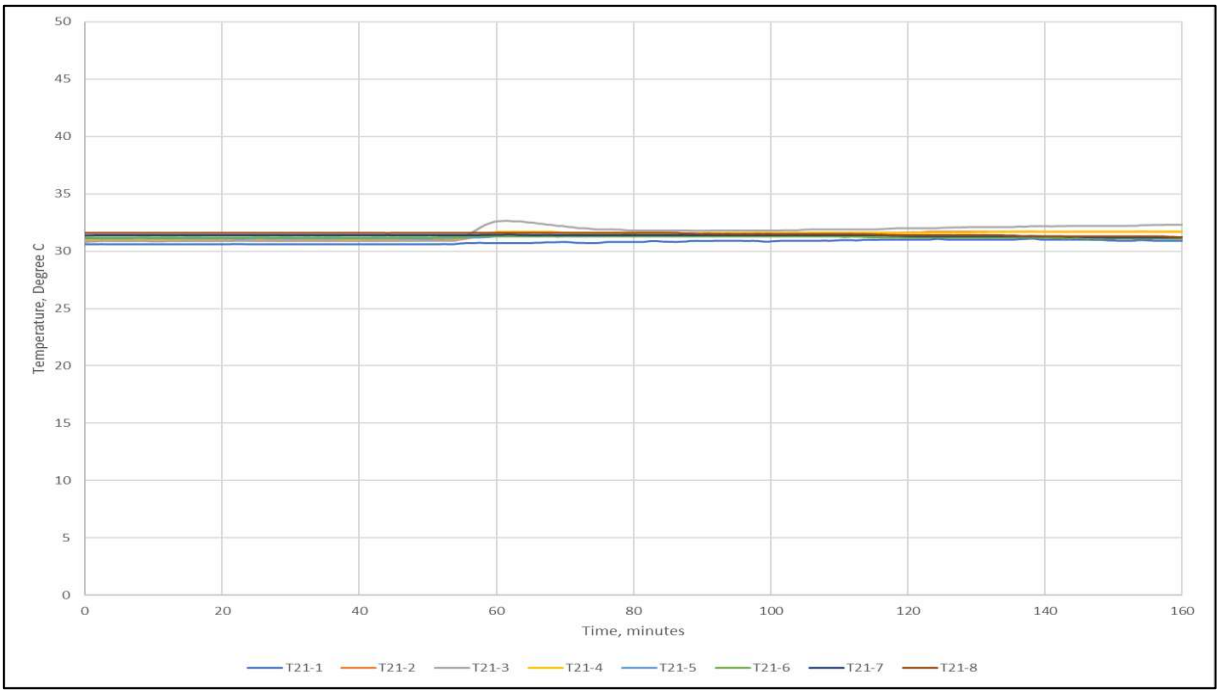

Figure 16: Target Unit-1 Temperature

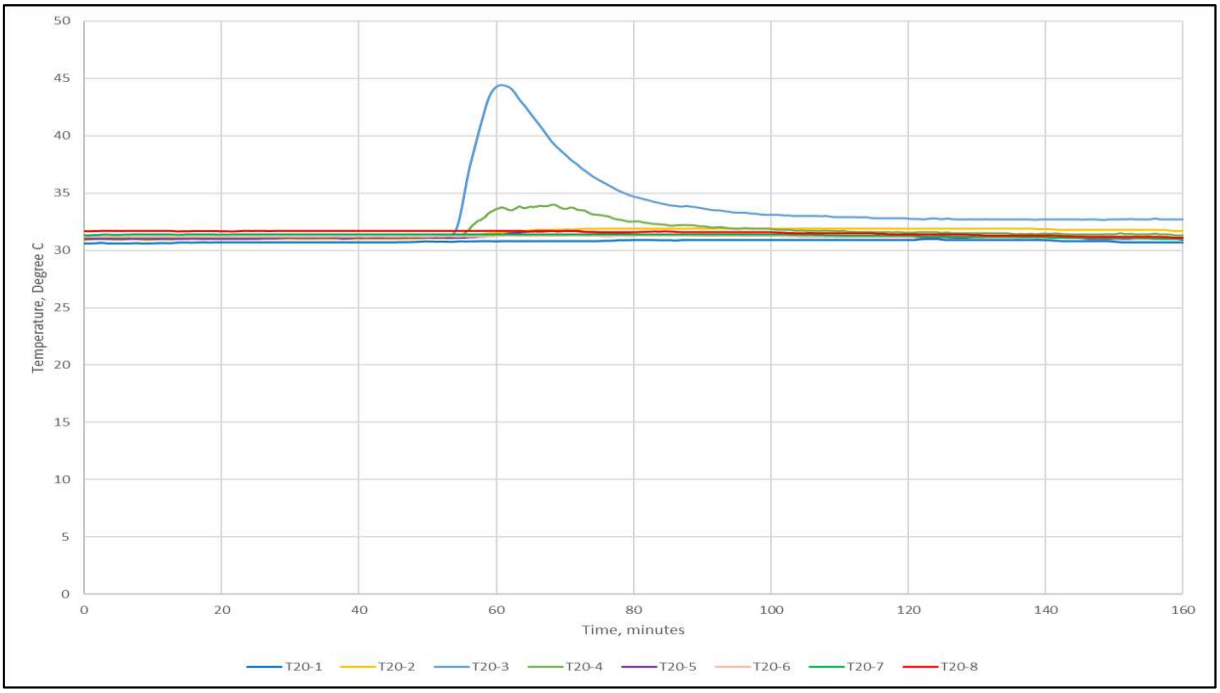

Figure 17: Target Unit-2 Temperature

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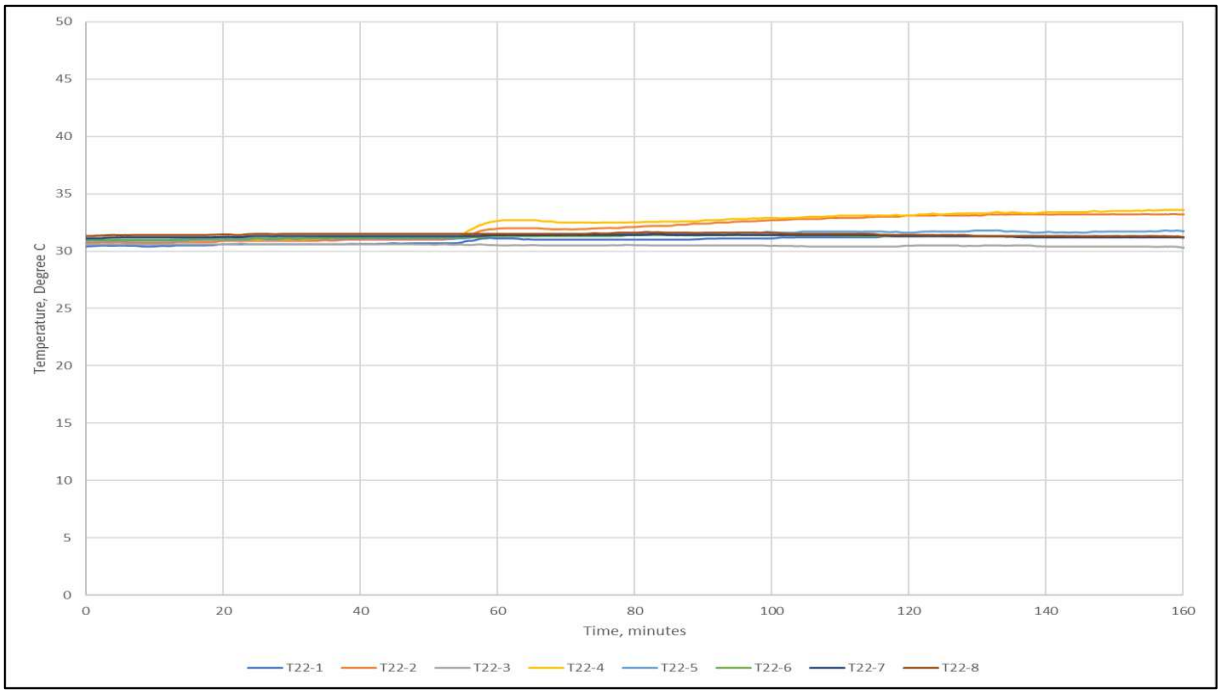

Figure 18: Target Unit-3 Temperature

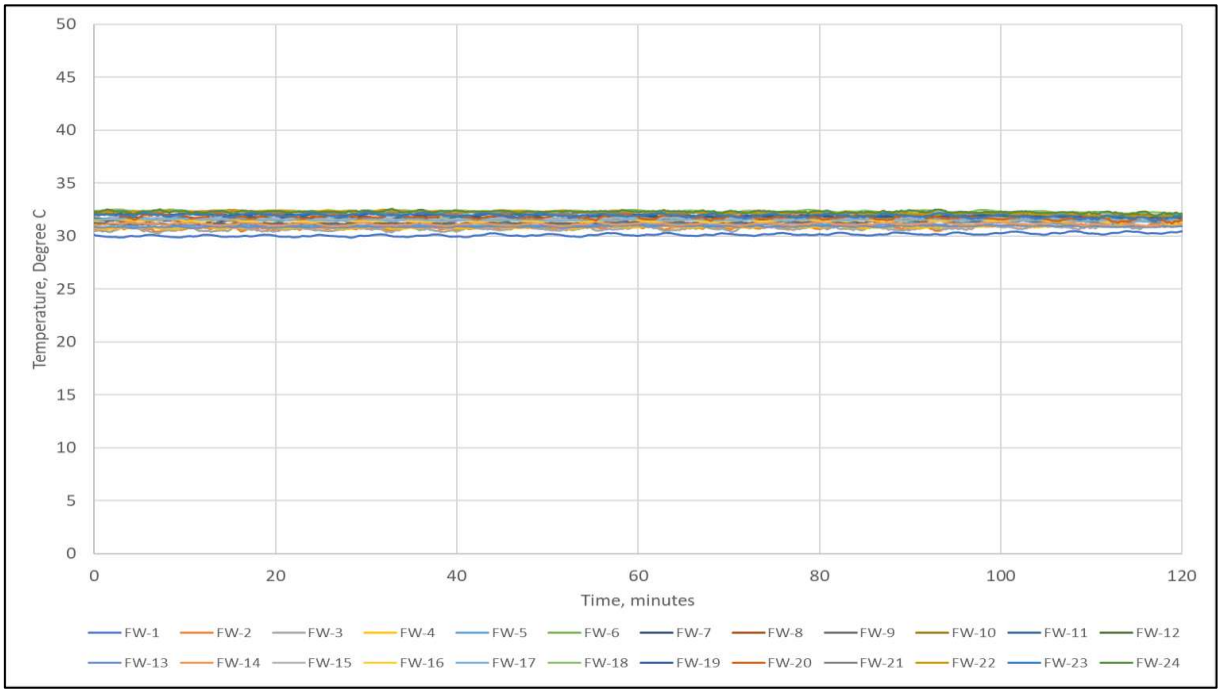

Figure 19: Front Wall Temperature

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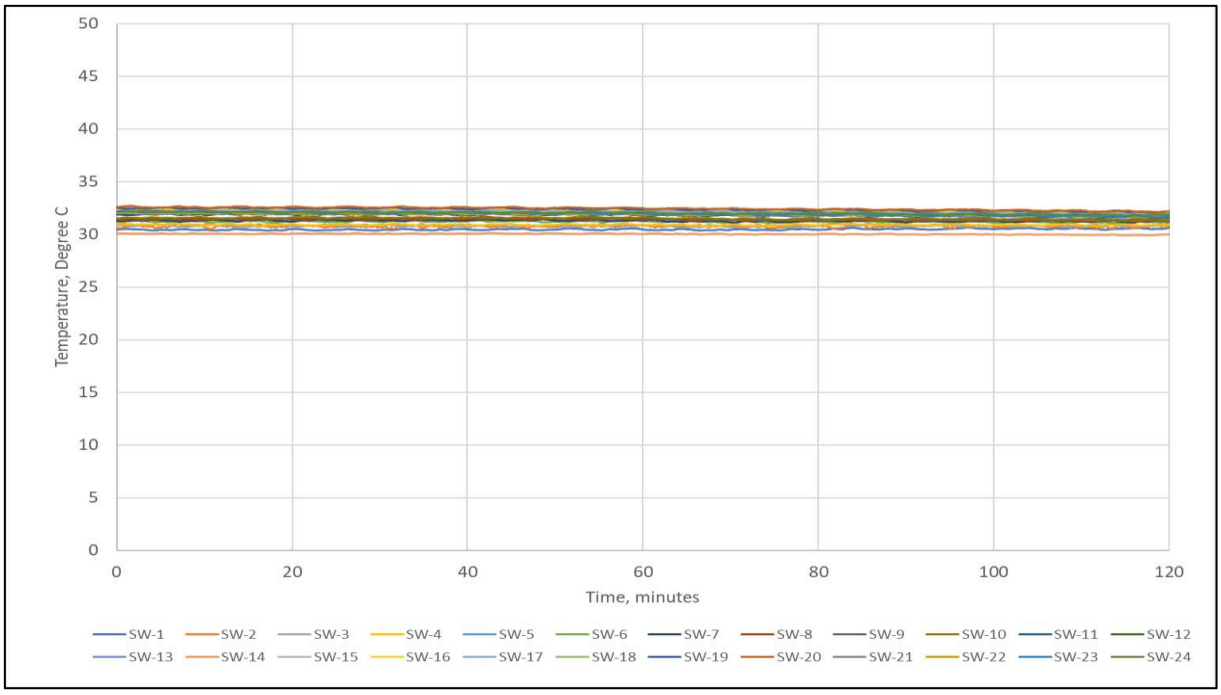

Figure 20: Side Wall Temperature

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Attachment E: BESS Testing Photos - (*Pages* 42 *through* 43)



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



(b) Vent initiating cell 20
[00:49:08]



(c) Initiating cell 20 Thermal runaway
[00:52:00]



(d) Cell 19Thermal runaway
[00:54:46]



(e) Cell 21 Thermal runaway
[00:56:33]



(f) Test Termination
[01:50:00]

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Figure 21: BESS Unit photos Post test

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Attachment F: BESS Gas Flow Rate, Heat Release Rates, Smoke Release Rate Profiles - (*Pages* 44 *through 46)*

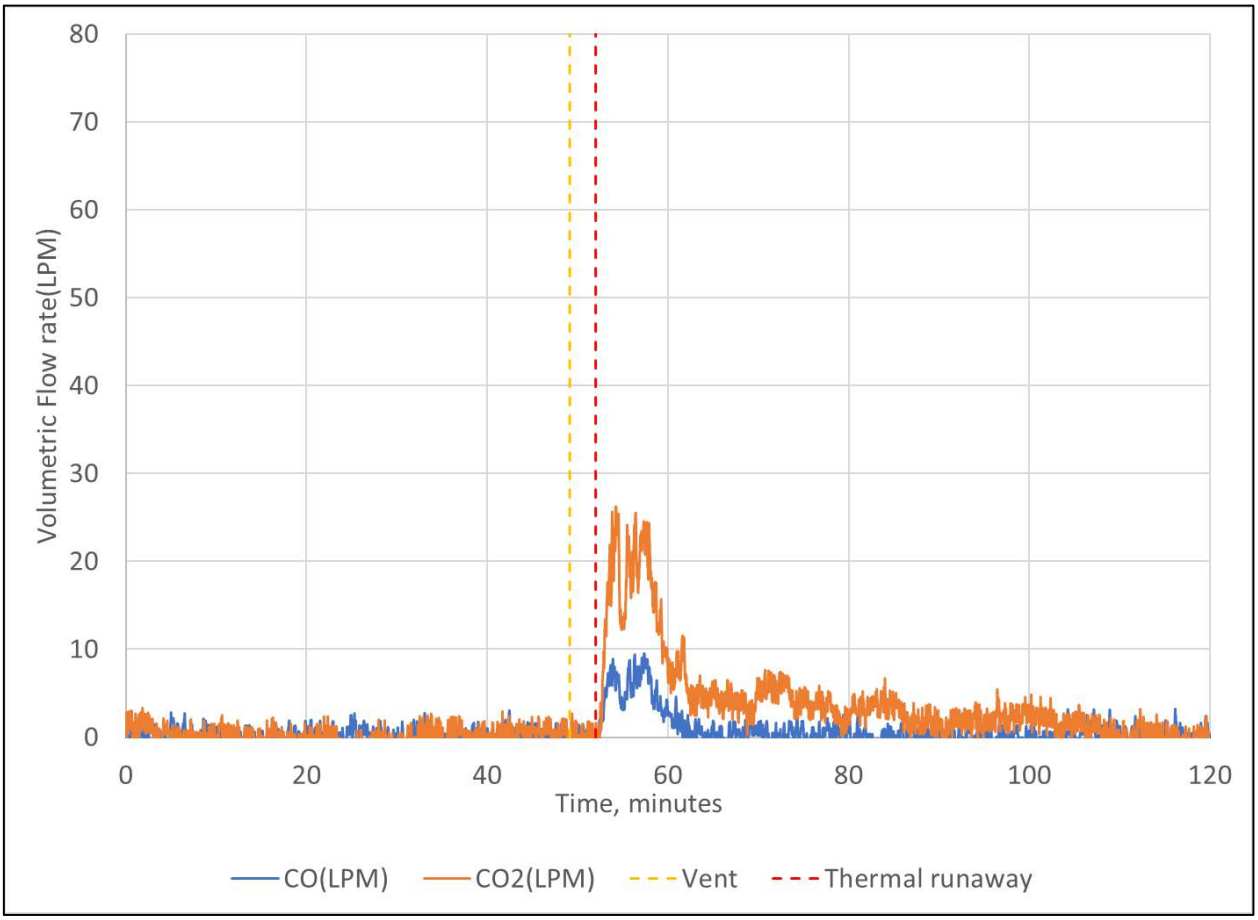

Figure 23: THC, H2 flow rates

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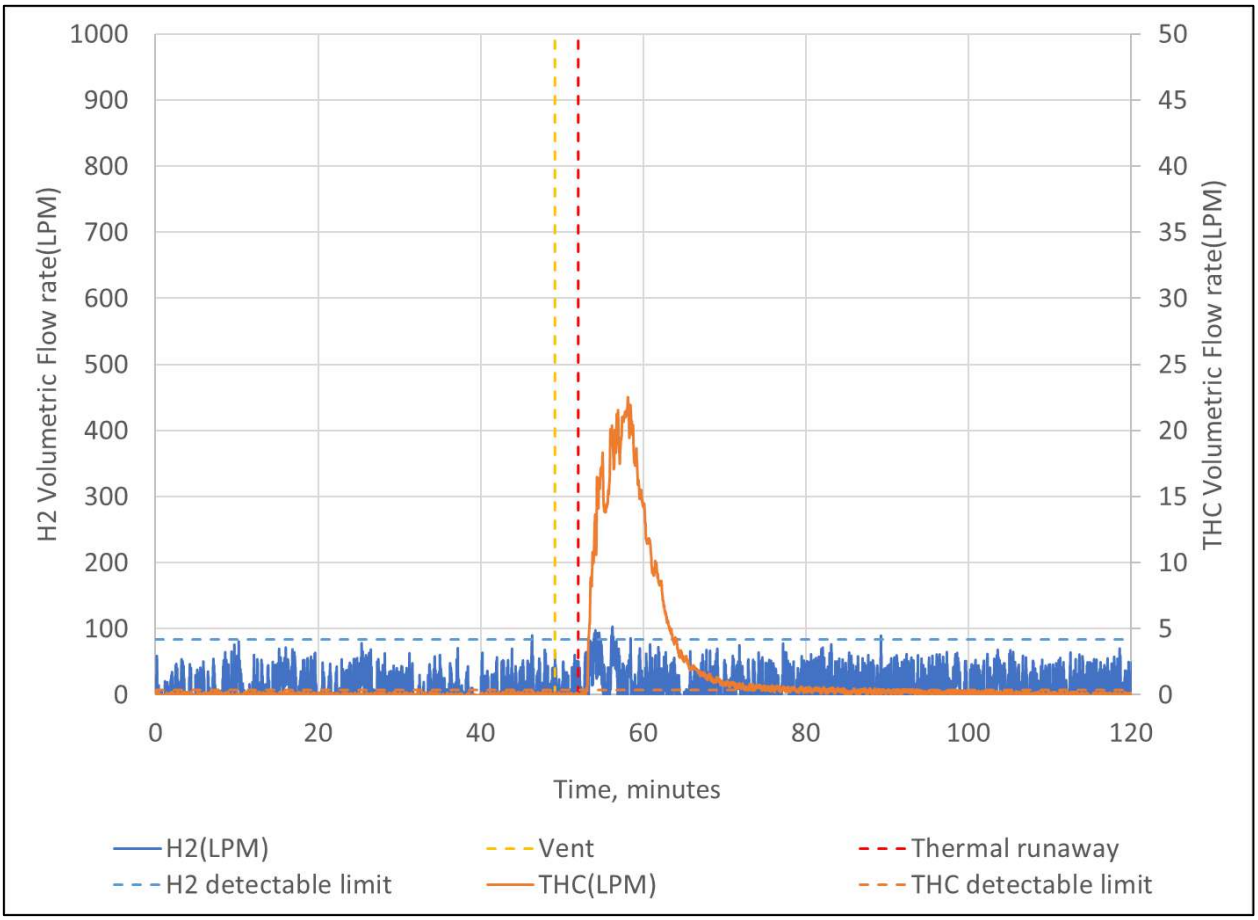

Figure 24: CO, CO2 flow rates

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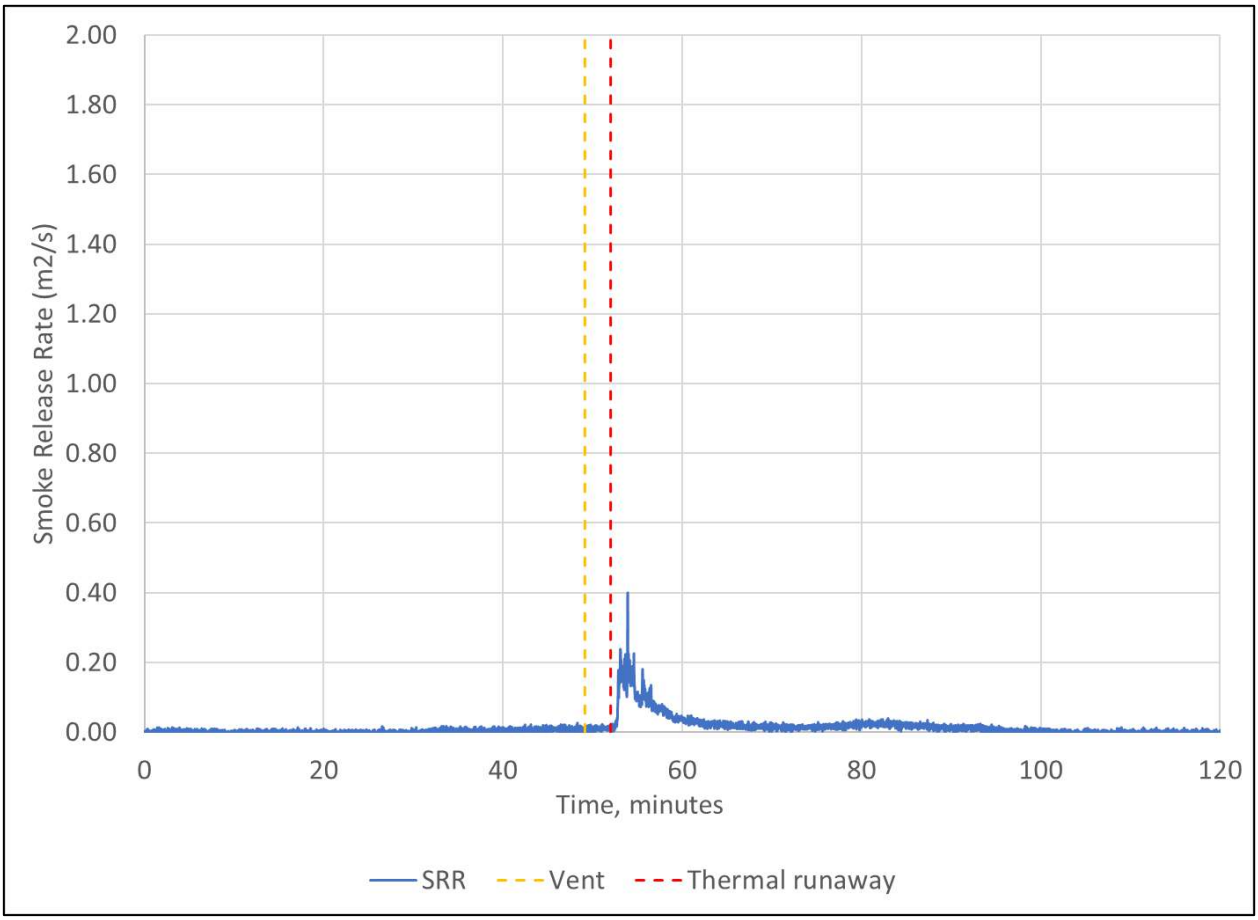

Figure 25: Smoke release rate

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Appendix of Report

The tested cell model is CBDC0, with PN number FC-FY5-71H4L4-XXXX.

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Appendix C

LSFT TEST REPORT

Large Scale Fire Test Report

Battery Energy Storage System model C04285P10L01 (3.79MWh)

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Issue Date	2025-12-15
Test Date	2025-11-05 ~ 2025-11-07
Title	Large Scale Fire Test Report for Battery Energy Storage System model C04285P10L01 (3.79MWh)

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Disclaimer

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

UL LLC did not select the sample(s), determine whether the sample(s) were representative of production samples, witness the production of the test sample(s), nor were we provided with information relative to the formulation or identification of component materials used in the test sample(s).

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The test method was established with reference to several test method documents, including the UL 9540 Task Group 3 Proposed Revisions to UL 9540A Installation Level – Large Scale Fire Test (hereinafter referred to as “9540 Technical Committee Proposal”), Appendix G.11 of NFPA 855: Standard for the Installation of Stationary Energy Storage Systems(hereinafter referred to as “Guidance on Implementing a Large-Scale Fire Test”) and Clause 9.7 of CSA/ANSI C800:25 – A New Standard for ESS Reliability and Quality Assurance(hereinafter referred to as “CSA C800”). Among these, the 9540 Technical Committee Proposal method served as the primary reference, as it is being discussed by a large technical committee that includes many AHJs (Authorities Having Jurisdiction), increasing the likelihood of broad acceptance of the final report. Where specific test method requirements were not clearly defined, CATL consulted with Registered Design Professional (RDP) to ensure that the procedure is sufficiently aligned with the intent of the Large-Scale Fire Test. The procedure outlined in this document reflects the final decisions and discussions from that consultation.

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Executive summary

This report summarizes the results of a large-scale fire test conducted on 3.79MWh battery energy storage system model C04285P10L01 to evaluate its thermal runaway behavior and fire propagation characteristics according to the configuration specified by CATL. The testing was conducted in accordance with procedures derived from UL 9540 Task Group 3 Proposed Revisions to UL 9540A Installation Level – Large Scale Fire Test, NFPA 855 Annex G11, and CSA C800 standards.

The test evaluates the fully or partially populated BESS container that represents the final installed configuration. The container of origin was fully populated and installed in its intended operating configuration, two target containers were partially populated and positioned according to separation distances provided by CATL, see Figure 1 for detail.

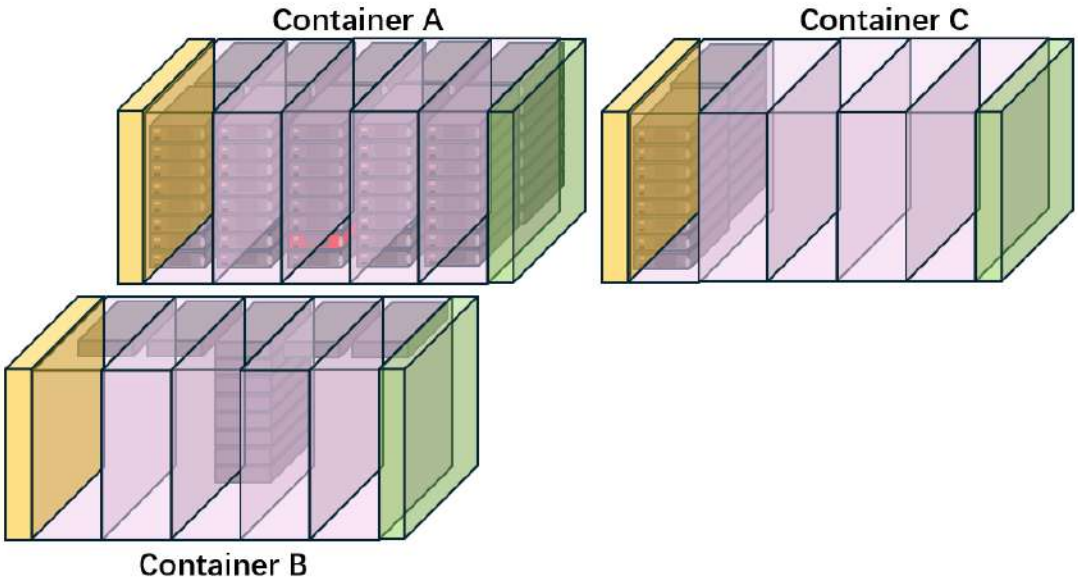

Figure 1-1 - Layout of Placement Position

The above figure1-1 shows the installation orientation of three containers, and the red pack in container A is the initiating module. Drawing of Packs represent real modules, the blank space represents the position for installing empty modules.

Note 1: All container diagrams in this report, the partitions were for illustrative purposes and reference only. The containers do not contain such partitions.

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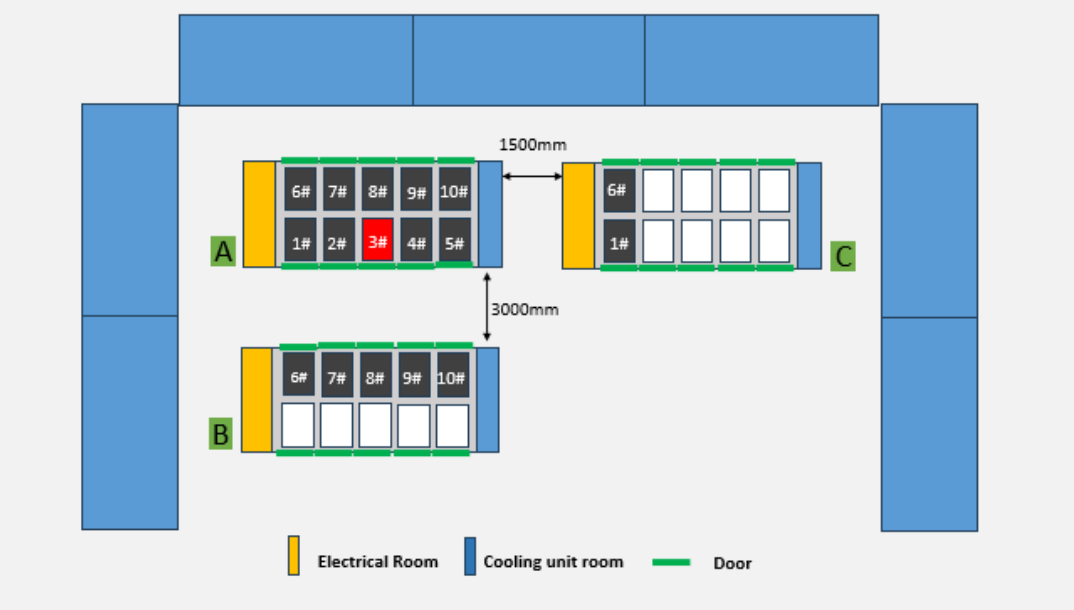

Figure 1-2 - Layout of Placement Position

The above figure shows the separation distances between containers, definition of numbering for containers and racks. The surrounding bule area are protective walls. The orange represents the electrical room, the blue represents the Liquid-cooling unit room, the green represents door, the white area represents empty, and the red area represents the location of the initiating unit in container A.

Container A: Origin (Initiating) container, the initial module's position within the rack is marked as a red box in Figure 1; in Rack 3 (M3-2), also see Figure 15 for detail.

Container B: Target Container. Positioned face-to-face with Container A, with 3000m separation distances. (Back-to-back installed Container keeps the same clearance as 3000mm.)

Container C: Target Container. Located on the right of Container A, arranged side by side with A, with 1500mm between them. (Side-to-side installed Container keeps the same clearance for both sides.)

Container A:
The container of origin was fully populated with 80 modules, while the surrounding target containers were equipped with real modules placed in the closest vicinity to the container of origin. All modules were fully charged, with the state of charge confirmed to be 100% prior to the test.

Before the test, the electrical room door, battery room doors, and ventilation window of the initiating container were all closed, and all the explosion-proof panels were opened.

Coolants were remain in all modules or cooling plates, the Liquid-cooling system of the original container was not circulating.

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There are two initiating modules (one of them was used as a backup), 8 initiating cells were selected for heating in each initiating module. Two spark plugs and one heating element ignitions were arranged 5cm away from and around the initiating module at designed vent locations. All target battery enclosures of containers were instrumented with thermocouples to monitor thermal exposure from the fire initiated in the enclosure of origin module. Thermal runaway was successfully triggered, which led to a fully developed fire and completed thermal runaway propagation in the container of origin.

Container B and Container C: Before the test, electrical room door, explosion-proof panels, and ventilation openings of the target containers were closed.

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1. Battery Energy Storage System Description

1.1 Cell

The cell model is the CBDC0, manufactured by Contemporary Amperex Technology Co., Limited. It's a lithium-ion cell with a nominal voltage of 3.2 volts and a capacity of 285 ampere-hours (Ah). The cell chemistry is Lithium Iron Phosphate.

In the UL 9540A cell-level test report (UL Project Number 4791943570) the average surface temperature during gas venting was 161°C and the temperature at the onset of thermal runaway was 220°C.

The cell released a gas volume of 176.3 L, and the composition of the gas was listed in Table 1. The flammability characteristics of the gas were tested. The lower flammability limit (LFL) of the gas mixture was 8.05% by volume in air at ambient temperature and 7.545% at the venting temperature. The burning velocity of these gases was 64.13 cm/s, and the maximum pressure during testing was 94.29 psig. Please refer to Table 1 for detailed information on the cell and the relevant test results.

Table 1 – Cell Information and the relevant test parameters

Cell Information

Items	Value	Items	Value
Manufacturer	Contemporary Amperex Technology Co., Limited	Charge power, kW	0.912
Type/Model	CBDC0	Charging cut-off voltage, Vdc	3.65
Nominal voltage, Vdc	3.2	Discharge power, kW	0.912
Rated capacity, Ah	285	Discharging cut-off voltage, Vdc	2.5
Dimensions L*W*H, mm	174.3±0.8 * 71.55±0.8* 207.3±0.8	Weight, kg	5.46 ± 0.3
Operating temperature (charge), ℃	0~60	Operating temperature (discharge), ℃	-20~60



Figure 2 – Photo of the cell

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Cell level Test information	
UL Project Number	4791943570
Average cell surface temperature at gas venting, °C:	161
Average surface temperature at thermal runaway, °C:	220
Gas Volume, L:	176.3
Lower flammability limit (LFL), % volume in air at the ambient temperature	8.05
Lower flammability limit (LFL), % volume in air at the venting temperature	7.545
Burning velocity (S_u) cm/s:	64.13
Maximum pressure (P_{max}) psig:	94.29

Cell Gas composition

Gas		Measured %
Carbon Monoxide	CO	10.610
Carbon Dioxide	CO2	30.116
Hydrogen	H2	43.569
Methane	CH4	6.625
Acetylene	C2H2	0.188
Ethylene	C2H4	4.159
Ethane	C2H6	1.245
Propadiene (Allene)	C3H4	0.005
Propylene	C3H6	1.056
Propane	C3H8	0.292
-	C4 (Total)	0.443
-	C5 (Total)	0.089
-	C6 (Total)	0.034
Benzene	C6H6	0.015
Toluene	C7H8	0.002
Dimethyl Carbonate	C3H6O3	1.477
Ethyl Methyl Carbonate	C4H8O3	0.077
Total	-	100

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1.2 Module

The module model is the M01285P10L01, battery module rated 166.4V, 285Ah employs cell model CBDC0, which was manufactured by Contemporary Amperex Technology Co. Limited, arranged in a 1P52S configuration.
The Project Number of UL 9540A Module-level test report is 4791943679.

Table 2 – Module information

Module Information			
Items	**Value**	**Items**	**Value**
Manufacturer	Contemporary Amperex Technology Co Limited	Charge power, kW	47.424
Type/Model	M01285P10L01	Charging cut-off voltage, Vdc	Any cell reaches of 3.65 or total voltage reaches 189.8
Nominal voltage, Vdc	166.4	Discharge power, kW	47.424
Rated capacity, Ah	285	Discharging cut-off voltage, Vdc	Any cell reaches of 2.5 or total voltage reaches 130
Dimensions W * D *H, mm	1150 ± 5*810 ± 5*241.5 ± 5	Weight, kg	325±10
Operating temperature (charge), ℃	0~57	Operating temperature (discharge), ℃	-20~57



Figure 3 – Photo of the Module

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1.3 Rack

Battery rack model C04285P10L01-R is lithium-ion racks manufacturer by Contemporary Amperex Technology Co., Limited.
The rack consists of 8 battery modules connected in series with a control box.
The Project Number of UL 9540A Unit-level test report is 4791943683.

Table 3 – Rack information

Rack Information			
Items	**Value**	**Items**	**Value**
Manufacturer	Contemporary Amperex Technology Co., Limited	Charge power, kW	379.392
Type/Model	C04285P10L01-R	Charging cut-off voltage, Vdc	Any cell reaches of 3.65 or total voltage reach 1518.4 for rack
Nominal voltage, Vdc	1331.2	Discharge power, kW	379.392
Rated capacity, Ah	285	Discharging cut-off voltage, Vdc	Any cell reaches of 2.5 or total voltage reach 1040 for rack
Dimensions W * D *H, mm	1231*832*2108	Weight, kg	2600±40
Operating temperature (charge), ℃	0~57	Operating temperature (discharge), ℃	-20~55



Figure 4 – Photo of the Rack

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1.4 Container

The battery energy storage system model C04285P10L01(3.79MWh) is BESS container designed to store electrical energy. It is applicable in various applications such as renewable energy integration, frequency regulation, and grid voltage regulation. The energy storage system (ESS) primarily consists of battery modules, a battery management system (BMS), a fire suppression system (FSS), a thermal management system (TMS), and an auxiliary distribution system.

The BESS container consists of 2x5P battery racks system. Each rack contains 8 battery modules, each module consists of 52 cells connected in series, totalling 4160 cells in the container.



Figure 5 – C04285P10L01(3.79MWh) battery energy storage system Overview

Table 4 - Container main technical parameters

Container Information	
Item	**Value**
Container model	C04285P10L01
Container Dimensions, W * D *H, mm	6058*2462*2896
Container Capacity, Ah	2850
Container Rack configuration, xS/yP	2x5P
Container Voltage, Nominal, Vdc	1332.1

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2. Large Scale Fire Test Description

The test method was established with reference to several test method documents, including the UL 9540 Task Group 3 Proposed Revisions to UL 9540A Installation Level – Large Scale Fire Test (hereinafter referred to as “9540 Technical Committee Proposal”) , Appendix G.11 of NFPA 855: Standard for the Installation of Stationary Energy Storage Systems(hereinafter referred to as “Guidance on Implementing a Large-Scale Fire Test”) and Clause 9.7 of CSA/ANSI C800:25 – A New Standard for ESS Reliability and Quality Assurance(hereinafter referred to as “CSA C800”). Among these, the 9540 Technical Committee Proposal method served as the primary reference, as it was discussed by 9540 Technical committee that included members from AHJs (Authorities Having Jurisdiction), Government and other stakeholders, increasing the likelihood of broad acceptance of the final report.

2.1 Test setup

The test was conducted in China on November 6, 2025. The test samples included one 20ft origin container A and two 20ft target containers B, C.

The test took place at the Hubei Jiandun Fire Technology Co., Ltd, located at No.55 Shanxiyao Road, Yichang High-tech Zone, Yichang City, Hubei Province, China. Testing was conducted outdoors and the environment conditions were as summarized in Table 5.

Table 5 – Environmental conditions measured during the test

Measured items	Measurements
Maximum Wind speed	1.92m/s
Wind direction	See Figure 6
Ambient temperature	16.3°C ~ 29.6°C
Humidity	41.3% R.H ~ 90.4% R.H

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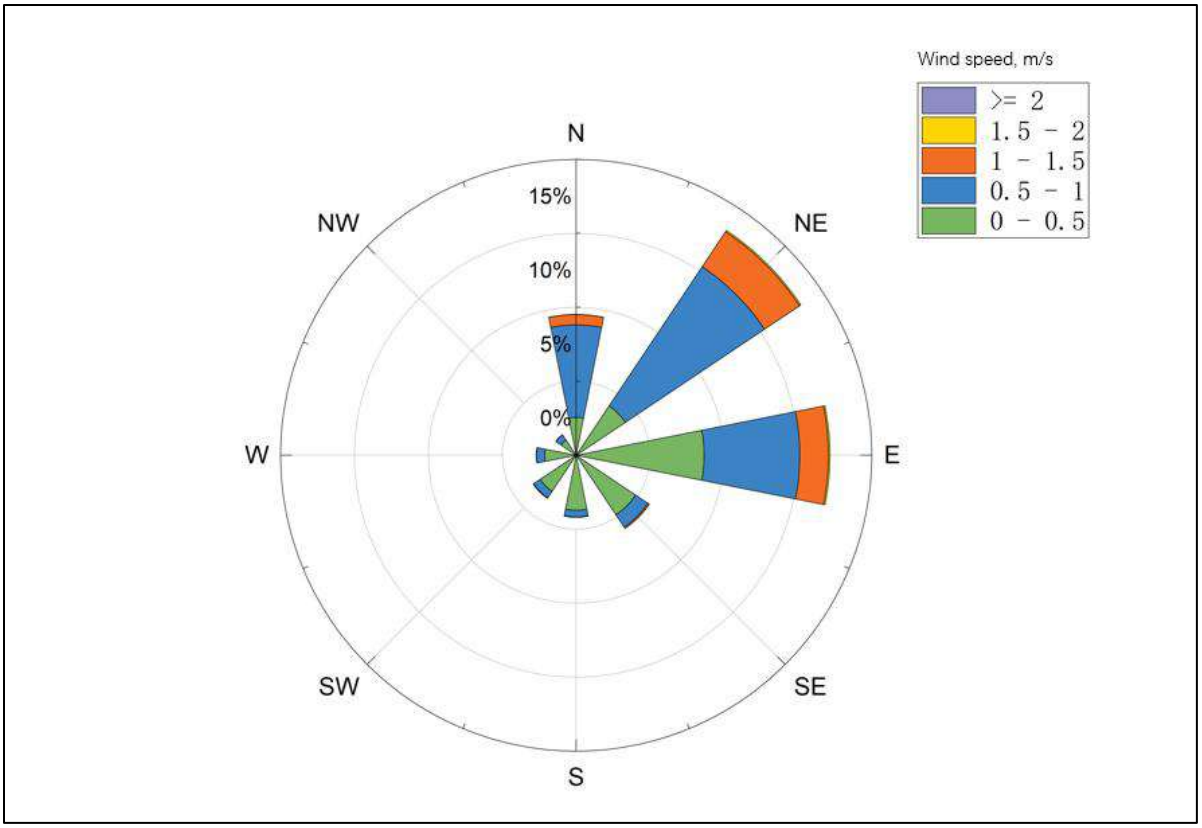

Figure 6 – Profile of the wind direction and speed measured during the test

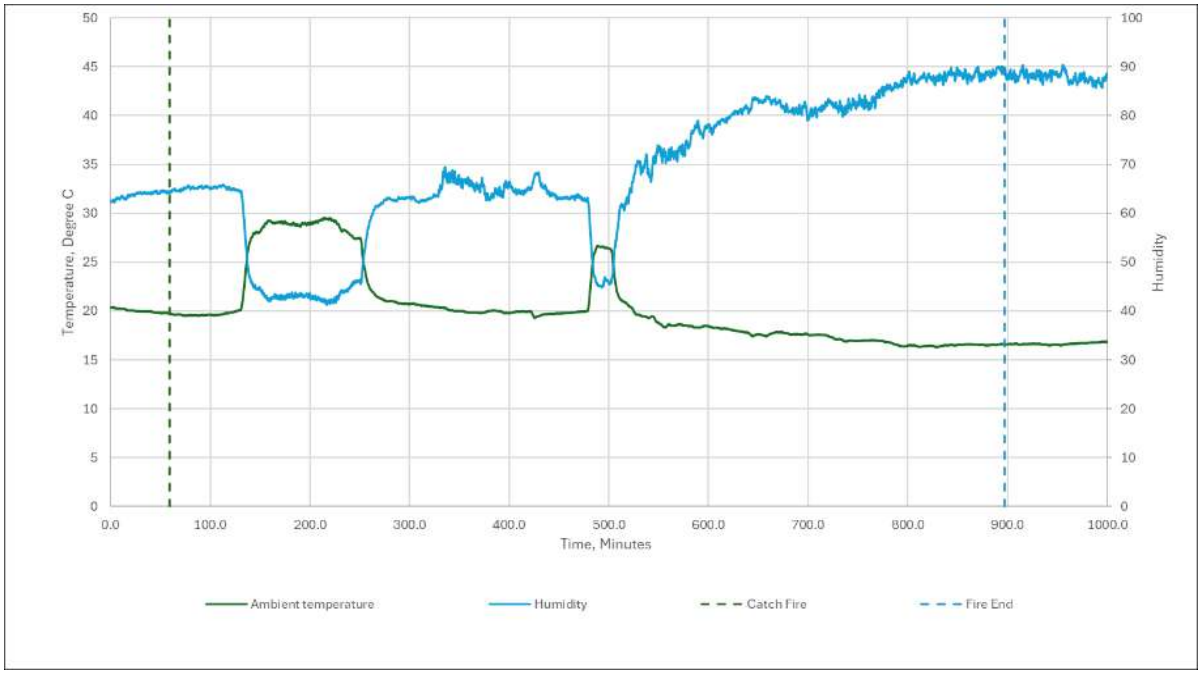

Figure 7 – Profile of the Ambient temperature and Humidity measured during the test

Sufficient light was present to allow for clear observation of the test. No precipitation was observed impacting the initiating or target racks during the testing. Vegetation and combustible materials in the test area were adequately controlled to prevent interference with the test and to

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mitigate the risk of unintended fire spreading beyond the designated area. Appropriate protection mechanisms were implemented to restrict unauthorized access to the test site and to ensure that personnel were not exposed to hazards resulting from the testing activities.



Figure 8 – Top and side view of the testing site with the containers

Figure 8 presents the view of the testing site, with the enclosure of origin at the center of the hood.

2.2 Configuration

Three containers, including the container of origin, were submitted for the test, and they were arranged in a representative installation configuration for the separation distances according to the CATL's installation instructions. Spacings between Initial container and target containers were provided in Figure 9 and summarized in Table 6.

Container A: Origin container, the initial module's position within the rack is indicated by the red box in Figure 9; this module positioned in Rack 3 (M3-2).

Container B: Target Container. Positioned face-to-face with Container A, with 3000mm separation distances. (Back-to-back installed Container keeps the same clearance as 3000mm.)

Container C: Target Container. Located on the right of Container A, arranged side by side with A, with 1500mm between them. (Side-to-side installed Container keeps the same clearance for both sides.)

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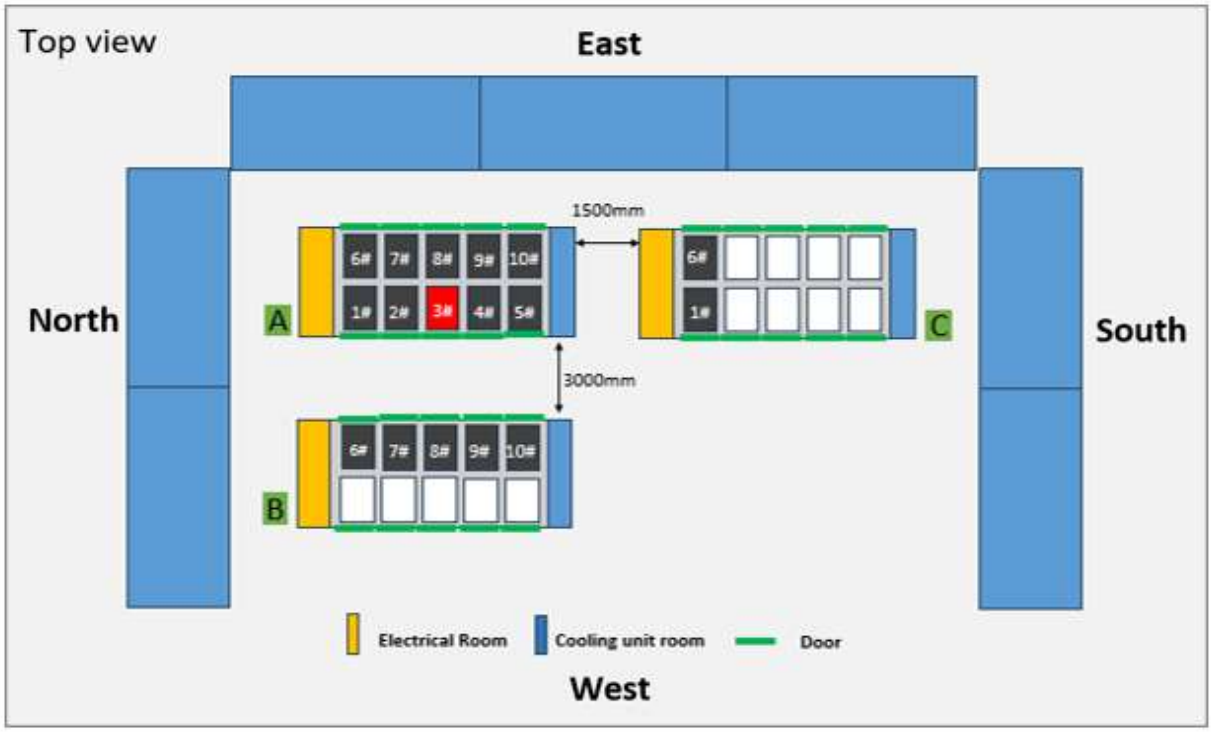

Figure 9 – Overall configuration of the installation for the test

	
Front view	Top view

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Left view	Right view

Figure 10 – pictures of the Overall configuration

Table 6 – Separation distance between the enclosure of origin to each target containers

Separation from container of origin to	Distance (mm)
Target Container B	3000
Target container C	1500

	
Initiating Container to Target B (far view)	Initiating Container to Target B (close view)
	
Initiating Container to Target C (far view)	Initiating Container to Target C (close view)

Figure 11 – pictures of the separation measurements to the target containers from the container of origin

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2.3 Charging

The BESS in the container of origin and all cells or modules in the targets, where provided, were charged to the maximum operating state of charge (MOSOC) in accordance with the manufacturer's specifications.

2.3.1 Container of Origin

The container of origin was fully populated, including the final installed configuration of the battery energy storage system, ancillary equipment, cabling, and outer enclosure. All the modules were charged to the MOSOC. Prior to initiating the test, the voltages of the modules were measured and recorded.

The charging information is summarized in Table 7 and See Figure 12.

Table 7 – Voltage and Charge information of the Origin container

Rack Location	Module No.	OCV Prior to Test (dc V)	OCV Prior to Test (dc V) for Rack	Rack Location	Module No.	OCV Prior to Test (dc V)	OCV Prior to Test (dc V) for Rack
Rack 1#	M1-1~M1-2	348.4	1392.4	Rack 6#	M6-1~M6-2	351.1	1403.1
	M1-3~M1-5	522.0			M6-3~M6-5	526.0	
	M1-6~M1-8	522.0			M6-6~M6-8	526.0	
Rack 2#	M2-1~M2-2	348.2	1392.4	Rack 7#	M7-1~M7-2	350.8	1401.8
	M2-3~M3-5	522.0			M7-3~M7-5	525.0	
	M2-6~M2-8	522.0			M7-6~M7-8	526.0	
Rack 3#	M3-1~M3-2	347.6	1391.6	Rack 8#	M8-1~M3-2	351.5	1403.5
	M3-3~M3-5	522.0			M8-3~M8-5	526.0	
	M3-6~M3-8	522.0			M8-6~M8-8	526.0	
Rack 4#	M4-1~M4-2	347.6	1391.6	Rack 9#	M9-1~M9-2	350.8	1402.8
	M4-3~M4-5	522.0			M9-3~M9-5	526.0	
	M4-6~M4-8	522.0			M9-6~M9-8	526.0	
Rack 5#	M5-1~M5-2	348.3	1391.3	Rack 10#	M10-1~M10-2	350.8	1402.8
	M5-3~M5-5	522.0			M10-3~M10-5	526.0	
	M5-6~M5-8	521.0			M10-6~M10-8	526.0	

Note: Racks M1 ~ M5 and Racks M6 ~ M10, see figure 13. Within each Rack, modules were numbered sequentially from bottom to top, such as in Rack 1#, from bottom to top, the module numbers are M1-1 to M1-8.

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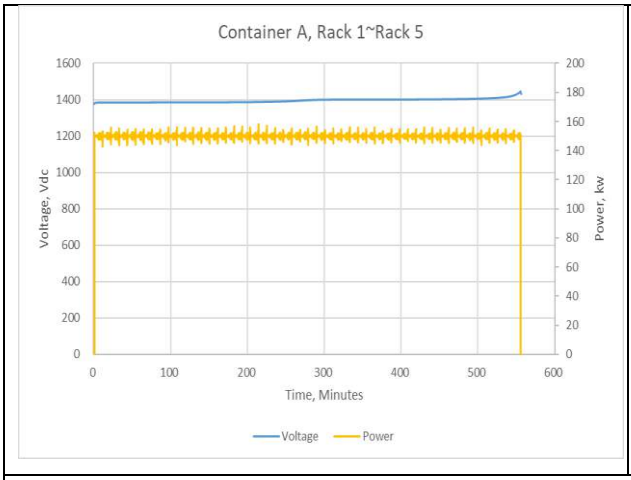

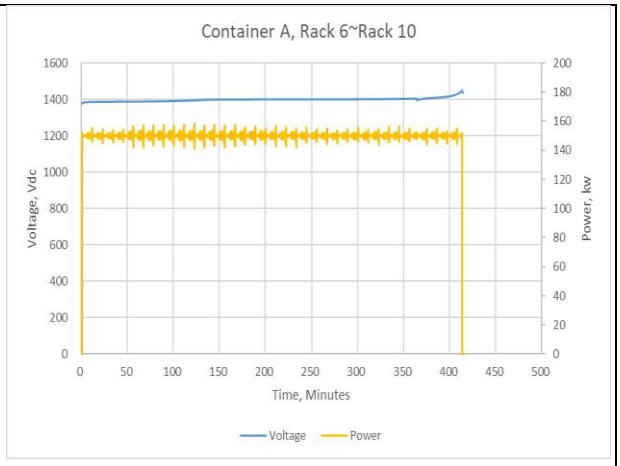

Note: Rack 1~Rack 5, the charging was completed on October 30, 2025, at 07:47, Rack 6~Rack 10, the charging was completed on October 30, 2025, at 20:26.

Figure 12-1 – Container A Charge Full Profiles

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2.3.2 Target container

All modules included in the targets were charged to 100% SOC prior to test.

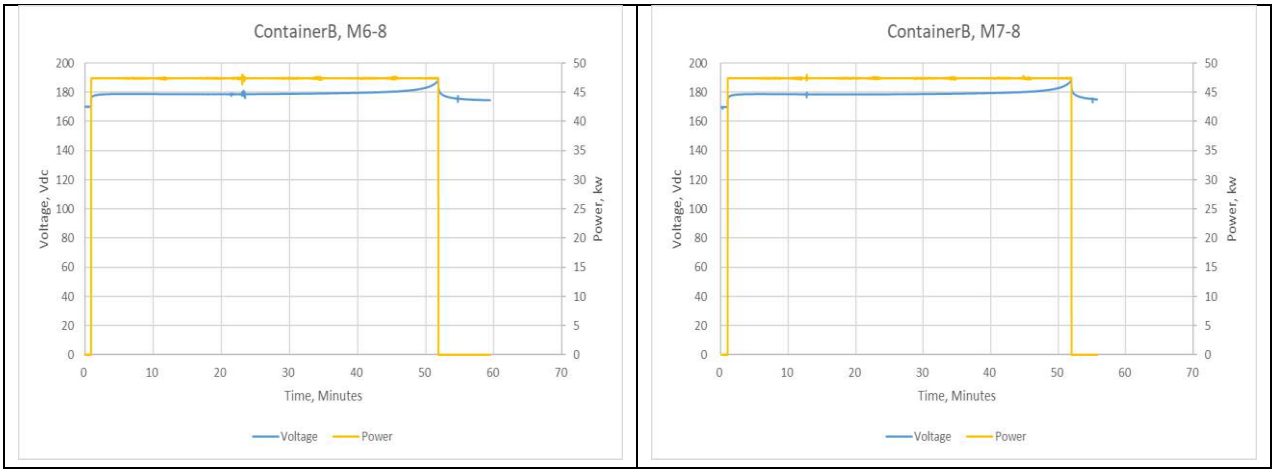
For container B, the module installation configuration is as follows: 1 real module installed at the top of each rack of 6, 7, 9, and 10. Rack 8 is configured with 8 real modules. And the remaining spaces are left blank.

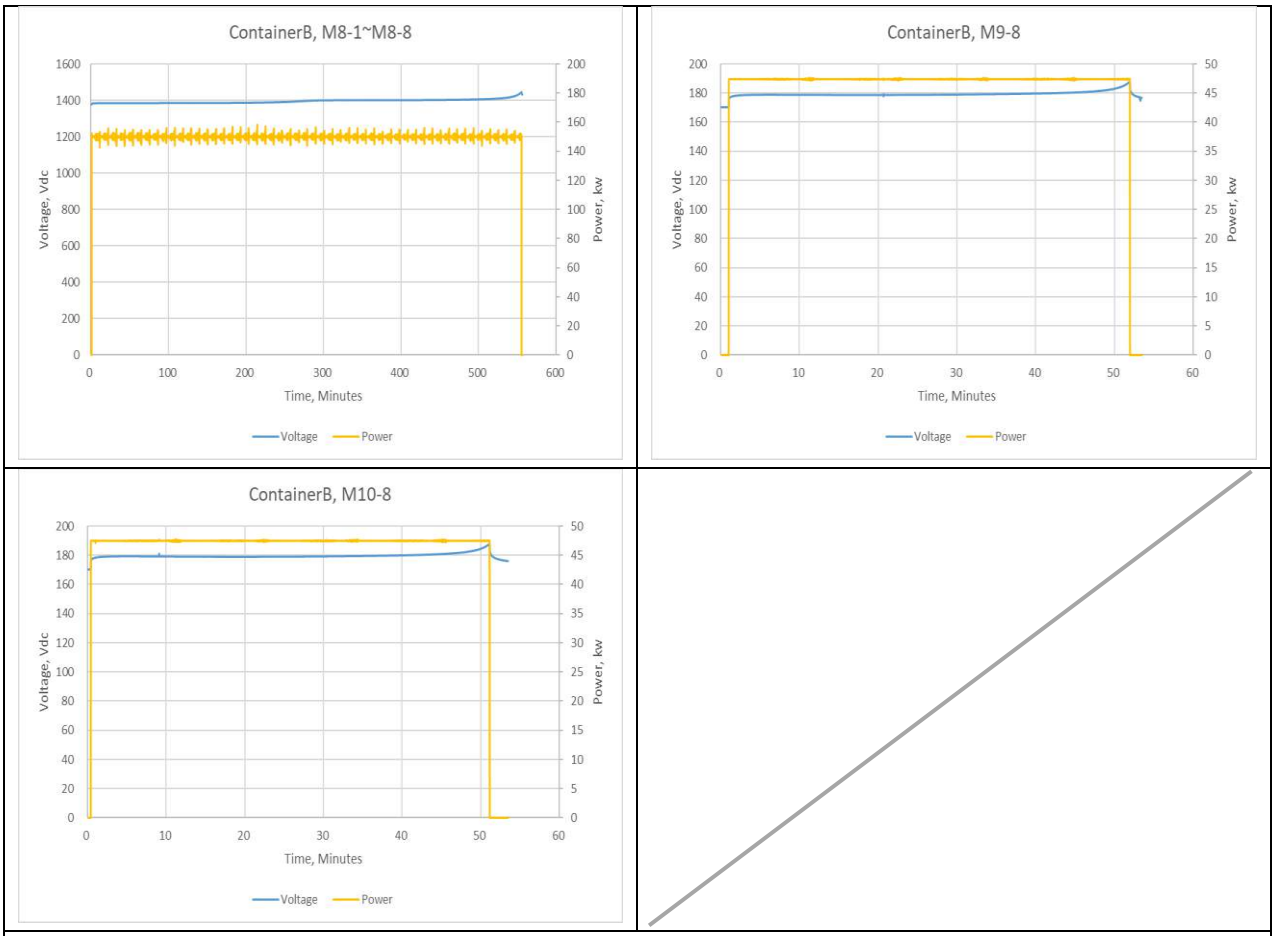
For Container C, the module installation configuration is as follows: Rack 1 and Rack 6 each configured with 8 real modules, and the remaining spaces are left blank.

The voltage information is summarized in Table 8.

Table 8 – Voltage of the Modules in Target Container B, C

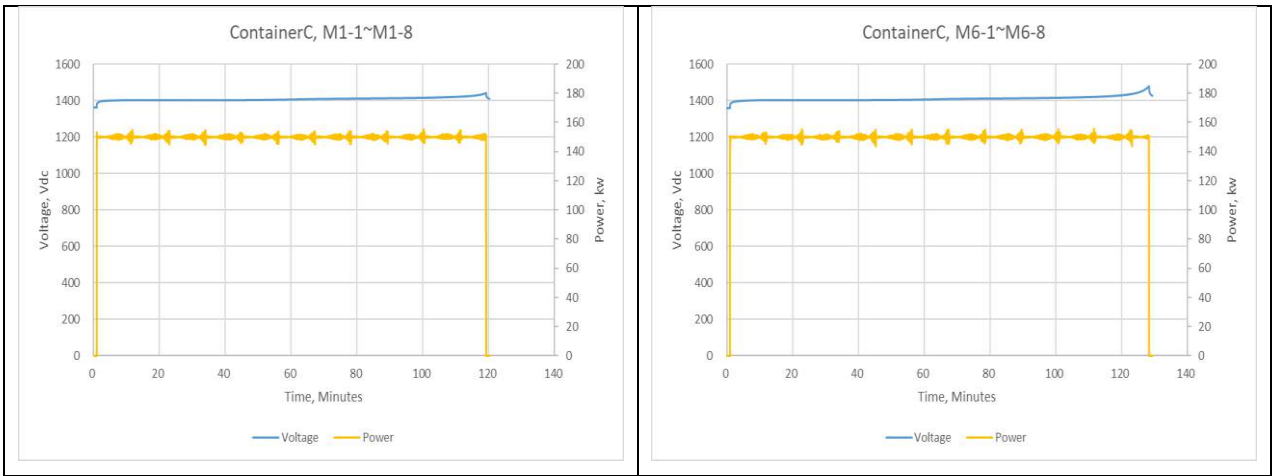
Container No.	Rack Location	Module No.	OCV Prior to Test (dc V)	OCV Prior to Test (dc V) for Rack
B	Rack 6#	M6-8	173.5	N/A
	Rack 7#	M7-8	173.5	NA
	Rack 8#	M8-1~M8-2	347.3	1387.3
		M8-3~M8-5	520.0	
		M8-6~M8-8	520.0	
	Rack 9#	M9-8	173.5	N/A
	Rack 10#	M10-8	173.4	N/A
C	Rack 1#	M1-1~M1-2	346.7	1386.7
		M1-3~M1-5	519.0	
		M1-6~M1-8	521.0	
	Rack 6#	M6-1~M6-2	347.2	1387.2
		M6-3~M6-5	520.0	
		M6-6~M6-8	520.0	





Note: M6-8, the charging was completed on November 1, 2025, at 15:14, M7-8, the charging was completed on November 1, 2025, at 14:11, M8-1~M8-8, the charging was completed on November 1, 2025, at 11:17, M9-8, the charging was completed on November 1, 2025, at 16:20, M10-8, the charging was completed on November 1, 2025, at 12:33.

Figure 12-2 – Container B Charge Full Profiles



Note: Rack 1, the charging was completed on October 31, 2025, at 15:24, Rack 6, the charging was completed on October 31, 2025, at 17:46.

Figure 12-3 – Container C Charge Full Profiles

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2.4 Container of Origin Installation

2.4.1 Overall Installation

The container of origin was equipped with a total of 80 battery modules.

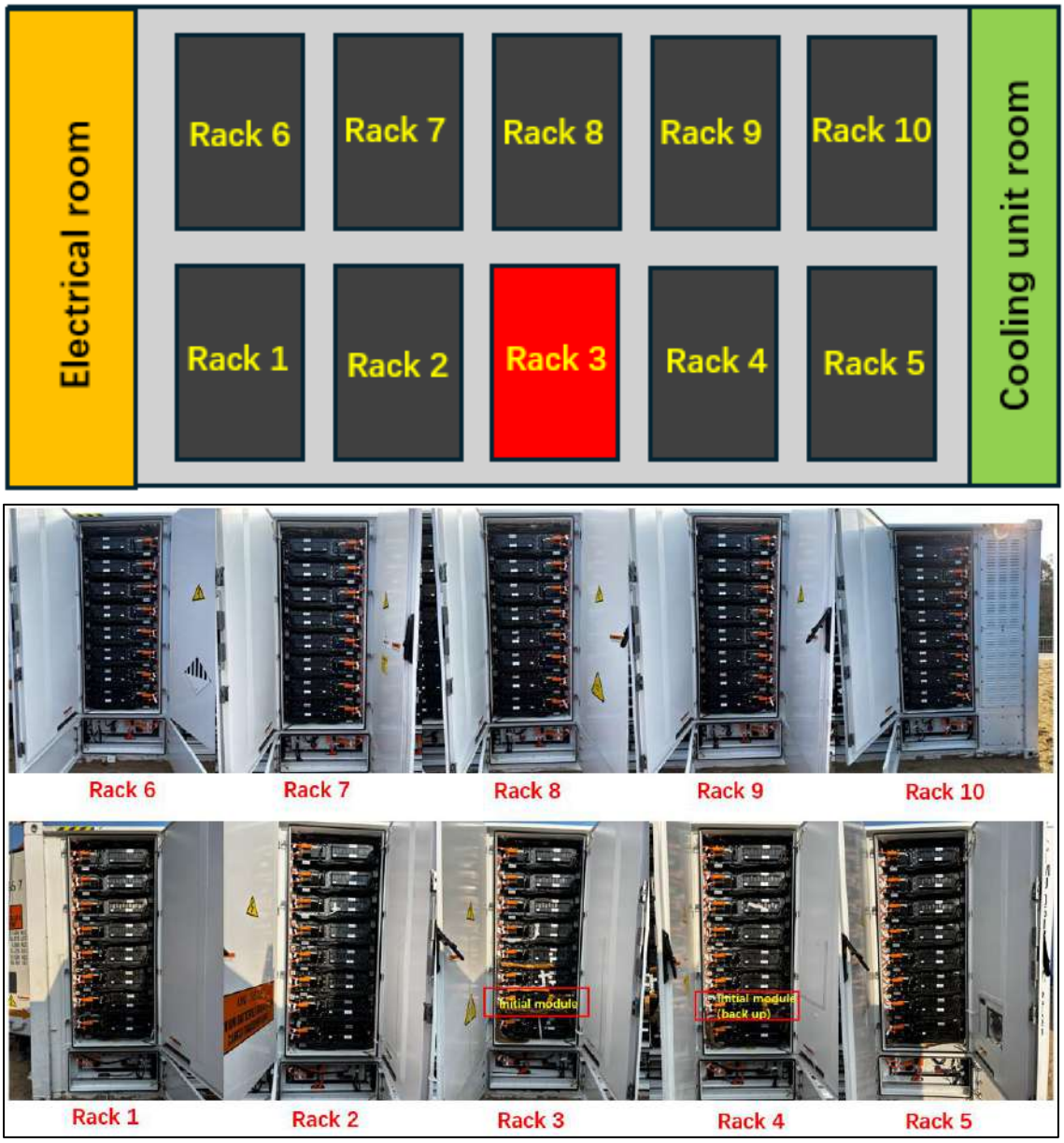

Figure 13 – Picture of fully populated container of origin (Rack1 is located near the electrical compartment)

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2.4.2 Ventilation Conditions

All ten doors of the original container remain closed. The louver remains closed, and the ventilation system is not operational. Electrical room door and Liquid -cooling room door are closed.

The NFPA 68 report was provided by CATL and prepared by Atar Fire, LLC. This report concluded that the design provided complies with the requirements of NFPA 68, all 8 deflagration panels at the top of the container are removed for testing.

2.4.3 Passive Thermal Runaway Mitigation Technologies

The battery modules were equipped with thermal isolation material that were designed to slow down the cell-to-cell propagation of the thermal runaway. For details, see picture 16, total of 52 cells and 16 pieces of *insulation* pads in the module. But in order to create thermal runaway propagation, total 8 pieces of *insulation* pads between Initiating cells have been removed.

2.4.4 Active Mitigation Systems

Active fire protection systems were deactivated within Container A of origin, such as water firefighting. Retain temperature detectors, smoke detectors and gas detectors of the fire detector system.

The liquid cooling system and combustible gas concentration reduction systems are not operational in the enclosure of origin container.

Coolants remain in all modules or cooling plates where they would be present per the manufacturer’s installation instructions.

2.4.5 Instrumentation

Total two initiating modules were prepared in advance in the container of origin. The selected locations of these initiating modules, shown in Figure 14, close to the exterior boundary of the enclosure, and in the second lowest vertical position.

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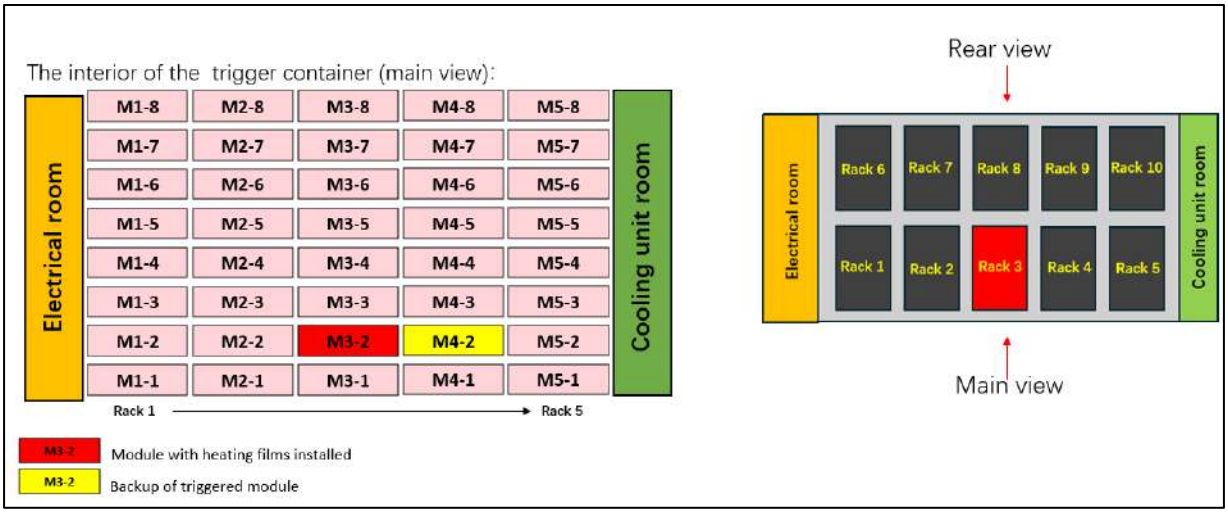

Figure 14– location of the initiating modules in the container of origin

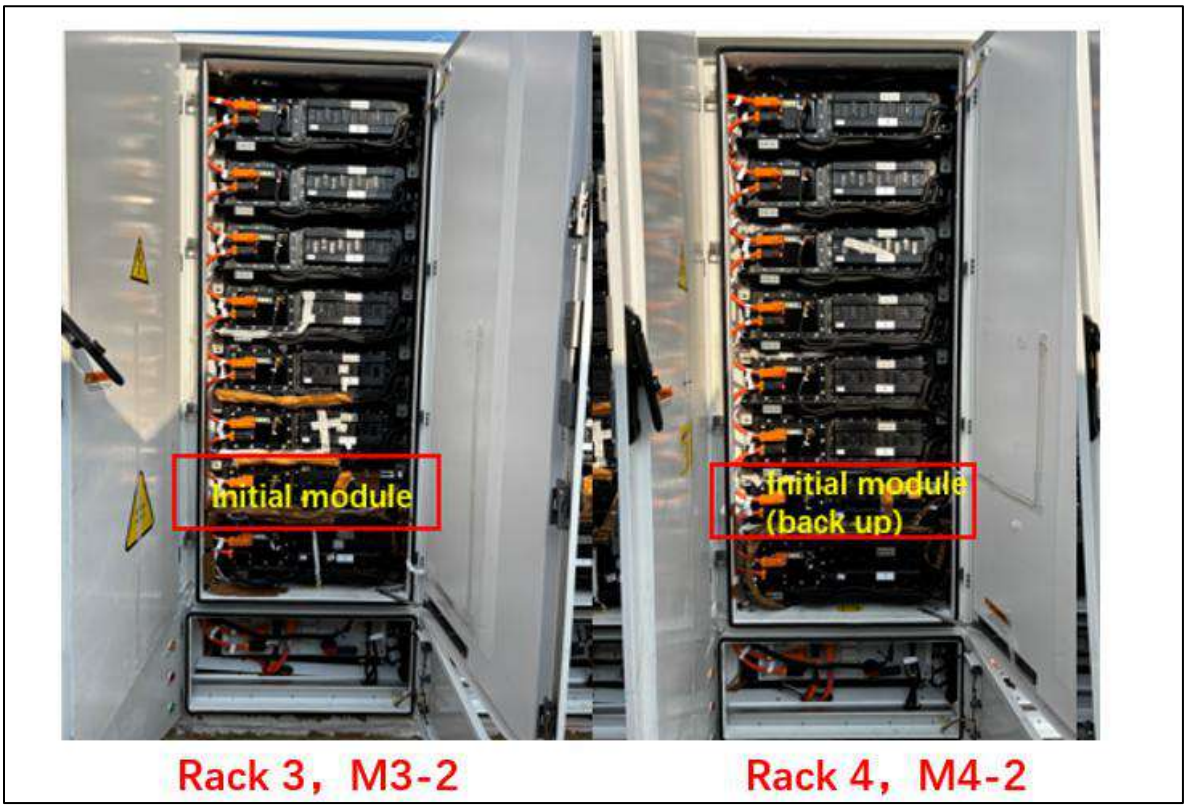

Figure 15 – Picture of the initiating module in the container of origin

The flexible film heaters were applied to large faces between two cells; the flexible film heaters size was 152.4mm*203.2mm. Four flexible film heaters used to heat eight cells simultaneously. As illustrated in Figure 16.

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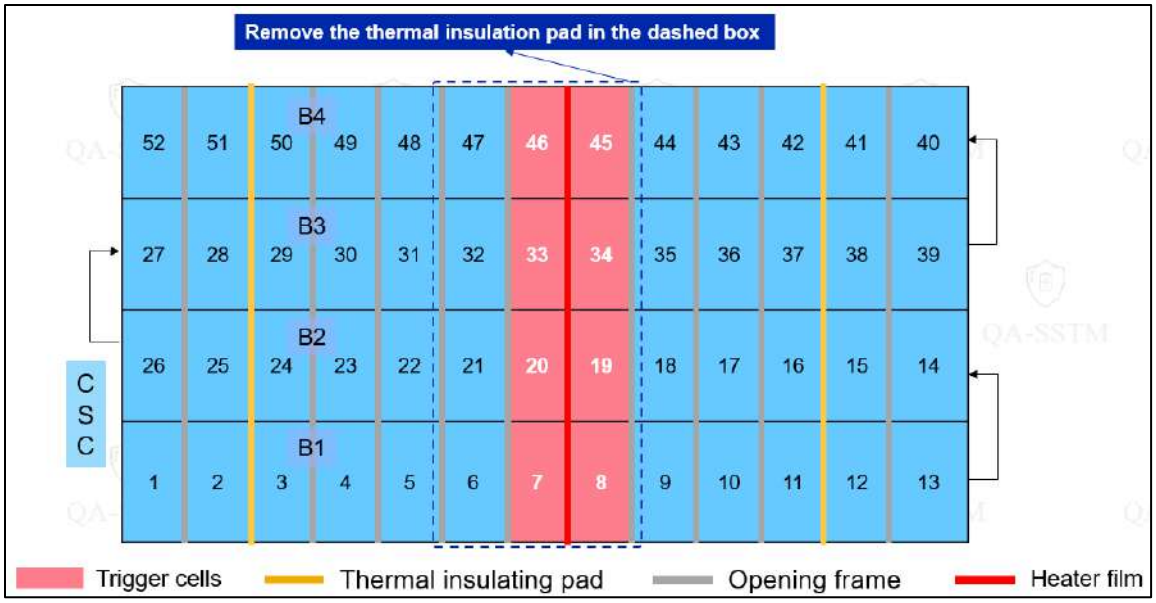

Figure 16 – Positions of initiating cells and heaters

The initiating cell central surface was instrumented with one Type K thermocouple, can be used as control feedback for the heating rate, as illustrated in Figure 17.



Cell thermocouples arrangement and Initiating cell heating film arrangement

Figure 17 – Thermocouples placement on the initiating cells

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Temperature Measurement Points for initiating Battery Module, as illustrated in Figure 18. T1, T8, T15, T22, these four temperature points were used to control the heating rate of the cells.

Voltage Measurement Points for initiating Battery Module M3-2, as illustrated in Figure 18. Voltage V1 for Cell #1, V2 for Cell #7, V3 for Cell #13, V4 for Cell #20, Voltage V5 for Cell #26, V6 for Cell #14, V7 for Cell #15, V8 for Cell #27, V9 for Cell #39, V10 for Cell #46, V11 for Cell #52, V12 for Cell #40.

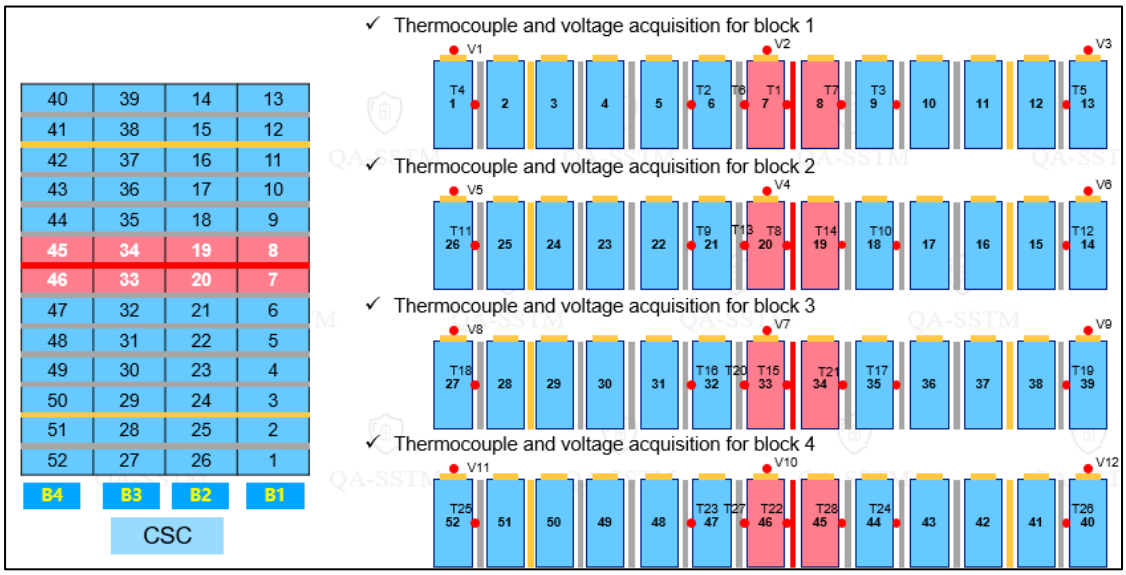
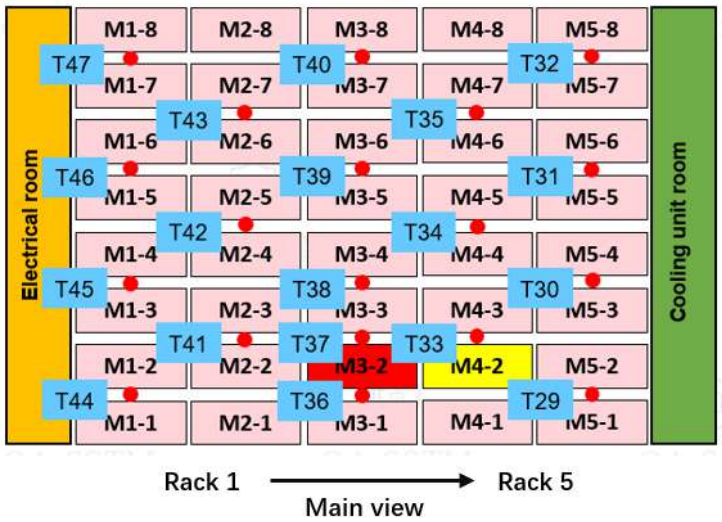


Figure 18 – Thermocouples and voltage points placement on the initiating Battery Module (M3-2)

The locations of thermocouples on the surface of the module enclosure in container A as illustrated in Figure 19.



TC number	Location description	TC number	Location description
T29	M5-1	T39	M3-5
T30	M5-3	T40	M3-7
T31	M5-5	T41	M2-2
T32	M5-7	T42	M2-4
T33	M4-2	T43	M2-6
T34	M4-4	T44	M1-1
T35	M4-6	T45	M1-3
T36	M3-1	T46	M1-5
T37	M3-2	T47	M1-7
T38	M3-3		

Note: The thermocouples inside the module were in the same position, thermocouples are arranged at the center of the cover surface of the module.

Figure 19 –Thermocouples placement on the outer Enclosure of Module

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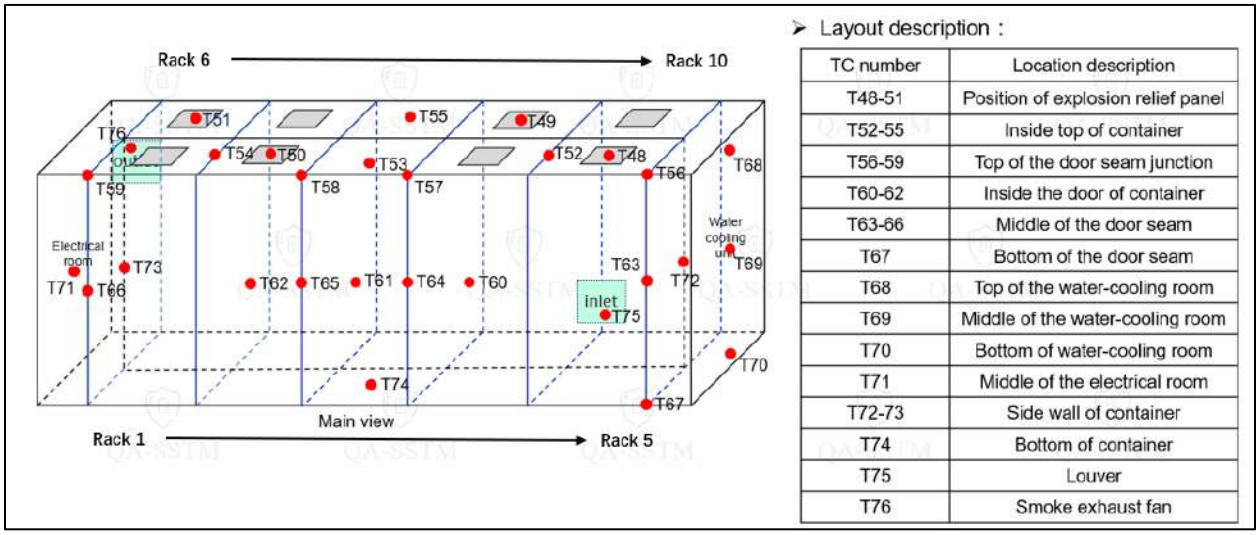
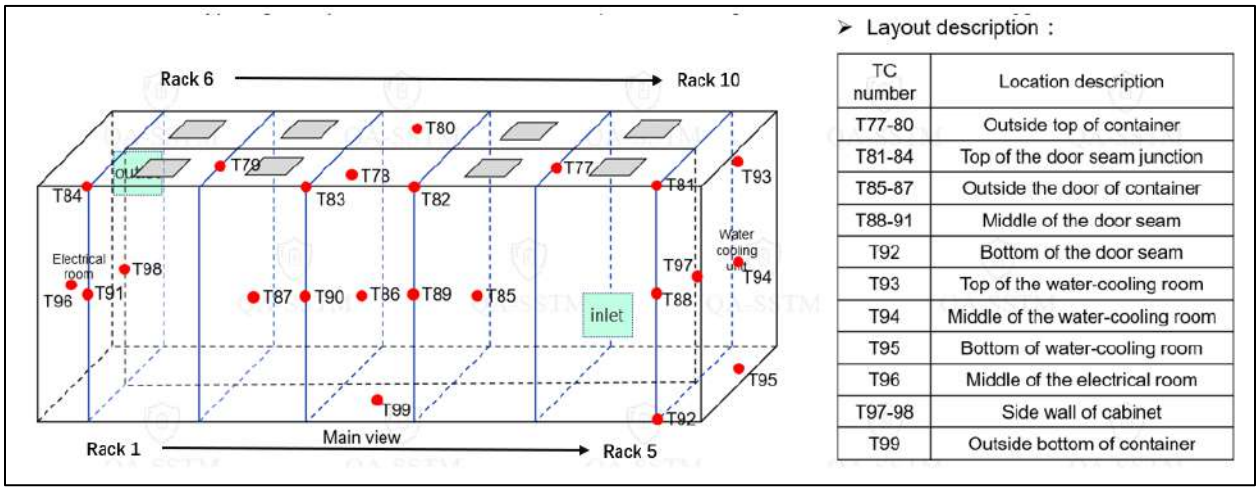
The container of origin was instrumented with thermocouples on the interior and exterior surfaces to monitor. As depicted in Figure 20.



➢ Layout description :

TC number	Location description
T48-51	Position of explosion relief panel
T52-55	Inside top of container
T56-59	Top of the door seam junction
T60-62	Inside the door of container
T63-66	Middle of the door seam
T67	Bottom of the door seam
T68	Top of the water-cooling room
T69	Middle of the water-cooling room
T70	Bottom of water-cooling room
T71	Middle of the electrical room
T72-73	Side wall of container
T74	Bottom of container
T75	Louver
T76	Smoke exhaust fan

Figure 20-1 – Thermocouples placement on the inner surfaces of the container of origin container



➢ Layout description :

TC number	Location description
T77-80	Outside top of container
T81-84	Top of the door seam junction
T85-87	Outside the door of container
T88-91	Middle of the door seam
T92	Bottom of the door seam
T93	Top of the water-cooling room
T94	Middle of the water-cooling room
T95	Bottom of water-cooling room
T96	Middle of the electrical room
T97-98	Side wall of cabinet
T99	Outside bottom of container

Figure 20-2 – Thermocouples placement on the outer wall and steel structure of the enclosure of origin container

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2.5 Target containers Installation

Container B and container C were positioned around container A of origin at distances specified by CATL based on the minimum separation distances allowed within the installation instructions. Throughout the test, both temperature/heat flux data and visual observations were continuously monitored to assess thermal exposure and to detect any potential thermal runaway events.

2.5.1 Overall Installation

Target B and Target C Containers were each partially populated with modules positioned closest to the container of origin. This configuration was intended to monitor temperature increases due to heat transfer from the container of origin and to evaluate the potential for venting or thermal runaway events in the target containers. as depicted in Figure 21, all installed modules are real ones.

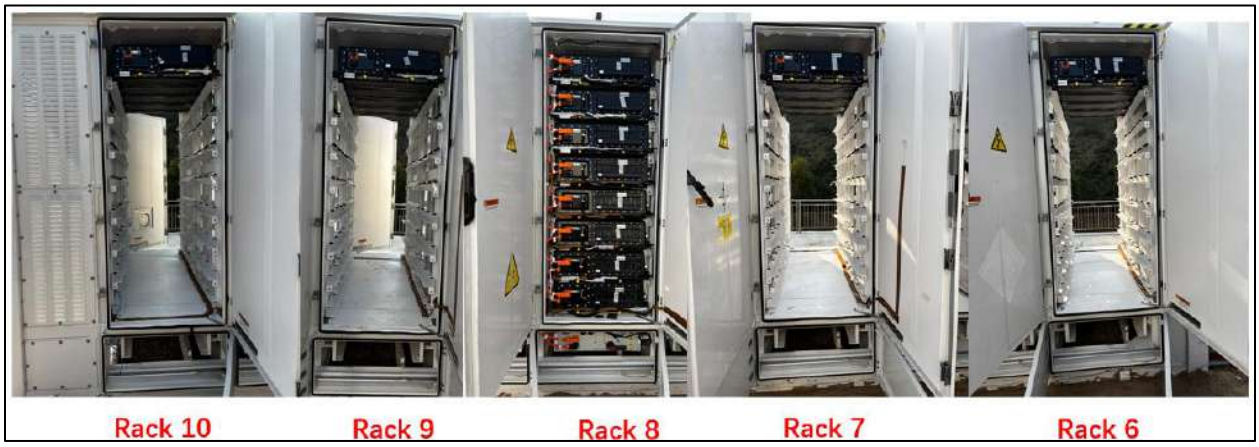

Figure 21-1 – The configuration of modules within the target container B

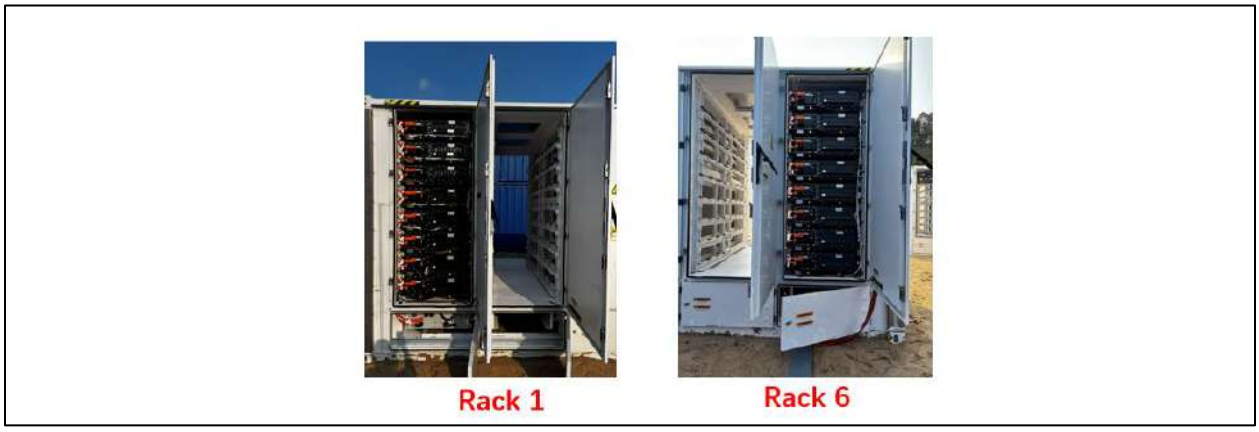

Figure 21-2 – The configuration of modules within the target container C

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2.5.2 Ventilation Systems

Target B and Target C Containers, all ten doors remain closed. The louver remains closed, and the ventilation system is not operational. Electrical room door and Liquid -cooling room door are closed. All 8 deflagration panels at the top of the container are closed.

2.5.3 Passive Thermal Runaway Mitigation Technologies

The battery modules were equipped with thermal isolation material that were designed to slow down the cell-to-cell propagation of the thermal runaway, that were installed between large surfaces of two cells.

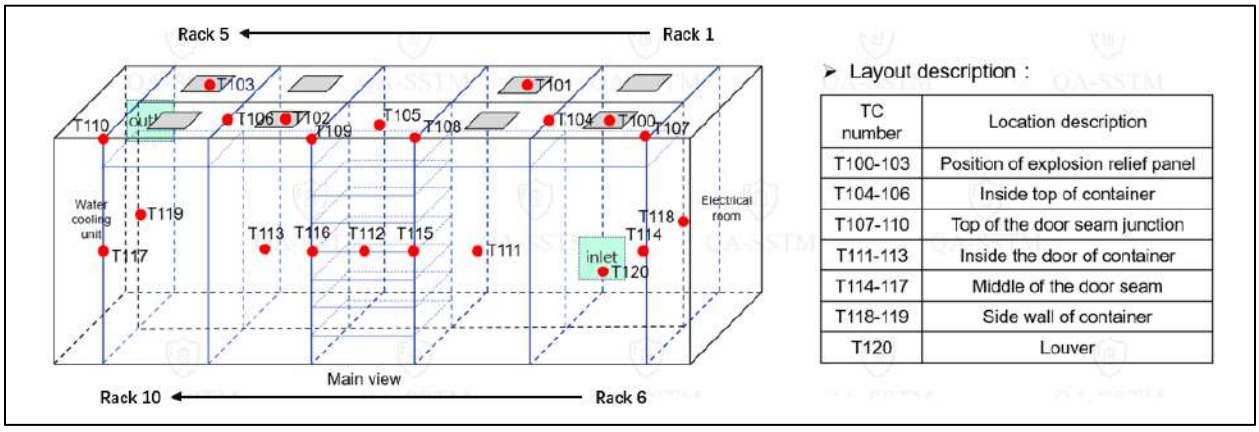
2.5.4 Active Mitigation Systems

The active fire suppression systems in target containers B and C have been deactivated.

2.5.5 Instrumentation

2.5.5.1 Target Container B

Target Container B instrumented with Type K thermocouples mainly located on internal and external surface of container enclosure, battery module enclosure surface and internal cell surface face of initiating container A, as shown in Figure 22.



TC number	Location description
T100-103	Position of explosion relief panel
T104-106	Inside top of container
T107-110	Top of the door seam junction
T111-113	Inside the door of container
T114-117	Middle of the door seam
T118-119	Side wall of container
T120	Louver

Figure 22-1 – Thermocouples placement on the inner surfaces of the target container B

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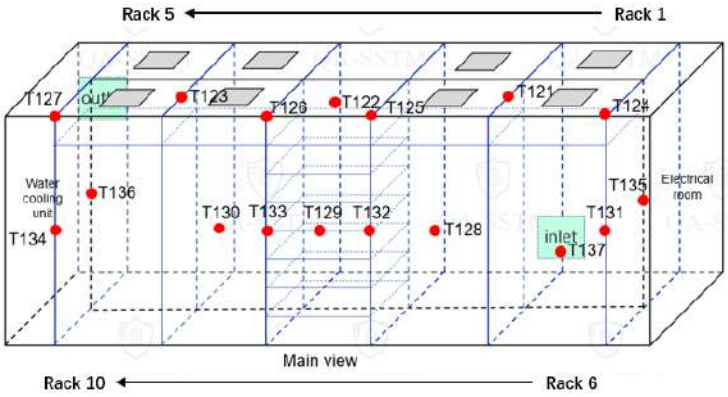
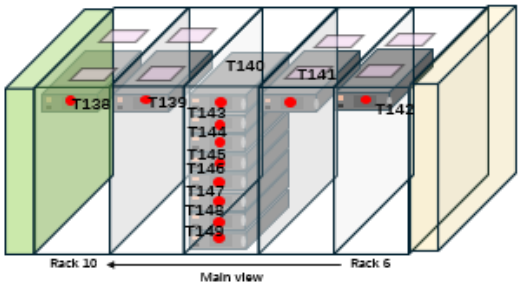
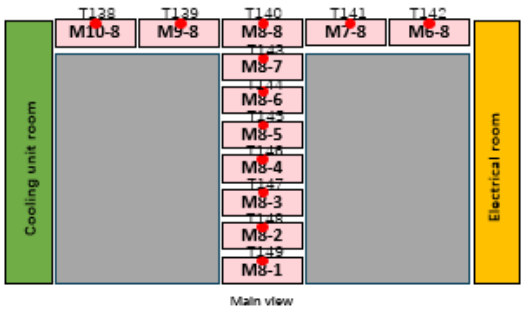


➢ Layout description :

TC number	Location description
T121-123	Outside top of container
T124-127	Top of the door seam junction
T128-130	Outside the door of container
T131-134	Middle of the door seam
T135-136	Side wall of container
T137	Louver

Figure 22-2 – Thermocouples placement on the outer surfaces of the target container B





➢ Layout description (CSC panel surface of module):

TC number	Location description
T138	M10-8
T139	M9-8
T140	M8-8
T141	M7-8
T142	M6-8
T143	M8-7
T144	M8-6
T145	M8-5
T146	M8-4
T147	M8-3
T148	M8-2
T148	M8-1

Note 1: In the container B model shown above, the filling modules are real modules, leave blank where not filled in and the TCs positions indicated in the above illustrations are all located on the CSC panel of the module's outer surface.

Figure 22-3 – Thermocouples instrumented on the container B battery module enclosure surface

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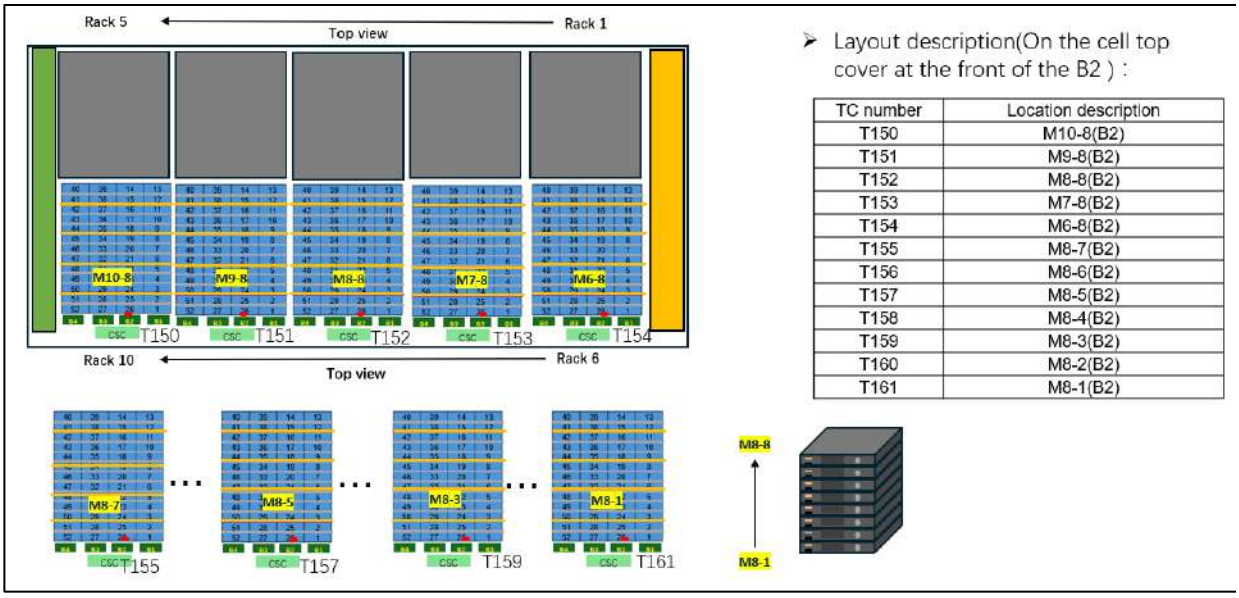

➢ Layout description(On the cell top cover at the front of the B2) :

TC number	Location description
T150	M10-8(B2)
T151	M9-8(B2)
T152	M8-8(B2)
T153	M7-8(B2)
T154	M6-8(B2)
T155	M8-7(B2)
T156	M8-6(B2)
T157	M8-5(B2)
T158	M8-4(B2)
T159	M8-3(B2)
T160	M8-2(B2)
T161	M8-1(B2)

Figure 22-4 – Thermocouples instrumented on the cell surface of container B battery module

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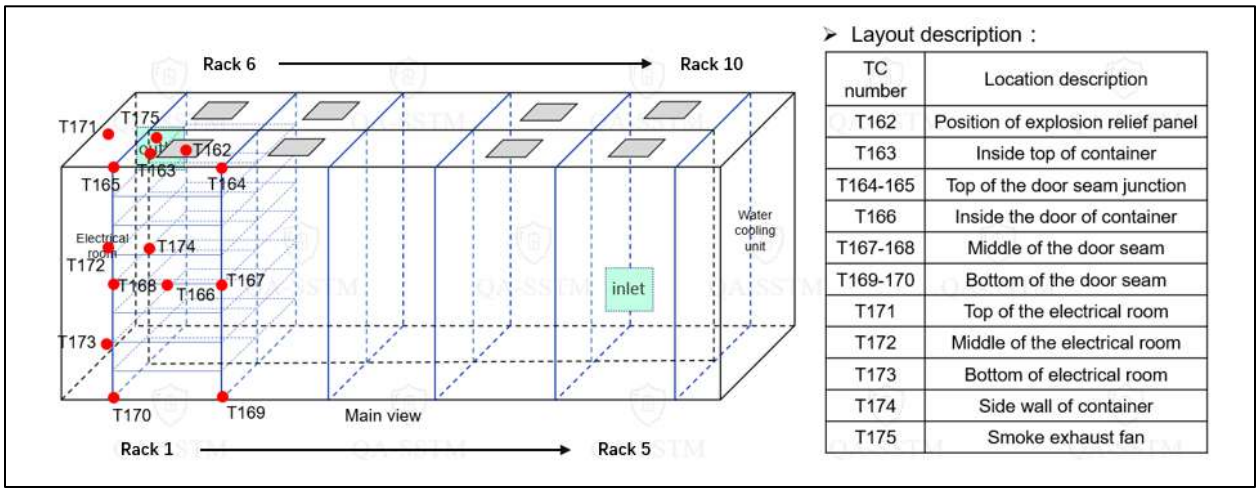
2.5.5.2 Target Container C

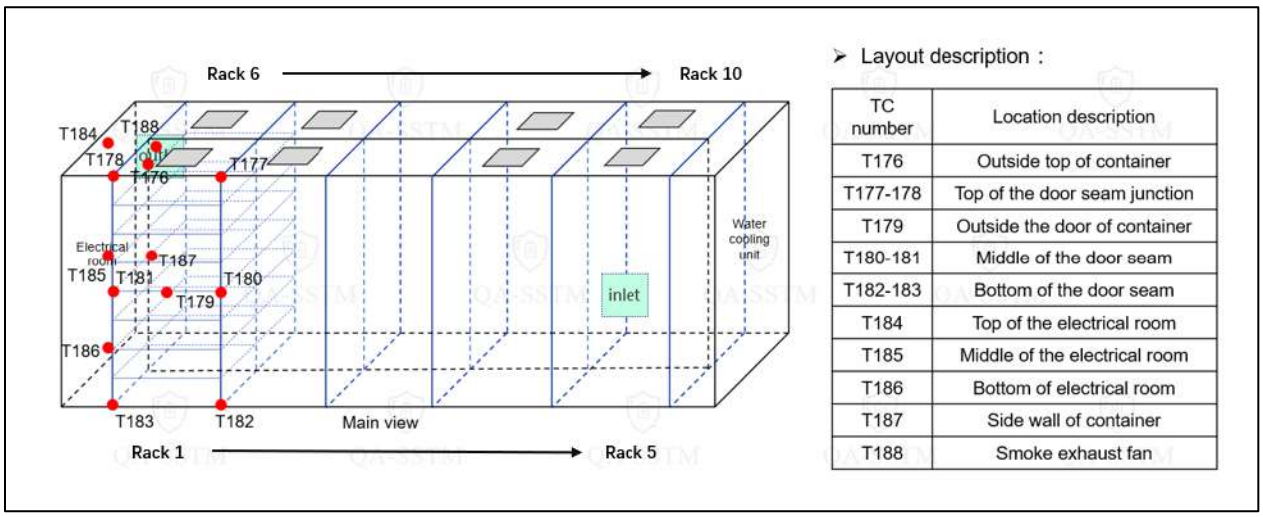
Target Container C instrumented with Type K thermocouples mainly located on external surface of container enclosure, battery module enclosure surface and internal cell surface near direction of initiating container A, as shown in Figure 23.



➢ Layout description :

TC number	Location description
T162	Position of explosion relief panel
T163	Inside top of container
T164-165	Top of the door seam junction
T166	Inside the door of container
T167-168	Middle of the door seam
T169-170	Bottom of the door seam
T171	Top of the electrical room
T172	Middle of the electrical room
T173	Bottom of electrical room
T174	Side wall of container
T175	Smoke exhaust fan

Figure 23-1 – Thermocouples placement on the inner surfaces of the target container C



➢ Layout description :

TC number	Location description
T176	Outside top of container
T177-178	Top of the door seam junction
T179	Outside the door of container
T180-181	Middle of the door seam
T182-183	Bottom of the door seam
T184	Top of the electrical room
T185	Middle of the electrical room
T186	Bottom of electrical room
T187	Side wall of container
T188	Smoke exhaust fan

Figure 23-2 – Thermocouples placement on the outer surfaces of the target container C

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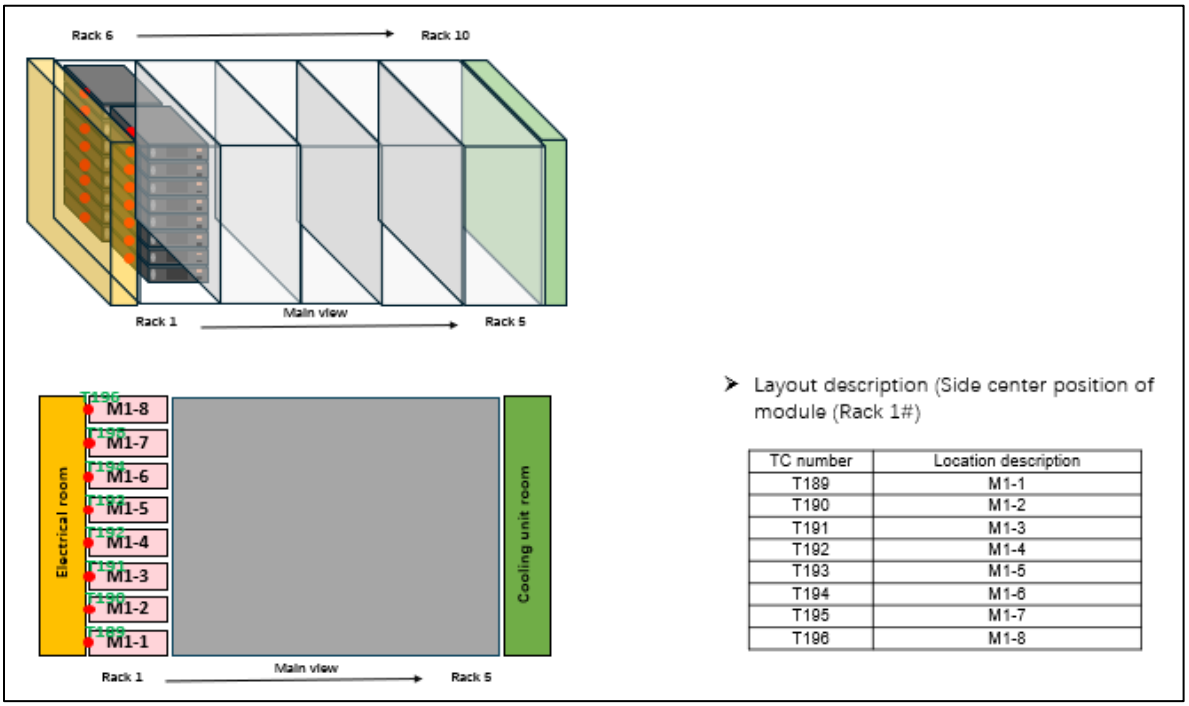
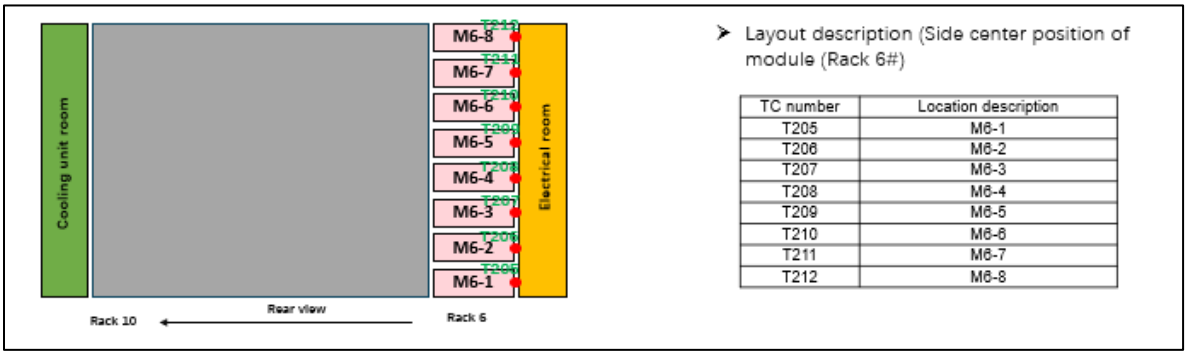


➢ Layout description (Side center position of module (Rack 1#)

TC number	Location description
T189	M1-1
T190	M1-2
T191	M1-3
T192	M1-4
T193	M1-5
T194	M1-6
T195	M1-7
T196	M1-8



➢ Layout description (Side center position of module (Rack 6#)

TC number	Location description
T205	M6-1
T206	M6-2
T207	M6-3
T208	M6-4
T209	M6-5
T210	M6-6
T211	M6-7
T212	M6-8

Note: In the container C model shown above, the filling modules are real modules, leave blank where not filled in and the TCs positions indicated in the above illustrations are all located on the side center of the module's outer surface.

Figure 23-3 – Thermocouples instrumented on the container C battery module enclosure surface

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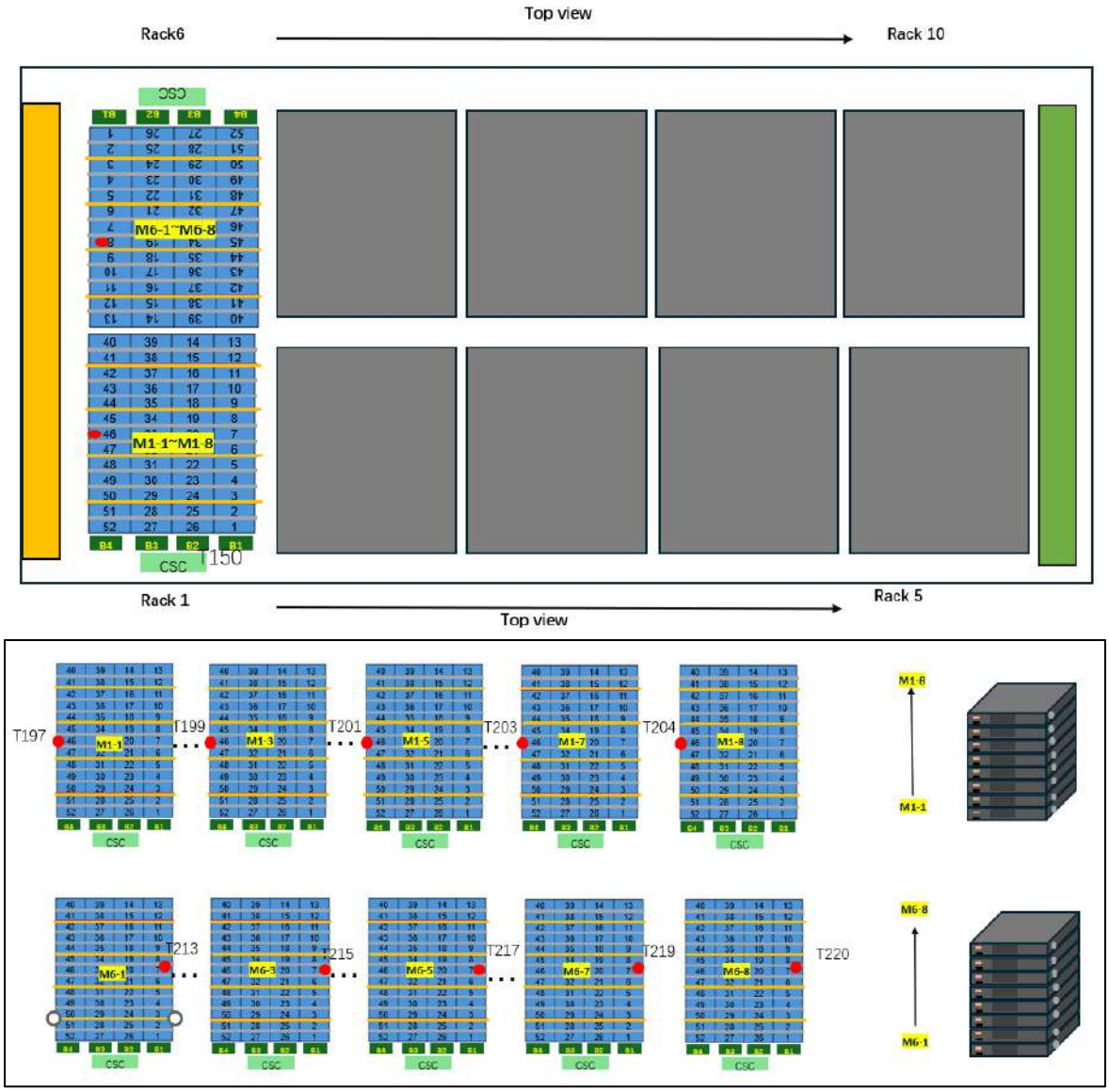

➢ Layout description (On the cell top cover at the middle of the B4,Rack 1#) :

TC number	Location description
T197	M1-1
T198	M1-2
T199	M1-3
T200	M1-4
T201	M1-5
T202	M1-6
T203	M1-7
T204	M1-8

➢ Layout description (On the cell top cover at the middle of the B1,Rack 6#) :

TC number	Location description
T213	M6-1
T214	M6-2
T215	M6-3
T216	M6-4
T217	M6-5
T218	M6-6
T219	M6-7
T220	M6-8

Figure 23-4 – Thermocouples instrumented on the cell surface in container C

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2.6 Ignition Device

One spark plug ignition and one heating element ignition were arranged 5cm apart at the initiating module M-2-2 vent of Container A, as shown in Figure 24.

Table 9 - Igniter specification

Parameter	Electronic pulse igniter	Electric heating igniter
Size	Length 71mm X Width 35mm X Thickness 25mm	Length 80mm Diameter 10mm
Voltage	DC 12V	AC 220V
Power	12W	50W
Ignition trigger mode	Pulse ignition arc	Heating wire heating

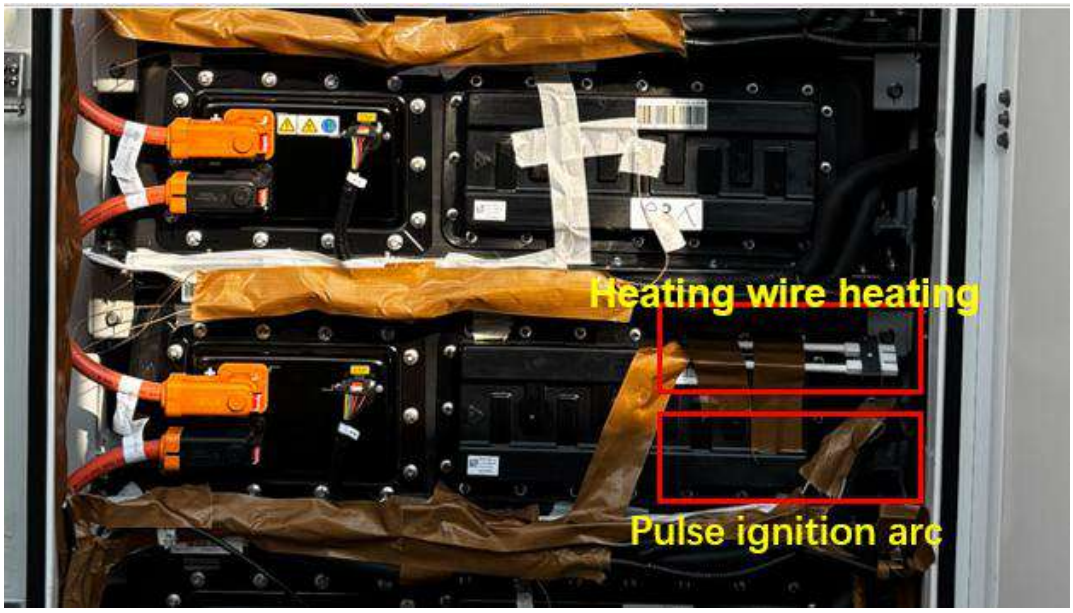

Figure 24 – Ignition Devices

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2.7 Heat Flux gauges

As requested by CATL, equipped with heat flux gauges to capture the greatest thermal exposure. as shown in Figure 25.

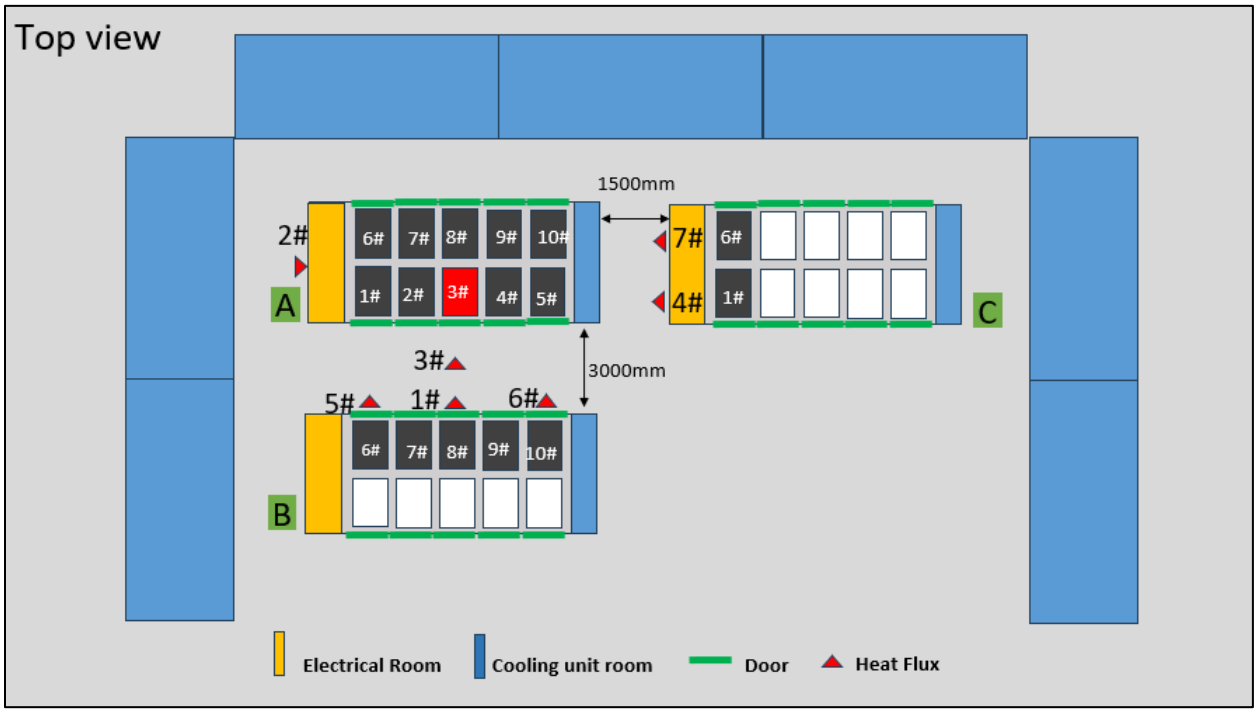

Figure 25 – View of the heat flux gauge placements

Table 10 – The heat flux gauge height

Heat Flux gauge No.	Height (mm)	Position
HF1	2896	The top middle position of the container B - Rack 8#, (Equal height with the door crack)
HF2	2362	Aim at the air outlet of the electrical room of container A.
HF3	1448	The middle position between Container A and Container B - Rack 3#, (Half height)
HF4	2896	The top middle position of the electrical room of the container C - Rack 1#.
HF5	2896	The top middle position of the Container B - Rack 6#, (Equal height with the door crack)
HF6	2896	The top middle position of the container B - Rack 10#, (Equal height with the door crack)
HF7	2896	The top middle position of the electrical room of the container C - Rack 6#

2.8 Surveillance Equipment

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The test site arranged 6 cameras, 2 thermal imaging cameras, 2 DVs, and a night vision camera was installed at the corresponding M3-2 position in container A. as shown in Figure 26.

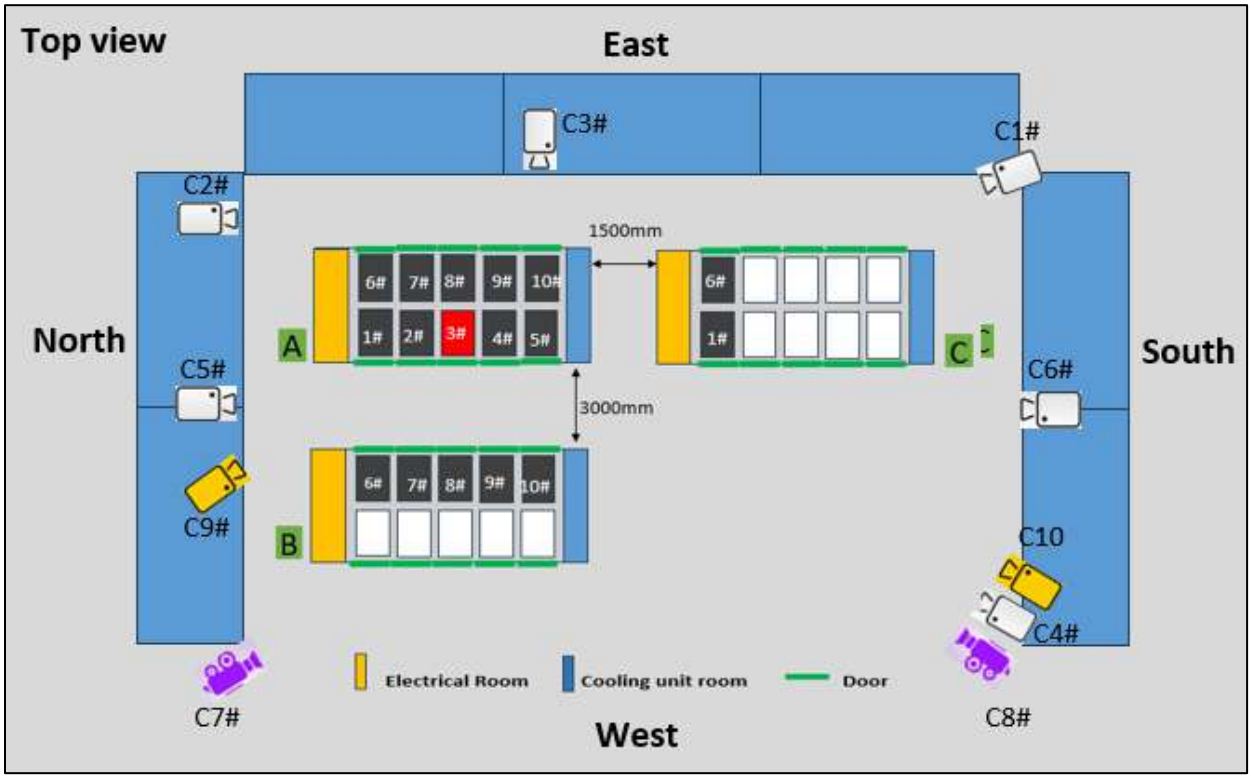

Figure 26 – Position of External Camera

Note：

：Explosion-proof camera/ordinary camera

：Thermal imaging camera

：DV camera

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3. Test results

3.1 Test Overview Timeline

The test started at 17:20:00 on November 5th, 2025, key events as shown in table 10 and Figure 27.

Table 10 - Test Overview Timeline

Time (HH:MM:SS)	Event	Description
00:00:00	Test Start	The test started and the heater was turned on to heat the initiating cells (Cell 7, Cell 8, Cell 19, Cell 20, Cell 33, Cell 34, Cell 45 and Cell 46) at a ratio of 4.5 °C/min. See Figure (a)
Around 00:57:46	First initiating cell Venting	Initiating cell (Cell 45) vented, measured through T28 by an indication of dip in cell's temperature curve. See Figure (b) Figure 27.
00:57:49	Initiating cell Thermal runaway	Initiating cell (Cell 45) thermal runaway measured through T28, the temperature of cell 45 began to increase in an uncontrollable manner. See Figure (c) and Figure 27.
00:57:51	Venting of initiating module	Initiating Module M3-2 vented and Release flammable gas from venting. See Figure (d)
00:59:09	Catch Fire	Used one spark plug and one heating element successfully ignited the combustible gas and sustained combustion. See Figure (e)
01:16:06	Flame Propagation	Flames were observed at the top vent port of Container A. See Figure (f)
01:20:12	Flame Propagation	Flames overflowed from the four central vent openings. See Figure (g)
02:35:21	Flame Propagation	Observed fragments of the cell's current collector being ejected from container A, accompanied by flames, then extinguished itself. See Figure (h), (i) and 49.
05:15:15	Flame Propagation	The flames continued to burn. See Figure (j) and (k)
09:33:29	Flame Propagation	The flames observed at the top of Container A are weakening. see figure (l) and (m)
11:24:54	Flame Propagation	The flames continue to weaken, at the same time, it was observed that the front side panels of sub control boxes at the bottom were opened in container A. See figure (n) and (o)
11:45:12	Flame Propagation	The flames were concentrated near the Liquid-cooling compartment and spread into the compartment. See figure (p) and (q)
12:57:10	Flame Propagation decrease	The fire continued to weaken, and no flames were observed around the container; only a small flame

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		was visible at the top of Container A. See figure (r) and (s)
15:27:30	Visiable Fire end	There was no visible burning flame on the enclosure outside of container A. See Figure (t)
16:40:00	No signs of reignition	Leave the containers on site for natural cooling and continue monitoring the temperature. See figure (u)

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



(b) First initiating cell Venting
Around [00:57:46]



(c) Initiating cell Thermal runaway
[00:57:49]



(d) Venting of initiating module
[00:57:51]



(e) Catch Fire
[00:59:09]



(f) Flame Propagation
[01:16:06]

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	--
(g) Flame Propagation [01:20:12]	--
	
(h) Flame Propagation increase [02:35:21]	(i) Flame Propagation increase [02:35:21]
	
(j) Flame Propagation [05:15:15]	(k) Flame Propagation [05:15:15]

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(l) Flame Propagation decrease [09:33:29]



(m) Flame Propagation decrease [09:33:29]



(n) Flame Propagation decrease [11:24:54]



(o) Flame Propagation decrease [11:24:54]



(p) Flame Propagation [11:45:12]



(q) Flame Propagation [11:45:12]

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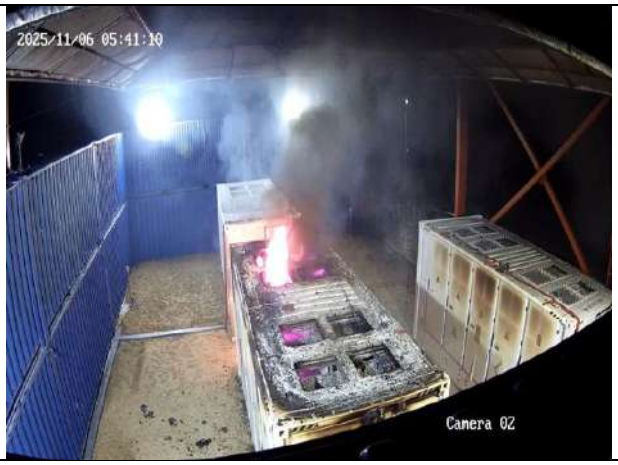

(r) Flame Propagation decrease [12:21:10]



(s) Flame Propagation decrease [12:21:10]



(t) Visible Fire end [15:27:30]



(u) No signs of reignition [16:40:00]

Figure 27 – Main event view

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3.2 Initiation and propagation of thermal runaway

The Initiating Cell 28 first occurred venting and thermal runaway, as Figure 28, the Initiating module thermal runaway as Figure 29.

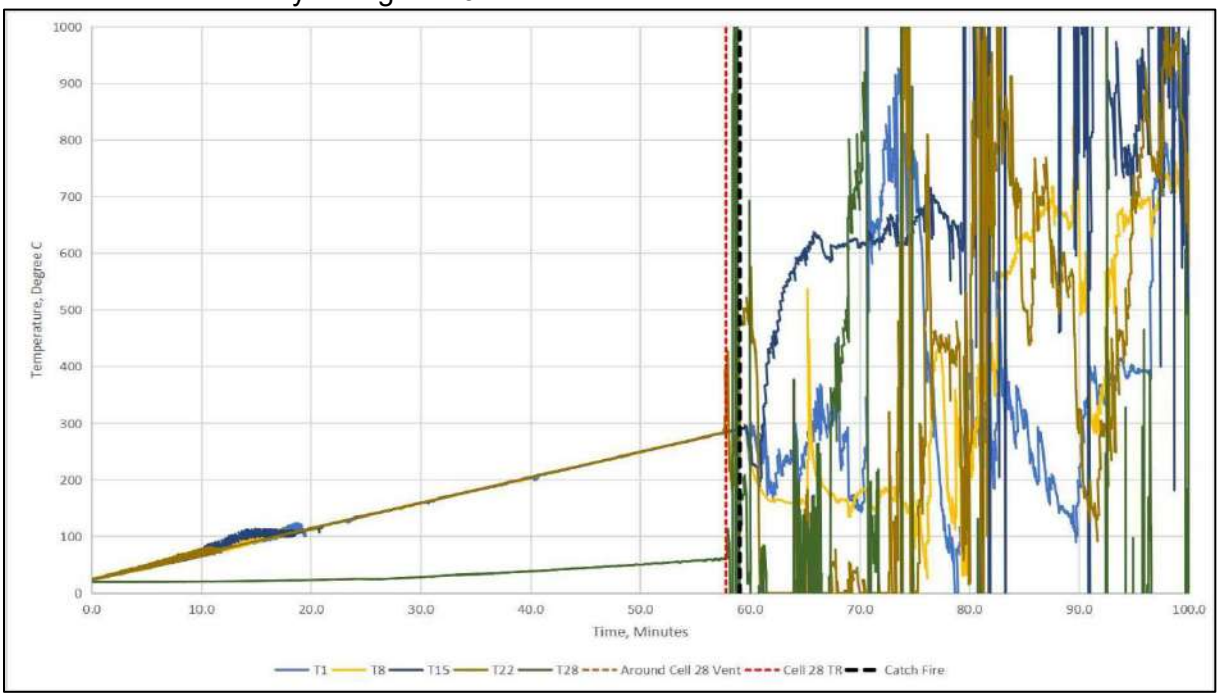

Figure 28 – Overall Initiating Cell temperature(M3-2)-Raw data curve

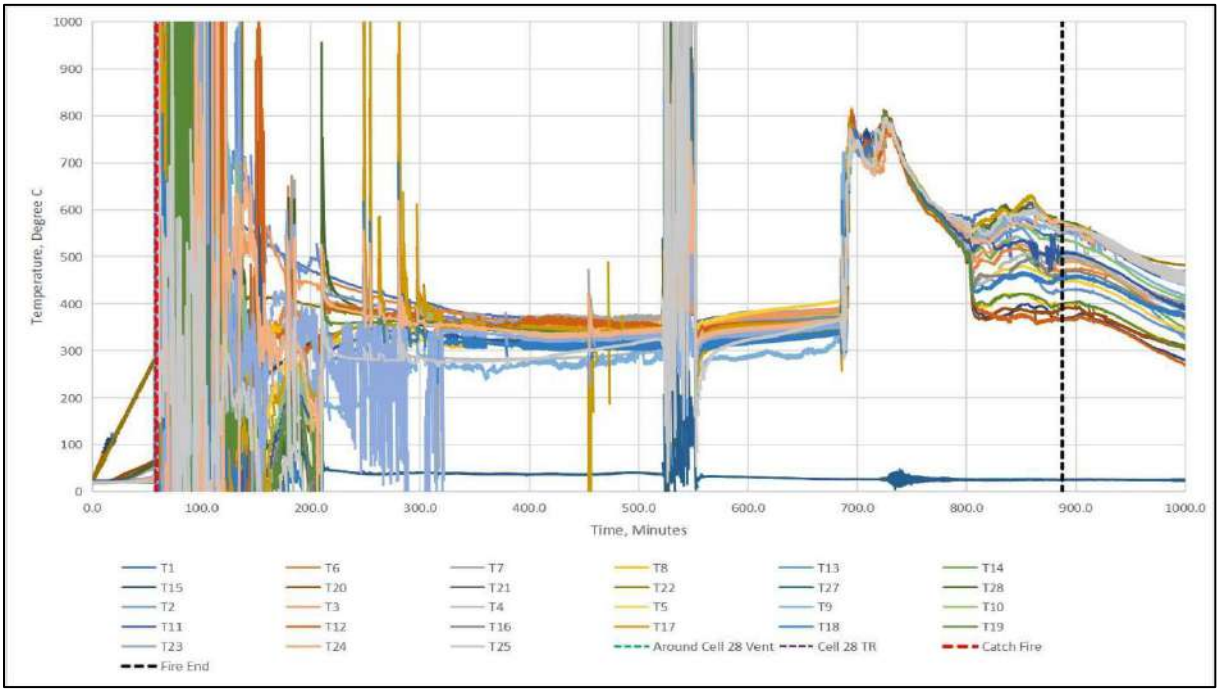

Figure 29 – Temperature of cells inside Container A initiating Module M3-2 -Raw data curve

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3.2.1 Container of Origin

Figure 30 - 32 were the temperature curves of Enclosure of origin module enclosure and Container enclosure that lasted 1000 minutes, after that no visible fire can be observed and temperatures started to decreased and trending towards ambient.

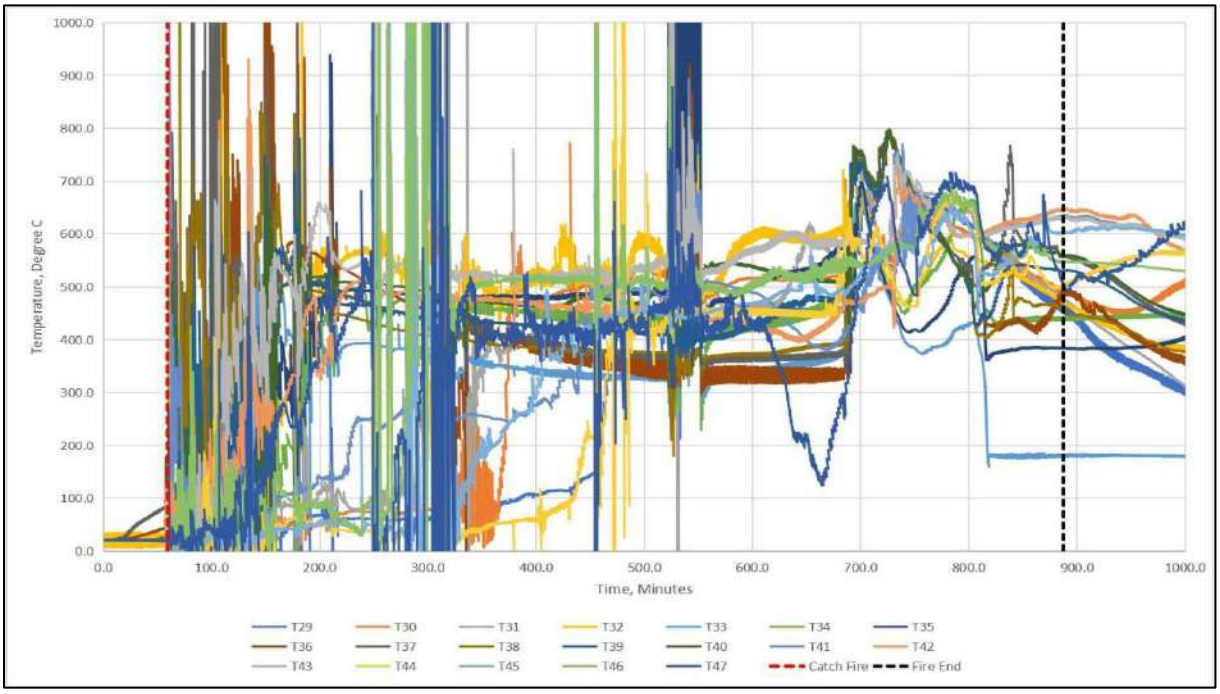

Figure 30 – Container A Module Enclosure temperature - Raw data curve

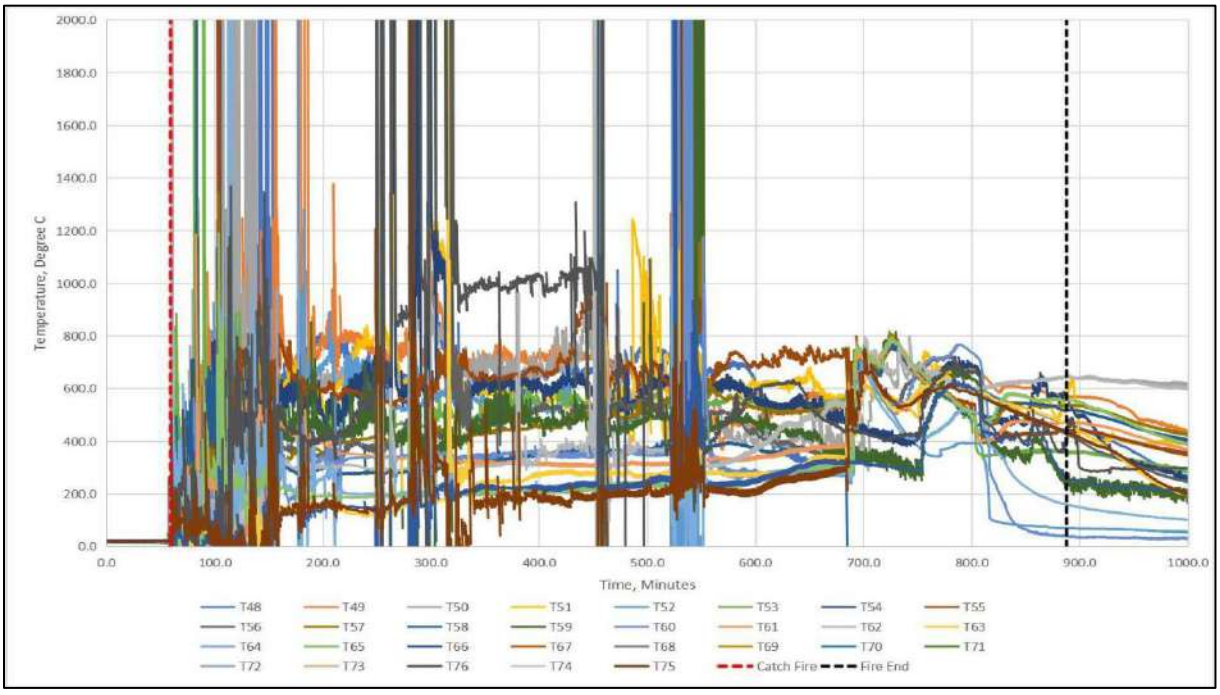

Figure 31 – Container A Enclosure temperature (inner side)- Raw data curve

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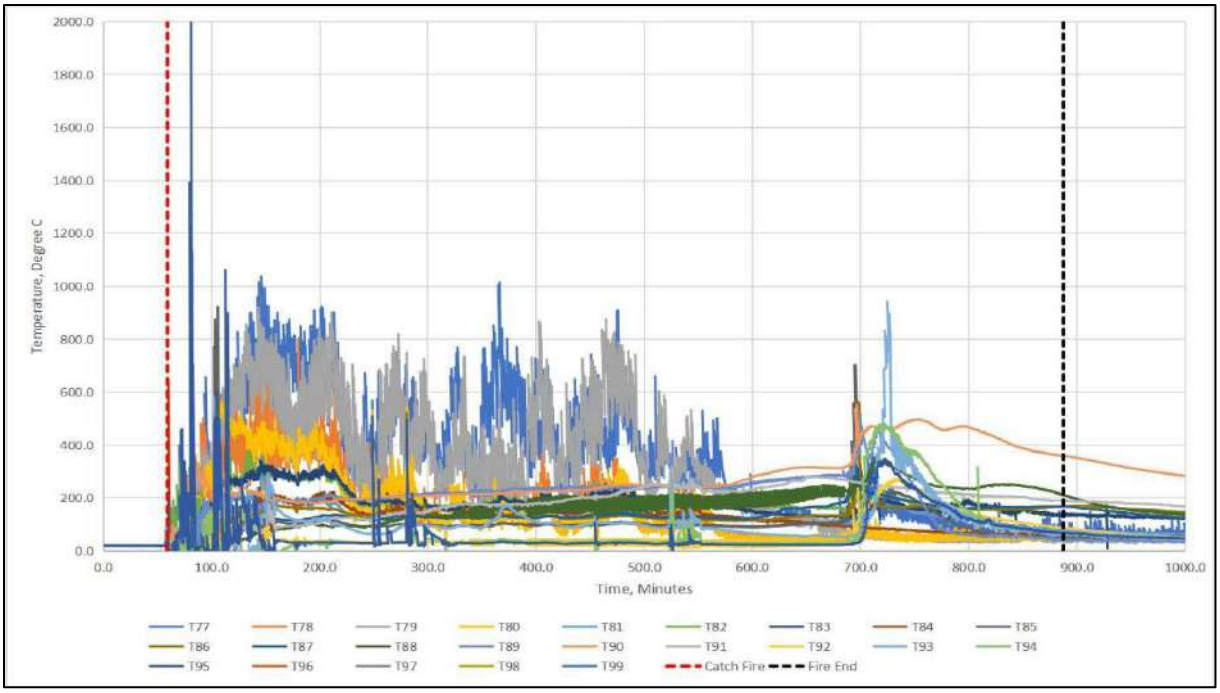

Figure 32 – Container A Enclosure temperature (outer side)- Raw data curve

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3.3 Target container temperature measurements

3.3.1 Target Container B

Note 1: During this test, temperature data for containers B and C showed abnormal spikes at certain time intervals. To investigate, we conducted a detailed review, including post-test voltage measurements and visual inspection of all modules. The maximum voltage difference between pre- and post-test values was 0.1 V. This indicated that the sudden temperature rise was not caused by cell thermal runaway. The anomalies were due to interference affecting the data acquisition equipment during the test, which resulted in erroneous readings. When selecting the maximum temperature values, we excluded the abnormal segments caused by interference. The maximum values were determined by segment-based filtering, as indicated between the two green dashed lines in the chart. See from raw data curve, all values recorded in the report are extracted from the raw data.

Note 2: To eliminate equipment interference, we attempted to regress the temperature data of Container B and Container C. The regressed temperature data and curves are provided for reference only. See figure data fitting curve*.

Maximum Temperatures on Container B enclosure surface (outer side)			
External TC No.	Maximum Temperature (°C)	Internal TC No.	Maximum Temperature (°C)
T121	109.6	T130	218.9
T122	153.3	T131	121.6
T123	110.3	T132	99.4
T124	134.9	T133	86.4
T125	135.5	T134	61.7
T126	138.4	T135	87.9
T127	69.7	T136	52.1
T128	223.6	T137	55.0
T129	225.6	-	-
Note: Temperatures were measured constantly and then averaged every 60-seconds.			

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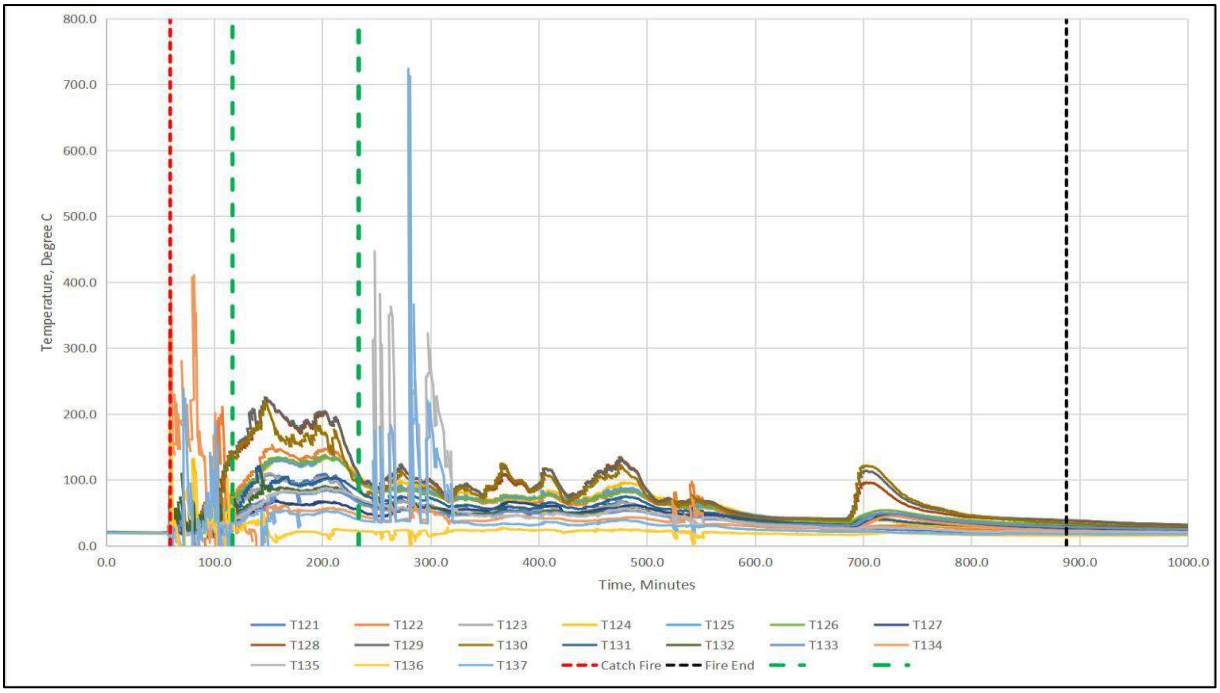

Figure 33-1 – Container B Enclosure temperature (outer side)- Raw data curve

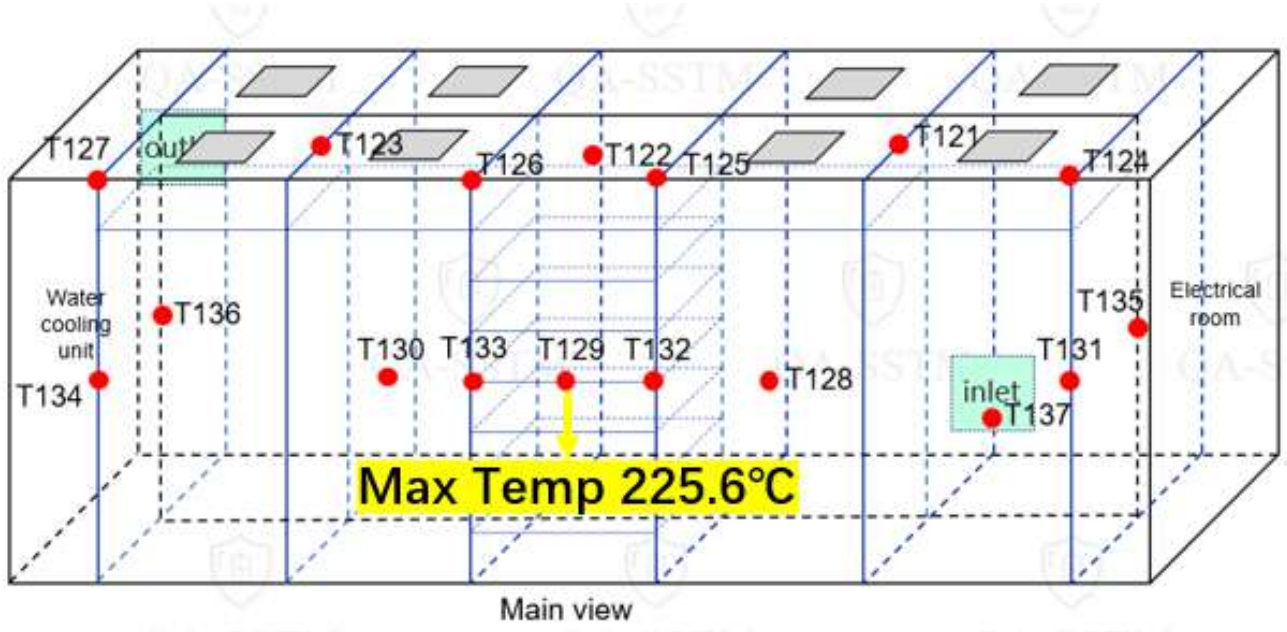

Figure 33-3 – Container B Enclosure Max temperature (outer side)- From raw data

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Maximum Temperatures on Container B enclosure surface (inner side)			
External TC No.	Maximum Temperature (°C)	Internal TC No.	Maximum Temperature (°C)
T100	76.1	T111	68.0
T101	67.8	T112	87.7
T102	80.4	T113	92.9
T103	81.7	T114	59.9
T104	83.3	T115	56.5
T105	73.4	T116	74.4
T106	73.9	T117	45.1
T107	106.7	T118	44.0
T108	104.7	119	37.7
T109	104.7	120	47
T110	68.5	-	-
Note: Temperatures were measured constantly and then averaged every 60-seconds			

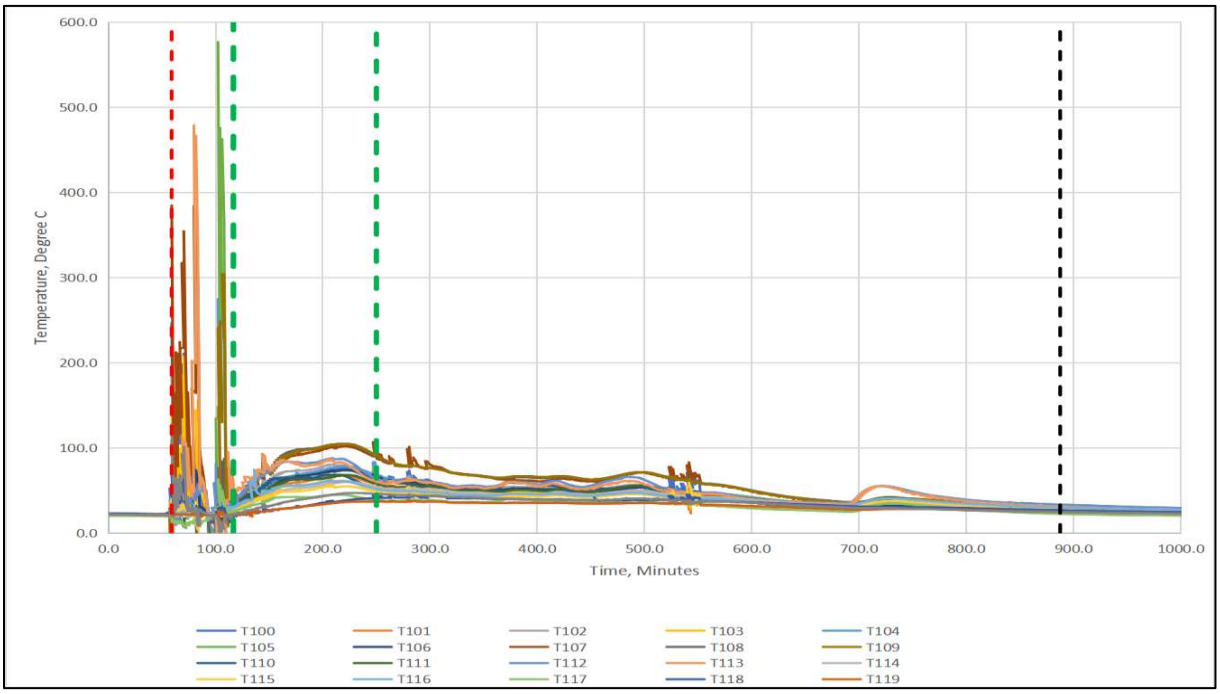

Figure 34-1 – Container B Enclosure temperature (inner side) - Raw data curve

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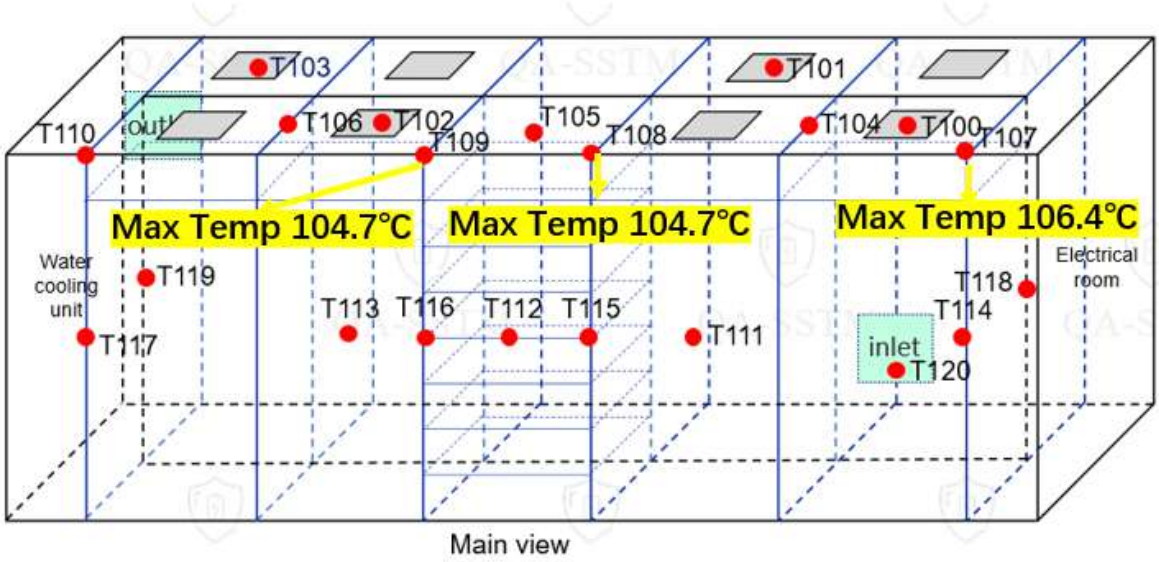

Figure 34-3 – Container B Enclosure Max temperature (inner side) - From raw data

Maximum Temperatures on Container B internal module enclosure surface			
TC No.	Maximum Temperature (°C)	TC No.	Maximum Temperature (°C)
T138	85.0	T144	60.2
T139	73.6	T145	59.4
T140	79.9	T146	67.6
T141	75.4	T147	52.7
T142	81.8	T148	47.5
T143	66.0	T149	56.0
Note: Temperatures were measured constantly and then averaged every 60-seconds.			

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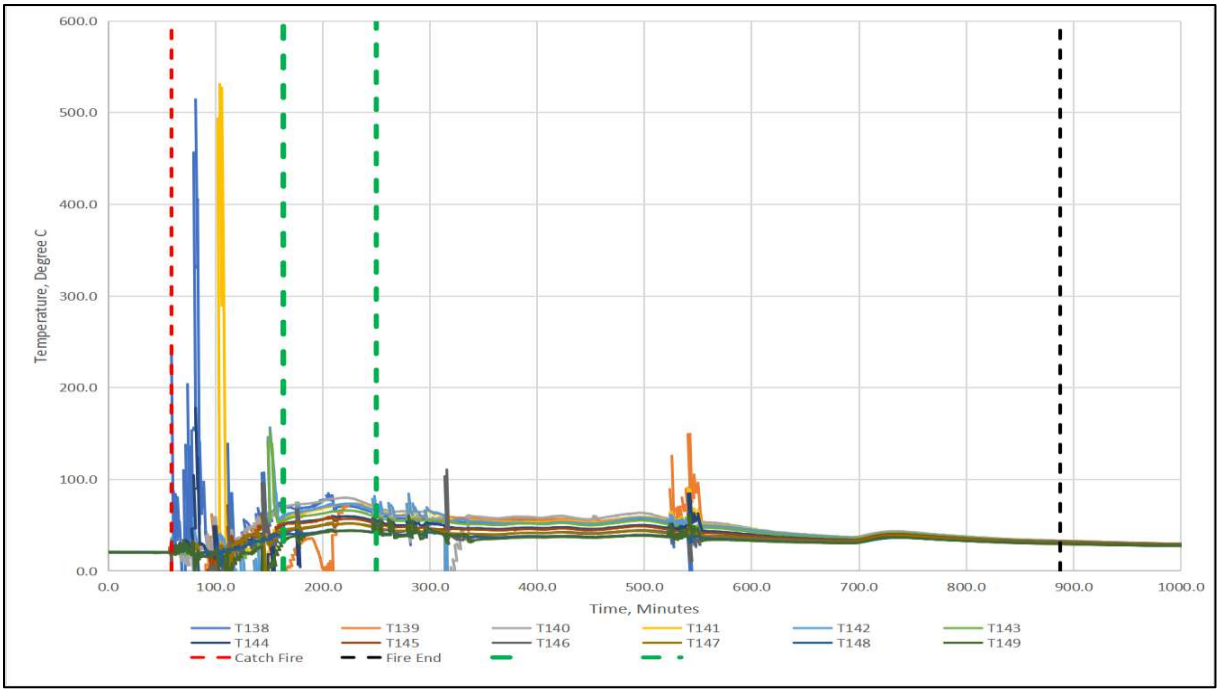

Figure 35-1 – Container B Module Enclosure temperature- Raw data curve

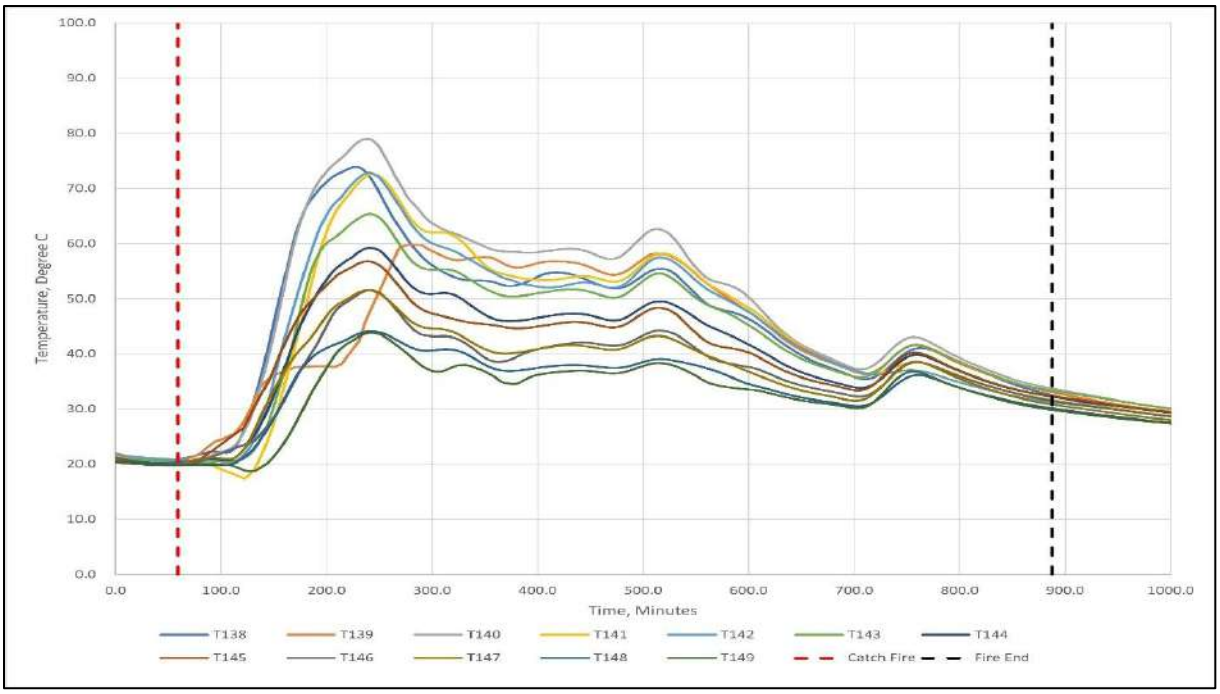

*Figure 35-2 – Container B Module Enclosure temperature - Data fitting curve**

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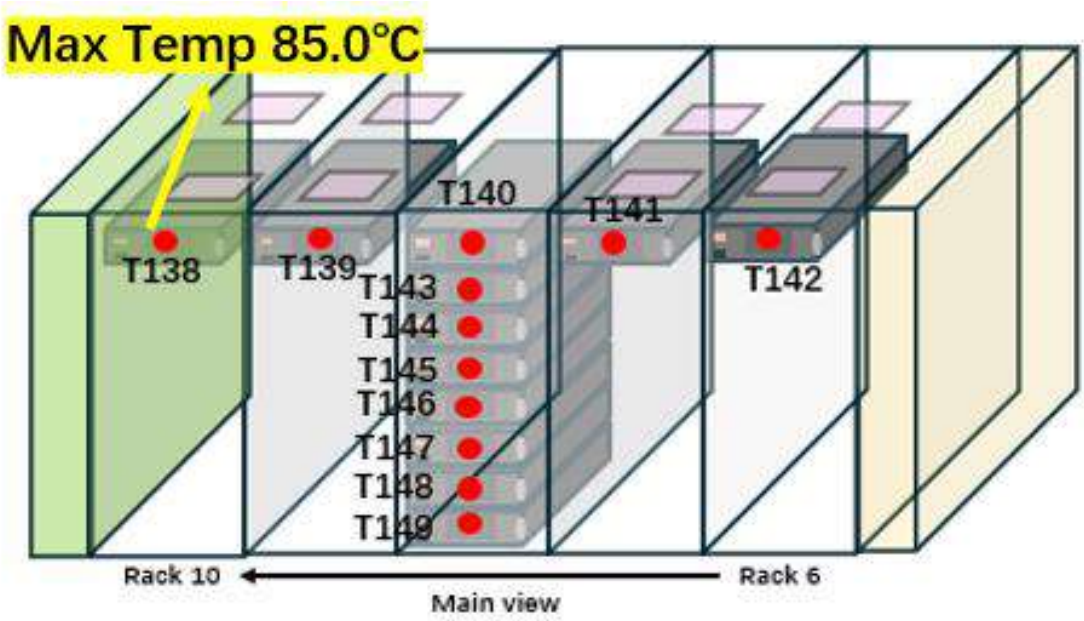

Figure 35 -3 – Container B Module Enclosure Max temperature- From raw data

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Maximum Temperatures on Container B internal cell surface			
TC No.	Maximum Temperature (°C)	TC No.	Maximum Temperature (°C)
T150	39.7	T156	30.7
T151	43.9	T157	28.3
T152	41.8	T158	26.7
T153	41.7	T159	27.1
T154	40.1	T160	26.4
T155	32.1	T161	27.2
Note: Temperatures were measured constantly and then averaged every 60-seconds.			

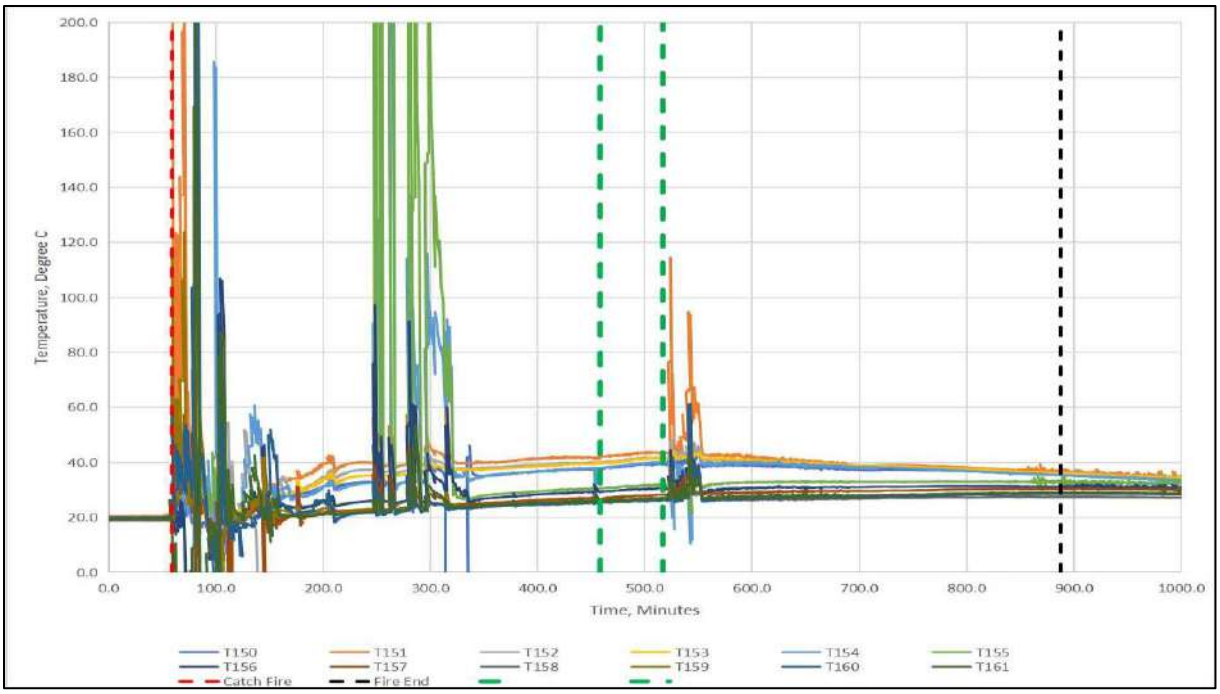

Figure 36-1 – Container B Module Cell surface temperature - Raw data curve

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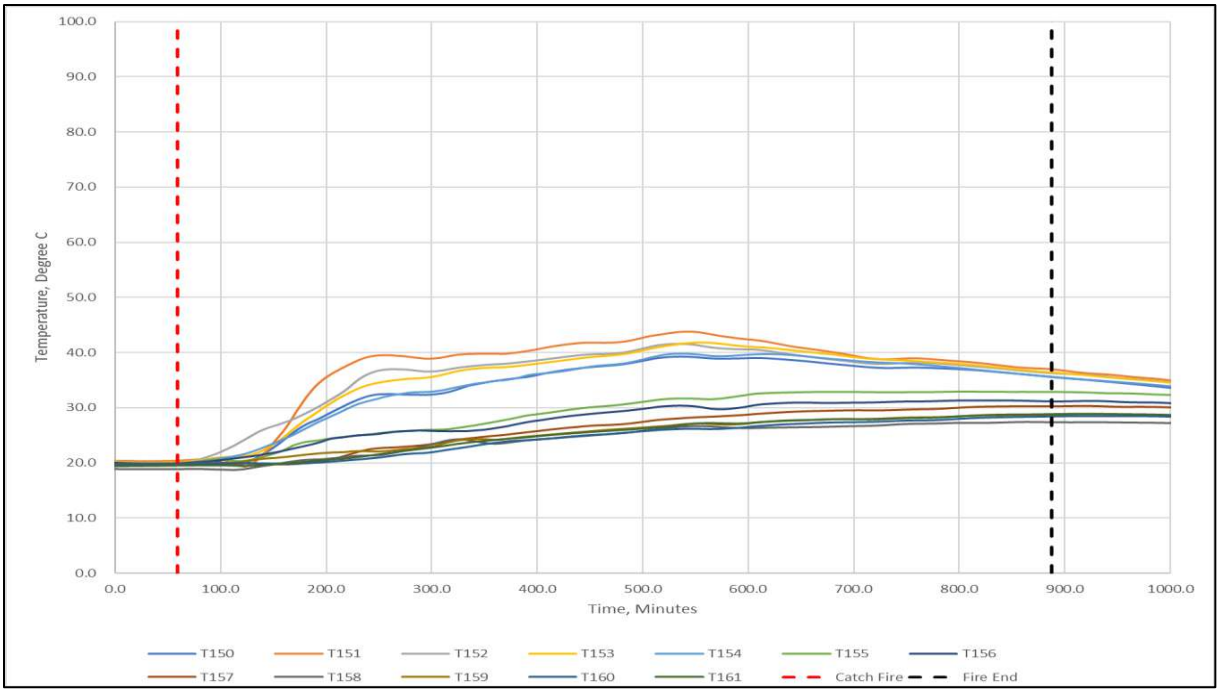

*Figure 36-2 – Container B Module Cell surface temperature - Data fitting curve**

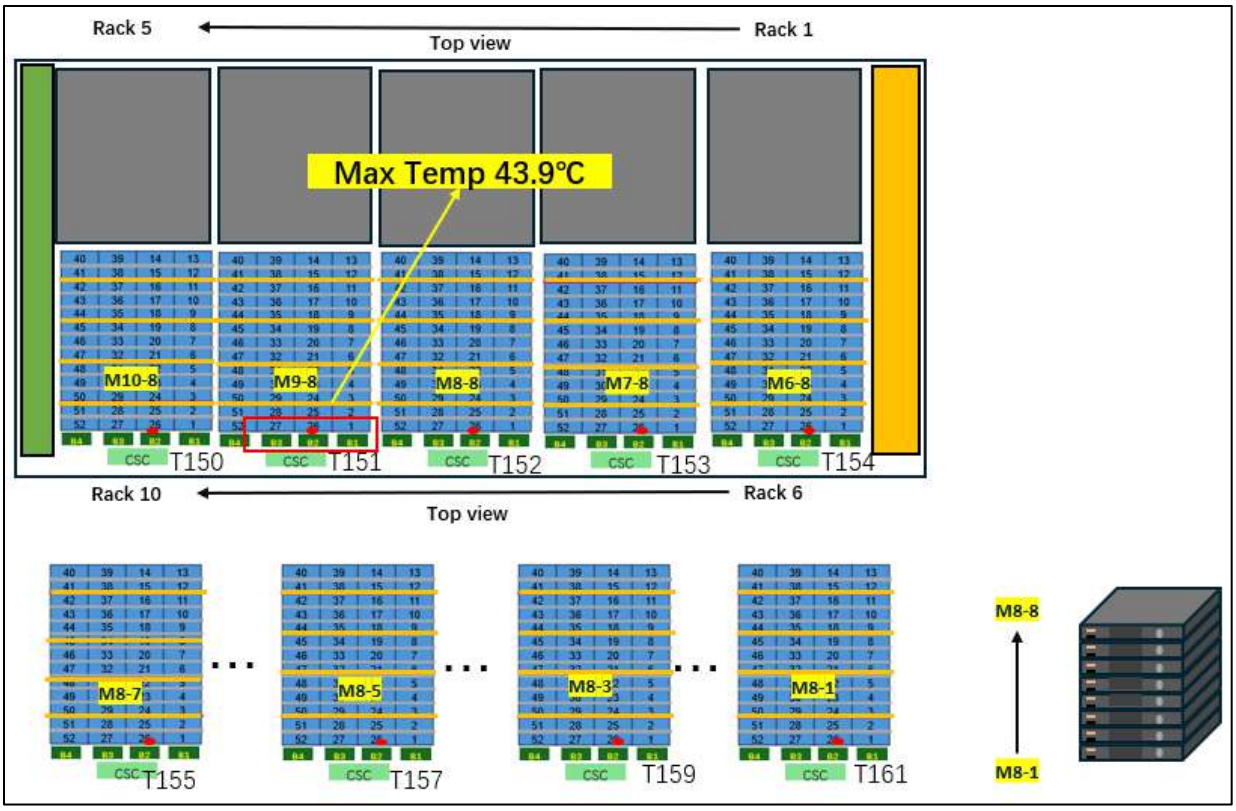

Figure 36-3 – Container B Module Cell surface Max temperature-- From raw data

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3.3.2 Target Container C

Note 1: Refer to 3.3.1.

Maximum Temperatures on Container C enclosure surface (outer side)			
External TC No.	Maximum Temperature (°C)	Internal TC No.	Maximum Temperature (°C)
T176	36.9	T183	23.2
T177	23.1	T184	255.4
T178	32.6	T185	153.3
T179	23.4	T186	138.8
T180	21.2	T187	99.8
T181	28.5	T188	93.7
T182	21.7	-	-
Note: Temperatures were measured constantly and then averaged every 60 seconds.			

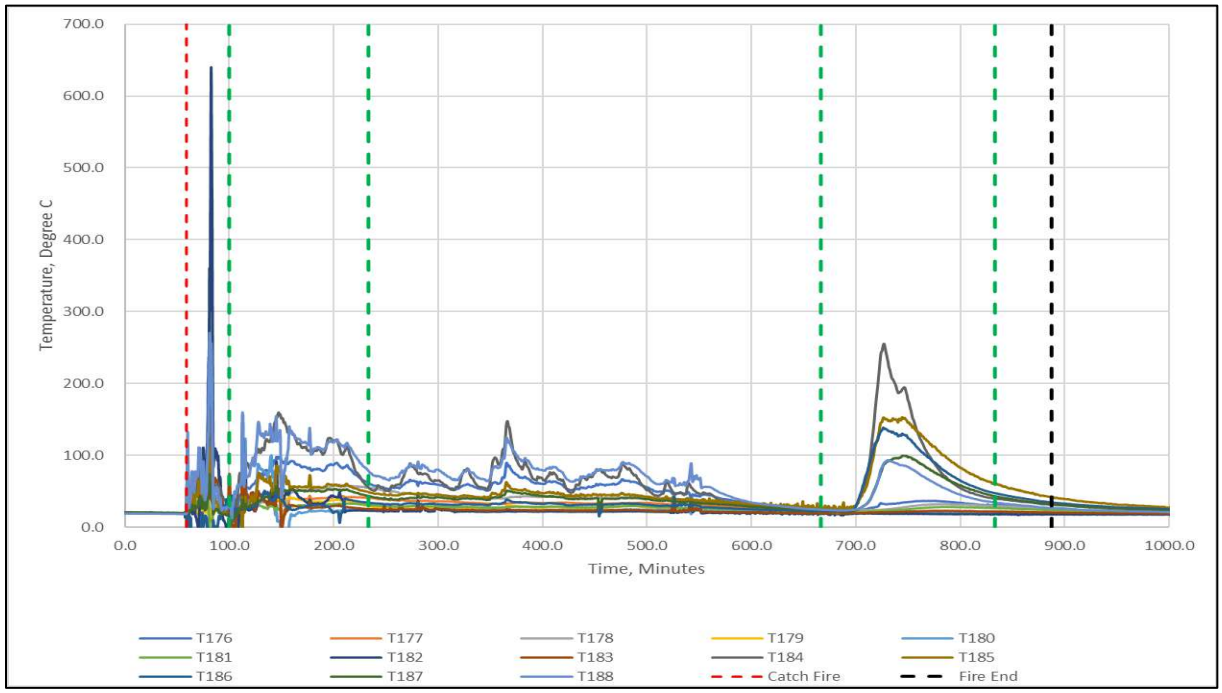

Figure 37-1– Container C Enclosure temperature (outer side) - Raw data curve

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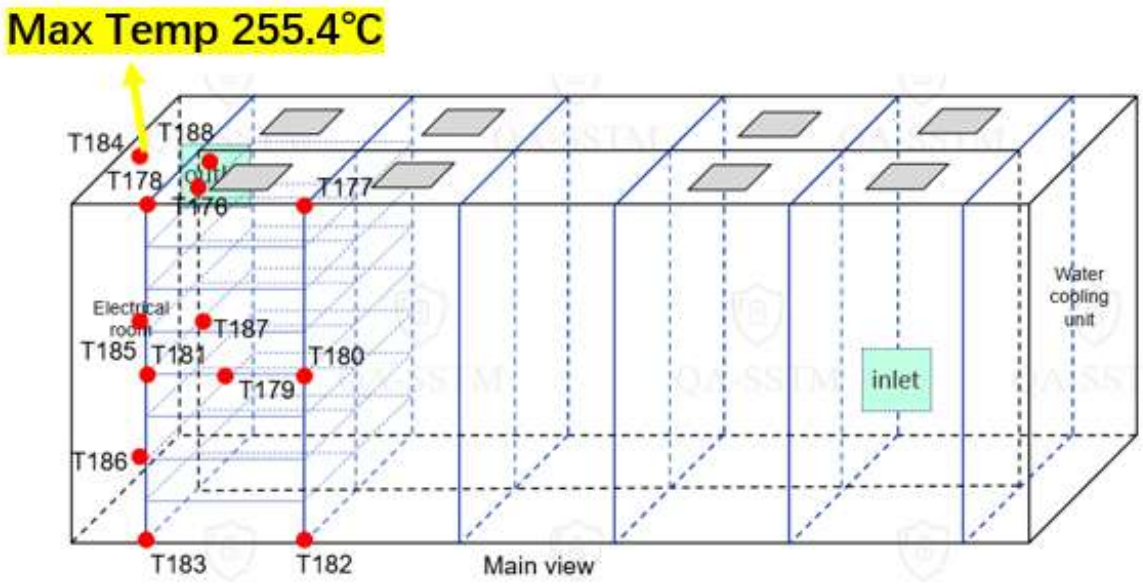

Figure 37-3– Container C Enclosure Max temperature (outer side) - From raw data

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Maximum Temperatures on Container C enclosure surface (inner side)			
External TC No.	Maximum Temperature (°C)	Internal TC No.	Maximum Temperature (°C)
T162	50.0	T169	30.7
T163	56.6	T170	33.0
T164	48.1	T171	97.7
T165	82.9	T172	50.4
T166	29.2	T173	70.1
T167	30.0	T174	36.3
T168	49.5	T175	73.2
Note: Temperatures were measured constantly and then averaged every 60-seconds.			

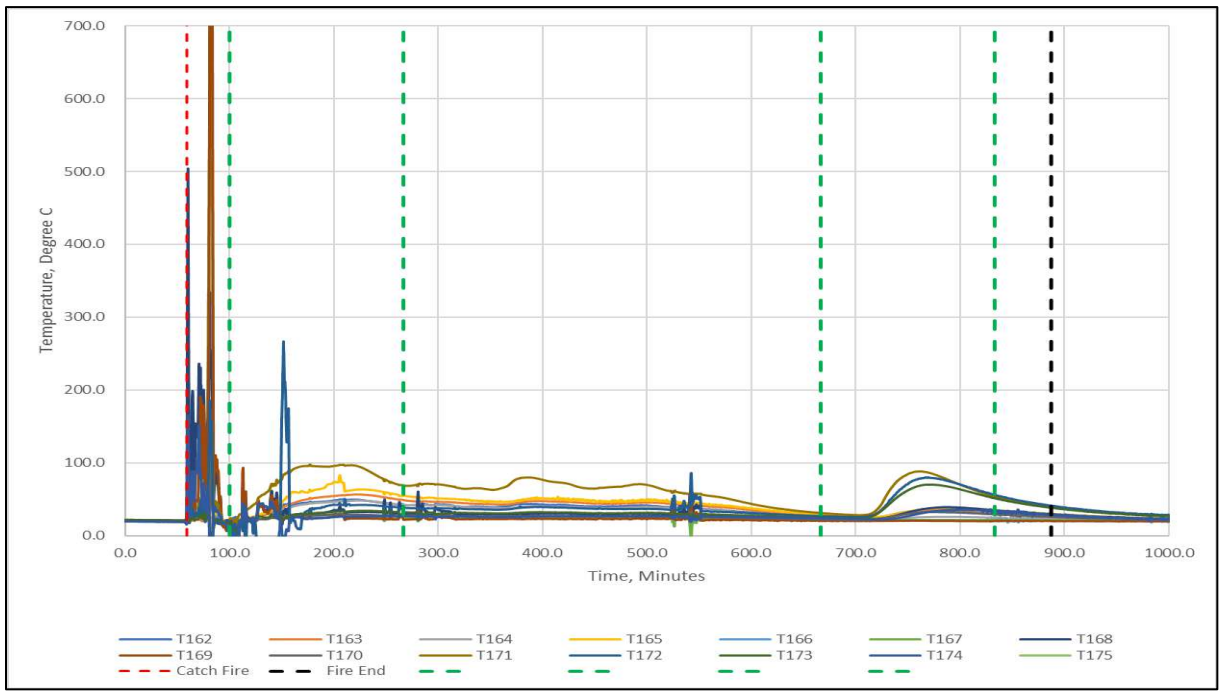

Figure 38-1 – Container C Enclosure temperature (inner side) - Raw data curve

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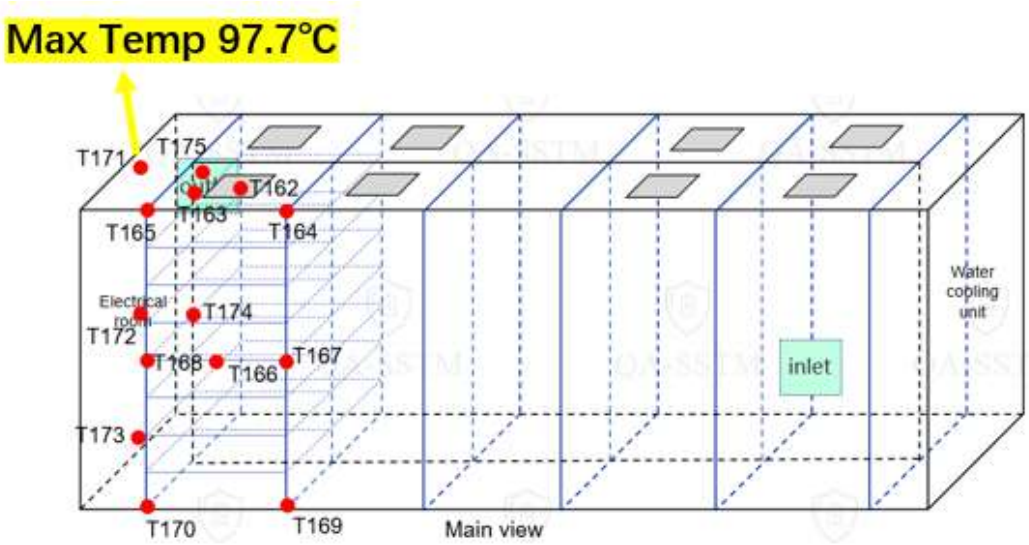

Figure 38-3 – Container C Enclosure Max temperature (inner side) - From raw data

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Maximum Temperatures on Container C internal module enclosure surface			
TC No.	Maximum Temperature (°C)	TC No.	Maximum Temperature (°C)
T189	33.0	T205	24.1
T190	24.8	T206	24.5
T191	26.3	T207	26.9
T192	25.6	T208	27.6
T193	28.0	T209	30.0
T194	27.1	T210	30.1
T195	29.0	T211	39.5
T196	33.9	T212	42.5
Note: Temperatures were measured constantly and then averaged every 60-seconds.			

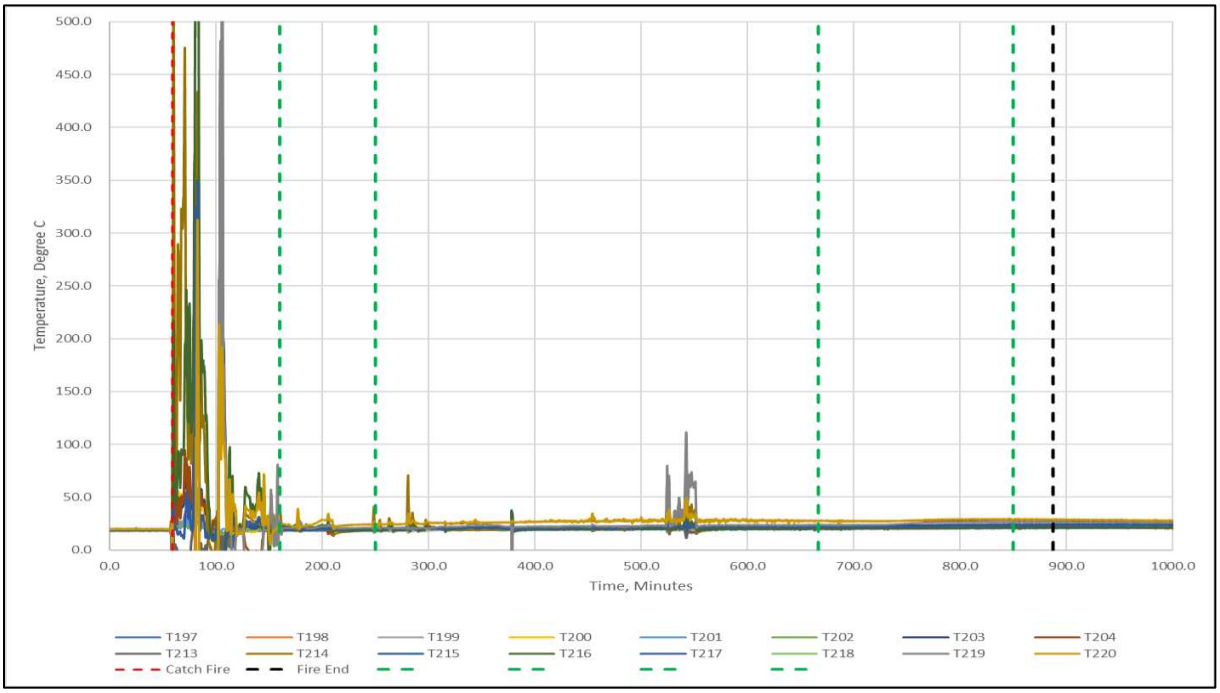

Figure 39-1 – Container C Module Enclosure temperature - Raw data curve

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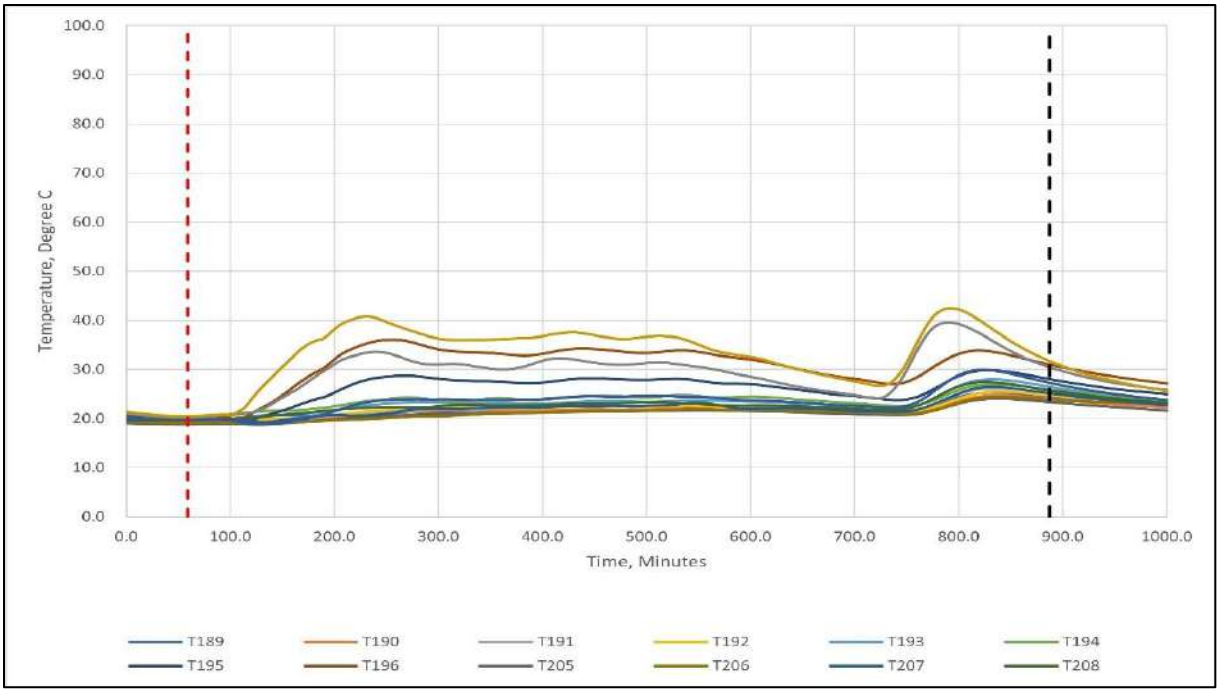

*Figure 39-2 – Container C Module Enclosure temperature- Data fitting curve**

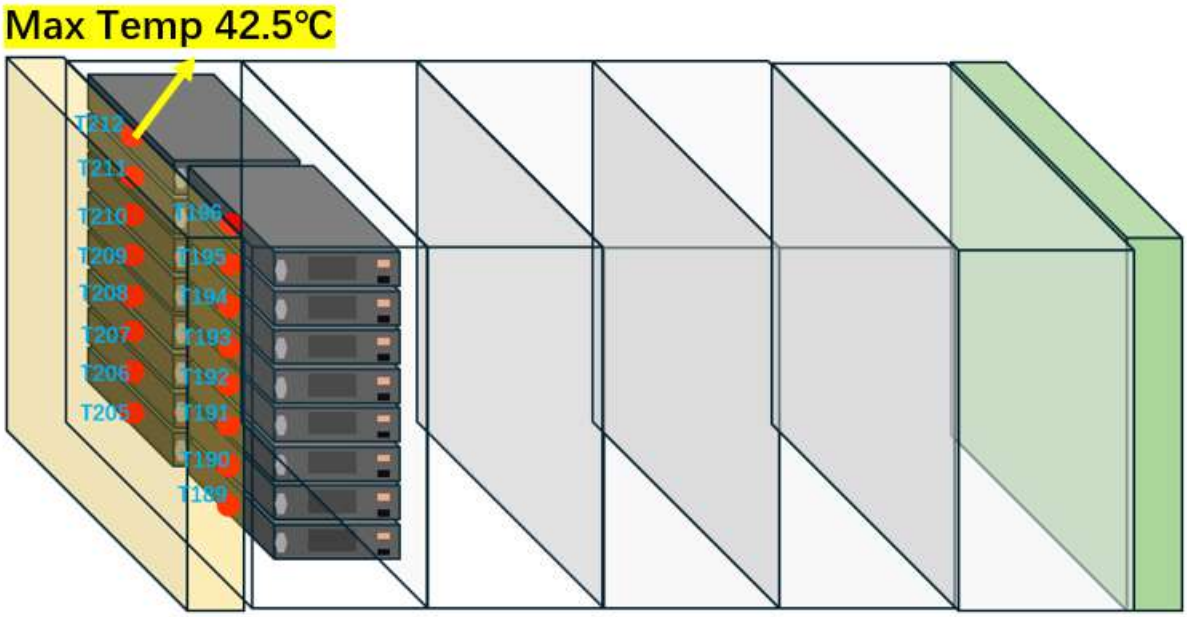

Figure 39-3 – Container C Module Enclosure Max temperature - From raw data

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Maximum Temperatures on Container C internal cell surface			
TC No.	Maximum Temperature (°C)	TC No.	Maximum Temperature (°C)
T197	21.4	T213	22.7
T198	21.9	T214	20.9
T199	21.0	T215	21.0
T200	21.4	T216	21.4
T201	22.3	T217	23.2
T202	22.6	T218	22.3
T203	24.1	T219	26.6
T204	28.7	T220	29.5
Note: Temperatures were measured constantly and then averaged every 60-seconds.			

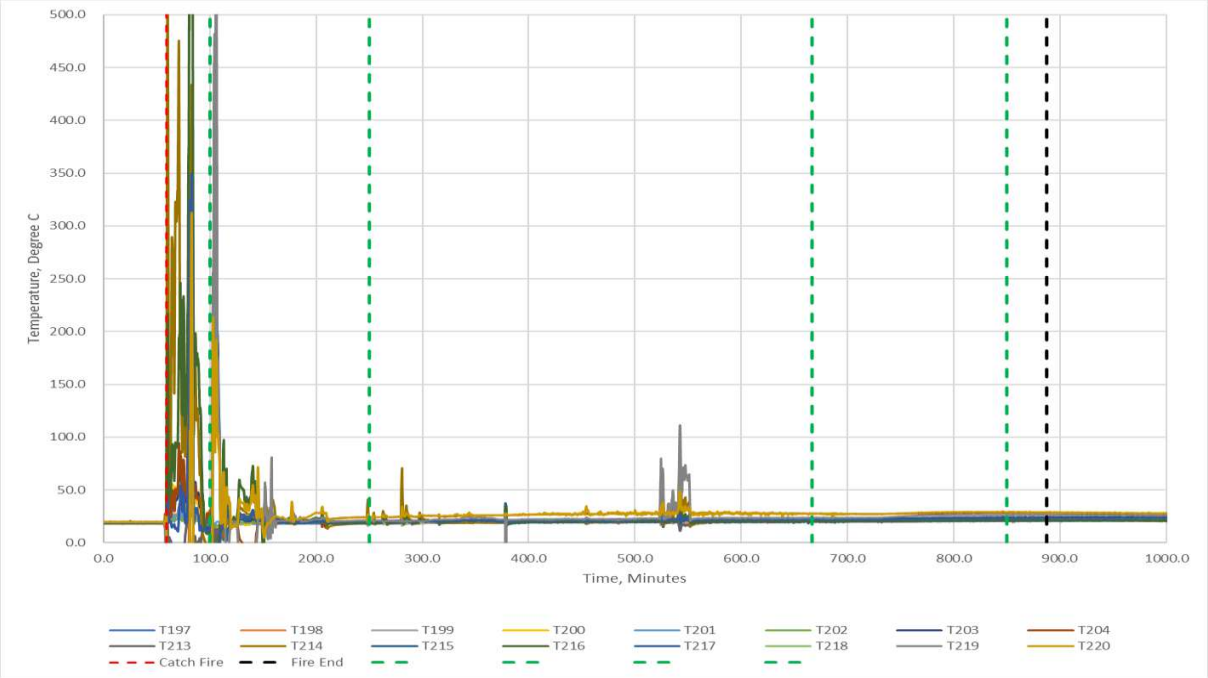

Figure 40 -1 – Container C Cell surface temperature - Raw data curve

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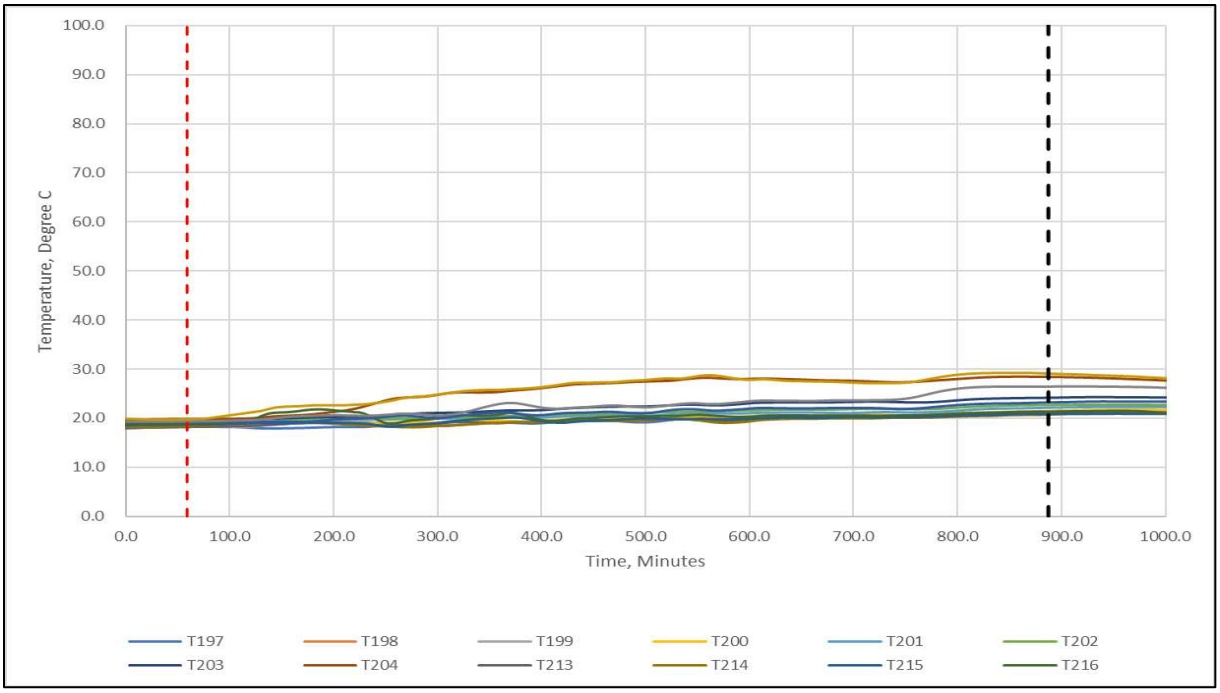

*Figure 40 -2 – Container C Cell surface temperature - Data fitting curve**

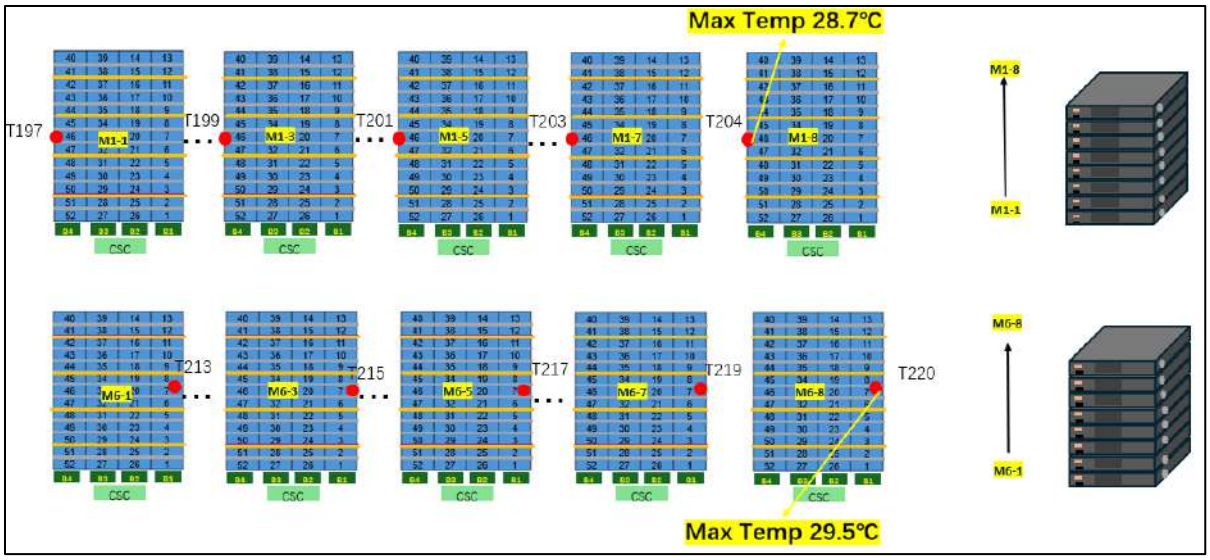

Figure 40 -3 – Container C Cell surface Max temperature - From raw data

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3.4 Heat flux measurements

Summary of maximum heat flux measured	
Heat Flux Gauge No.	kW/m^2
HF-1	17.5
HF-2	1.7
HF-3	4.4
HF-4	35.0
HF-5	14.9
HF-6	15.1
HF-7	11.0
Note: Heat Flux were measured constantly and then average every 60 seconds. See Figure 25 for the heat flux meter location.	

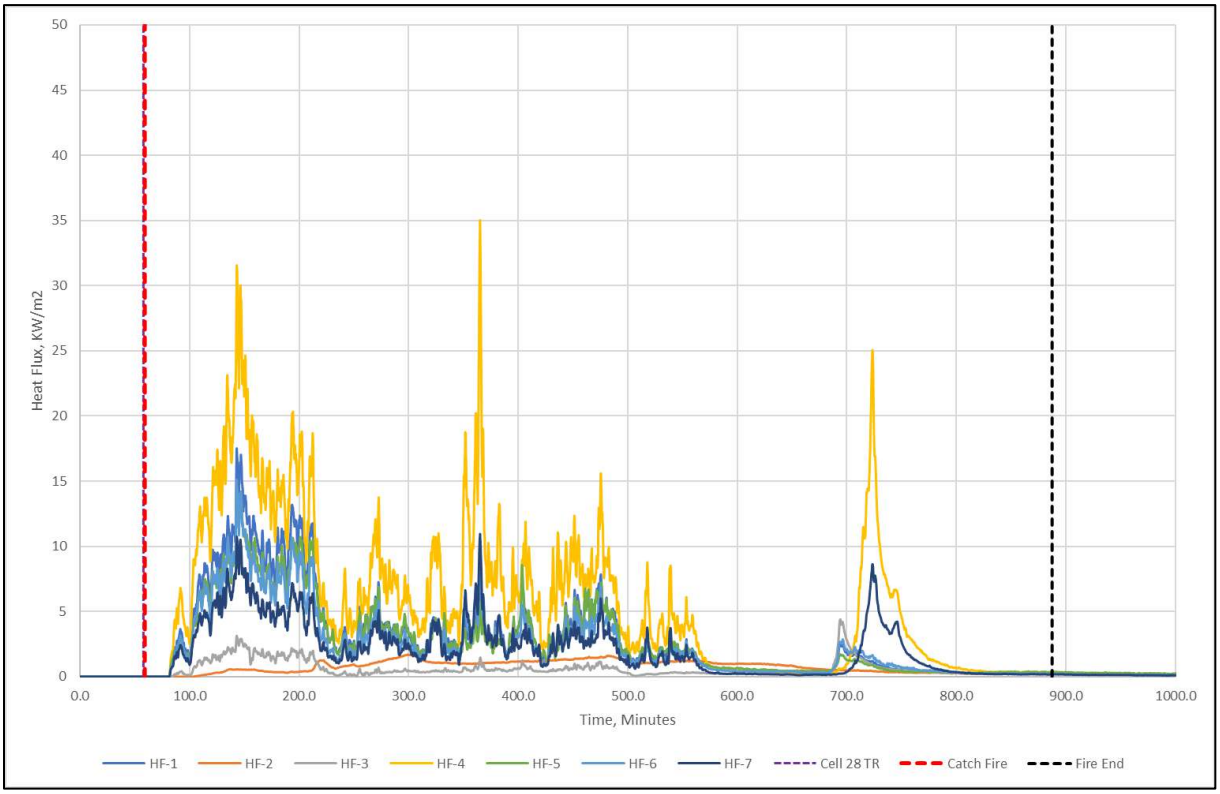

Figure 41 – Heat Flux Measurements

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3.5 Smoke Release Rate

Smoke Release Rate (SRR)	
Maximum SRR (m^2/s)	43.58
Total Smoke Released (m^2)	565796.6

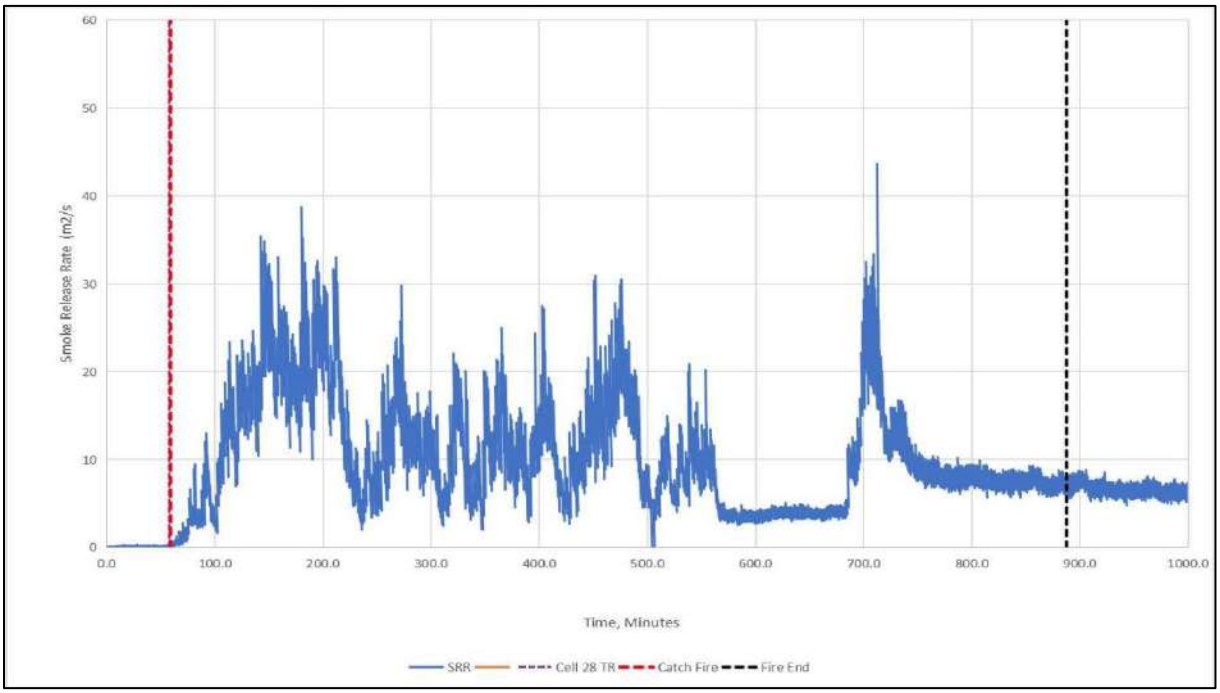

Figure 42 – Smoke Release Rate

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3.6 Heat Release Rate

Heat Release Rate (HRR)	
Peak Chemical HRR (kW)	8102.07
Peak Convective HRR, (kW)	1864.74

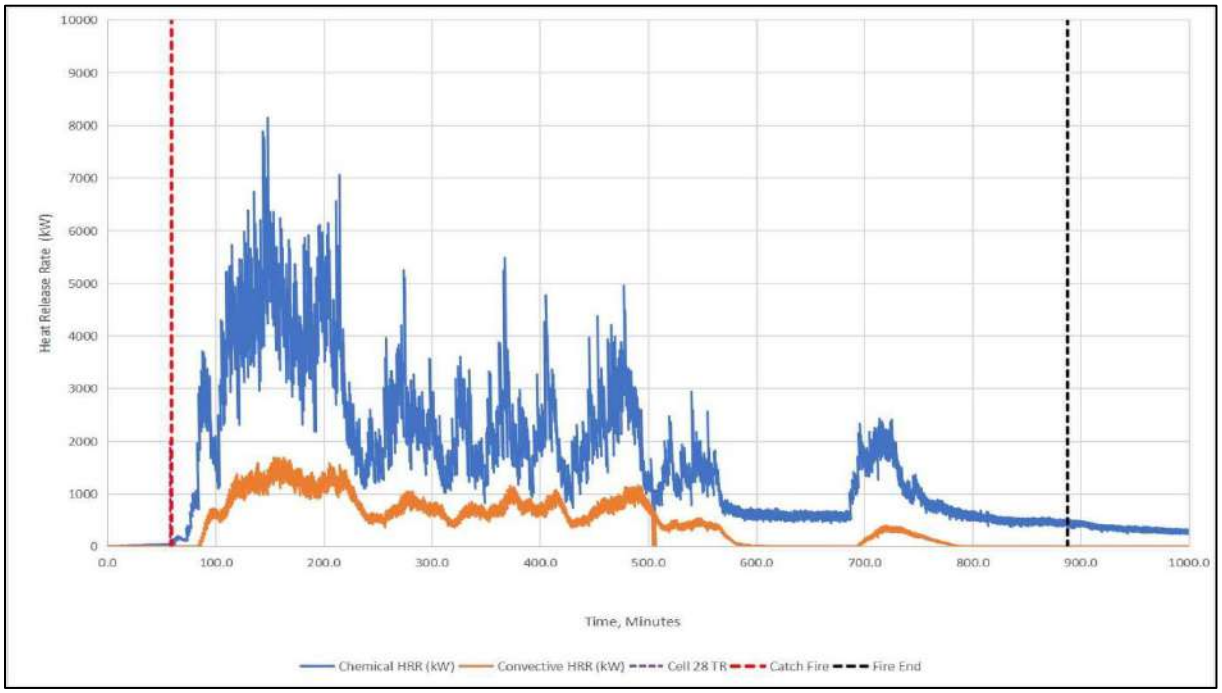

Figure 43 – Heat Release Rate

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4. Performance Criteria

The following are the relevant criteria clauses in 10.1J.1 in 9540 Technical Committee Proposal (Preliminary Review Proposal).

10.1J.1.1 There shall be no venting in any cells or modules in the target enclosures.

10.1J.1.2 There shall be no thermal runaways in any cells or modules in the target enclosures.

10.1J.1.3 If target enclosures are not populated with cells or modules, there shall be no penetration of flames through existing interconnection paths that result in breaches from the enclosure of origin into the target enclosure.

10.1J.1.4 The temperature criteria in 10.1J.1.5 – 10.1J.1.9 shall not be exceeded, as summarized in Table 10.1. Temperature measurements shall be evaluated with 60 seconds averaging. The selected criterion shall correspond to the test instrument placement for target BESS. Performance criteria shall be evaluated at the nearest representation to the location to where cells are installed. For example, if the enclosure interior and cell locations are both instrumented, the cell location shall be used to evaluate the performance criteria. Similarly, if the enclosure interior and module surfaces are both instrumented, the module surfaces shall be used to evaluate the performance criteria.

NOTE: Temperature criteria is used to assess thermal runaway risk in batteries in adjacent BESS. Superficial damage to paint or enclosure exteriors does not constitute failure conditions.

Table 10.1
Temperature Criteria for Outdoor Installations

Exposures	***Limit***
Cells within the target enclosures	*90 % of the average temperature of venting temperature from the Cell Level test*
Modules within the target enclosures	*Average temperature of venting temperature from the UL9540A cell level test*
Interior surface of target enclosures	*110 % Average temperature of venting temperature from the Cell Level test*
Instrumented Wall, if used in place of target enclosure	*97 °C (175 ºF) rise above ambient*

10.1J.1.5 With reference to 10.1J.1.4, the temperatures measured by thermocouples placed on cells within the targets per 10.1E.7 shall not exceed 90 % of the average temperature of venting temperature from the Cell Level test, Section 7.

NOTE: The 90% is calculated in Celsius with respect to 0 °C (32 °F). For example, 90 % of an average cell vent temperature of 100 °C (212 °F) is 90 °C (194 °F).

10.1J.1.6 With reference to 10.1J.1.4, the temperatures measured by thermocouples placed on empty modules within the targets per 10.1E.8 shall not exceed the average temperature at which thermally initiated cell venting occurs according to the Cell Level testing as specified in Section 7.

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10.1J.1.7 With reference to 10.1J.1.4, the temperatures measured by thermocouples placed on the interior surface of target enclosures per 10.1E.9 shall not exceed 110 % of the average temperature at which thermally initiated cell venting occurs according to the Cell Level testing as specified in Section 7.

10.1J.1.8 With reference to 10.1J.1.4, surface temperature measurements along instrumented wall surfaces shall not exceed a temperature rise of 97 °C (175 °F) above ambient when used as target BESS enclosures.

10.1J.1.9 Heat flux measurements shall not exceed 12.5 kW/m2 where used to determine separation distances to combustible structures. Heat flux measurements shall be evaluated with 60-second averaging.

NOTE: This criterion is applied for clearance to combustible structures only, not BESS enclosures. This criterion is consistent with the threshold established in NFPA 80A for tolerable level of radiation at the face of an exposed building.

10.1J.1.10 For stacked BESS, the enclosure of origin, stacked target enclosures, and any target structures, platforms, or supports shall not collapse.

The test result of this test was compared to the criteria outlined above in Table 10.2.

Table 10.2 – Test result summary.

Relevant Clauses	Topic	Comments	Results
10.1J.1.1	No venting in any cells in the target containers.	-	Pass
10.1J.1.2	No thermal runaways in any cells in the target containers.	-	Pass
10.1J.1.3	No penetration of flames through interconnection paths between the enclosure of origin and target containers	No interconnection paths	N/A
10.1J.1.4	The temperature criteria in 10.1J.1.5 – 10.1J.1.9 shall not be exceeded, as summarized in Table 10.1.	-	Pass
10.1J.1.5	Temperatures measured by thermocouples placed on cells within the targets not exceeding 90% of the cell level average venting temperature.	The Max temperature measured for the battery cell was 43.9°C.	Pass

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10.1J.1.6	Temperatures measured by thermocouples placed on dummy modules within the targets not exceeding the cell level average venting temperature.	The Max temperature measured for the module was 85.0°C.	Pass
10.1J.1.7	Temperatures measured by thermocouples placed on the interior surface of target containers not exceeding 110% the cell level average venting temperature.	The Max temperature measured for the interior surface of the reference target containers was 106.4°C, the location of this module was container B, and the thermocouple number was T107.	Pass
10.1J.1.8	surface temperature measurements along instrumented wall surfaces shall not exceed a temperature rise of 97 °C (175 °F) above ambient.	N/A	N/A
10.1J.1.9	Heat flux measurements shall not exceed 12.5 kW/m^2 where used to determine separation distances to combustible structures.	Not applicable.	N/A
10.1J.1.10	For Stacked BESS, the enclosure of origin, stacked target containers, and any target structures, platforms, or supports shall maintain structural integrity.	Not Stacked BESS	N/A

There are no performance criteria in CSA C800, 9.7.6 test report – observations were recorded.

Table 10.3 – Observations summary for C800

Items	Topic	Comments
a)	Any penetrations of flames or flammable gas into the adjacent target units.	No penetrations of flames or flammable gas into the adjacent target units
b)	Thermal runaway events of cells in the adjacent target units	No thermal Runaway Events of Cells in the Adjacent Target Units

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c)	Status and loss of BMS communication during test	N/A
d)	Status and loss of fire detection, and any other alarm systems, during the test	N/A
e)	Damage to the initiating unit and any damage (soot, smoke, or otherwise) to target adjacent units	Refer to 5.1
f)	Pictures of the initiating unit every 10 minutes from post-fire detection up to 2 hours	Video continuous recorded
g)	Temperature data at the following locations: i) external faces of the target units and initiating units, ii) various internal points of the target units, initiating unit, and adjacent battery racks, iii) HVAC system, cabling, wiring, switchgear, and other combustibles	Temperature data was recorded for both target and initiating containers.
h)	Heat Flux gauges installed on all target units and exposures per the manufacturer's installation instructions	Heat Flux gauges installed
i)	Peak heat release rate from the main initiating unit	Refer to 3.6
j)	Size, duration, and location of the largest flames seen during the test	Refer to 3.1
k)	Pre- and post-test adjacent module voltages	Refer to 5.1
l)	Deflagration events observed during the test	Refer to 3.1
m)	Visual and IR video footage of the test	Visual and IR video recorded

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5. Post Test Sample Check

5.1 Test sample status after the test

Container A: All battery modules completely burned down. The overall structure of the container remained intact and did not collapse. Container doors remained closed. The front side panels of sub control box were opened. Container B and C: All maintained structural integrity with no visible deformation, and the voltage check of post-test as below table.

Container No.	Rack Location	Module No.	OCV Prior to Test (V)	OCV Post Test (V)	voltage difference (V)
B	Rack 6#	M6-8	173.5	173.4	0.1
	Rack 7#	M7-7	173.5	173.5	0.0
	Rack 8#	M8-1~M8-2	347.3	347.3	0.0
		M8-3~M3-5	520.0	520.0	0.0
		M8-6~M8-8	520.0	520.0	0.0
	Rack 9#	M9-8	173.5	173.5	0.0
	Rack 10#	M10-8	173.4	173.5	-0.1
C	Rack 1#	M1-1~M1-2	346.7	346.7	0.0
		M1-3~M1-5	519.0	519.0	0.0
		M1-6~M1-8	521.0	521.0	0.0
	Rack 6#	M10-1~M10-2	347.2	347.2	0.0
		M10-3~M10-5	520.0	520.0	0.0
		M10-6~M10-8	520.0	520.0	0.0

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1# -camera view	2# -camera view
	
3# -camera view	4#- camera view
	
5#- camera view	6#- camera view
	
7#- DV view	8#- DV view

Figure 44 – Overall view of post test

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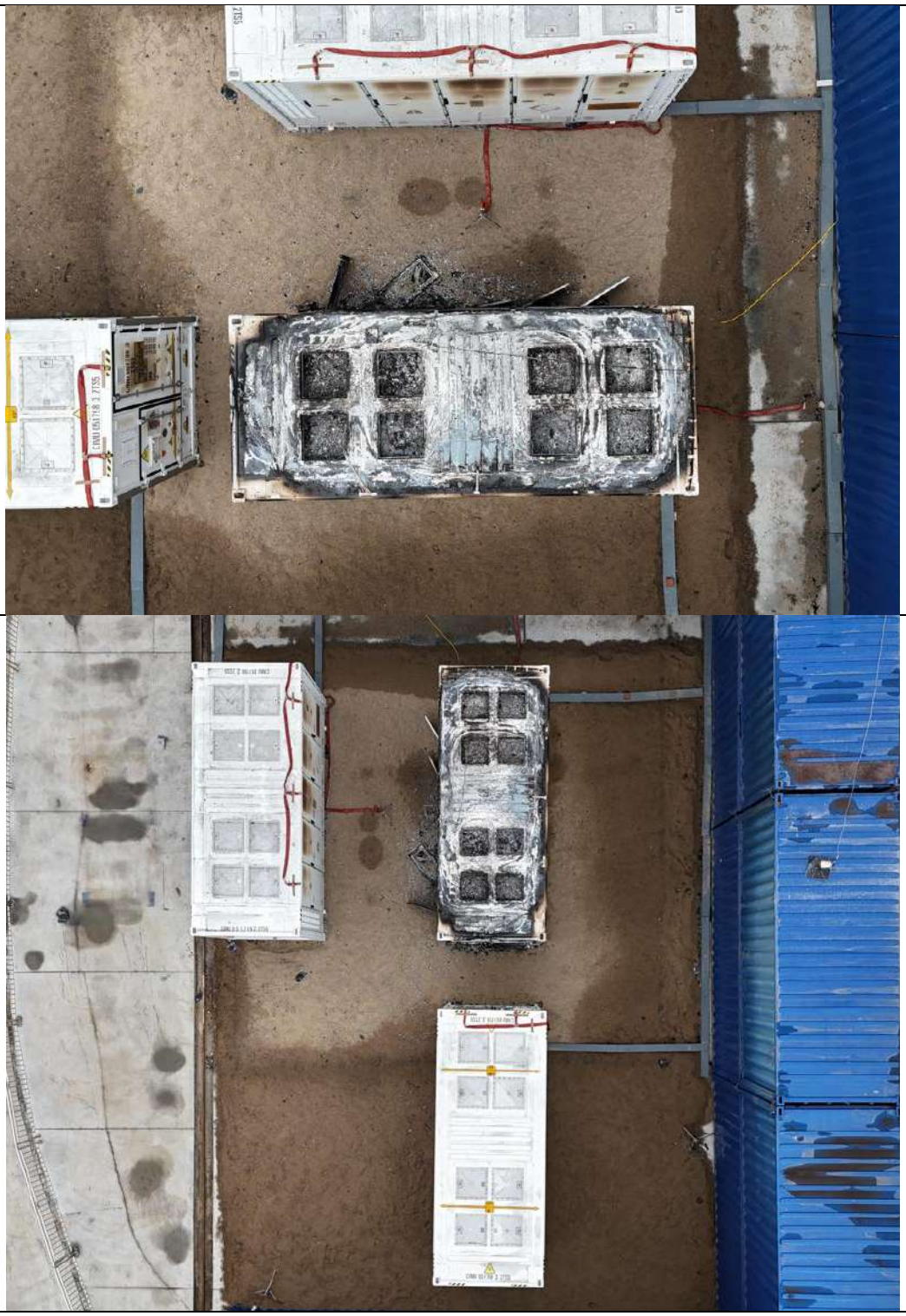

Figure 45 – Top view of post test

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Container A



Front view



Back view

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Side view-1	Side view-2
	
Internal view -Front	Internal view - Back
	
Internal view – (Represents the status of all modules on Racks 1~ 5)	Internal view - (Represents the status of all modules on Racks 6~ 10)

Figure 46 – Overall view of container A post test

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Container B



Front view



Back view

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Side view-1	Side view-2
	
Internal view (M6-8)-1	Internal view (M6-8)-2

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Internal view(M7-8)-1	Internal view(M7-8)-2
	
Internal view(M8-1~M8-8)	Internal view(M8-6~M8-8)

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Internal view(M9-8)-1	Internal view(M9-8)-2
	
Internal view(M10-8)-1	Internal view(M10-8)-2

Figure 47 – Overall view of container B post test

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Container C



Front view



Side view-1



Side view-2

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Internal view(M1-1~M1-8)	Internal view(M1-1~M1-3)
	
Internal view(M1-4~M1-6)	Internal view(M1-7~M1-8)

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Internal view(M6-1~M6-8)	Internal view(M6-1~M6-3)
	
Internal view(M6-4~M6-6)	Internal view(M6-7~M6-8)

Figure 48 – Overall view of container C post test

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6. Test Equipment Information

No.	Equipment Name	Equipment ID	Range/Tolerance	Calibration Due Date
1	Thermometer and hygrometer	SLS106R25011701	15~30℃，±1℃ 40%~80%RH, ±3%	2026-05-19
2	Anemometer	25SR10010200052	0.51~30m/s, ±1.00m/s	2026-05-19
3	Battery Charging/Discharge test system	75F2300015	50~1600V, ±0.8V, 50~400A, ±0.2A	2026-03-31
4	Heat Flux gauges	F0925-08	0~50kW/m^2	2026-05-25
5	Optical filter	LGP-01	0~100%	2026-04-28
6	Pneumatic Differential Pressure Transducer	11349286	0-500Pa, ±2Pa	2026-04-28
7	Infrared Temperature Sensor	OM018023	0~500℃, ±2.5℃	2026-04-28
8	Thermocouple	K12411294063	200~1000℃ Max tolerance 7.5℃	2026-04-28
9	Data logger	241121668	-50~500℃ Max tolerance 1.5℃	2026-04-28
10	Data logger	241121669	-50~500℃ Max tolerance 1.5℃	2026-04-28
11	Data logger	241121670	-50~500℃ Max tolerance 1.5℃	2026-04-28
12	Oxygen sensor	M2503117	15%~50%， Max tolerance 1.5%	2026-04-28
13	Steel measuring tape	GJC-01	0-10m, Max tolerance 1.2mm	2026-04-28
14	Clamp meter	H12E-K335606	4~600V DC, 0.1%	2026-04-28

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2025

CATL

LARGE SCALE FIRE TEST

Supplemental Interpretation Report



Prepared by:

ATAR FIRE

SIGNATURE PAGE

Test Witnessed By:	Denis Helebuyck, ir. (Burgerlijk Ingenieur)
Email Address:	denis@atarfire.com

Report Prepared By:	Nicholas Bartlett, P.E.
License Number/ Expiration	#1839 Expiration 3/31/2026
Email Address:	nick@atarfire.com
Phone:	510-710-9080
Signature:	

Nicholas Bartlett

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DN: C=US, E=nick@atarfire.com, O="Atar Fire, LLC", CN=Nicholas Bartlett
Date: 2025.12.19 07:23:42-07'00'



Reviewed By:	Michael Torkelson, P.E.
Email Address:	mike@atarfire.com

REVISION HISTORY

Date	Report Number	Rev. Number	Description
11/11/2025	20251101	0	Interim Report Prior to UL Solutions Report
12/19/2025	20251101	1	Final Report Based on UL Solutions Report

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Purpose

This report provides an independent, third-party summary of large-scale fire testing performed on the CATL battery energy storage system (BESS), Model C04285P10L01. Large-scale fire testing was conducted on November 5, 2025, at a test facility located in Yichang, China. The test was coordinated by UL Solutions, including the development of the test plan and managing the overall test implementation and oversight. Execution of the testing from end-to-end required close coordination between UL Solutions, CATL, and the test facility. The test plan was developed in accordance with the draft large-scale fire test protocol in place during the time of test plan development, namely, the June 27, 2025 Draft Edition of UL 9540A [1][1], as well as best practices established by CSA/ANSI C800:25 [2]. Based on a review of the test plan by Atar Fire, LLC, it was determined that the plan additionally met the intent of NFPA 855, 2026 Edition [3], Annex G.11, *Guidance on Implementing a Large-Scale Fire Test (LSFT)* (note: annex material is not considered part of the requirements of NFPA 855 and is used for informational purposes only). On-site test observation and test protocol validation were provided for CATL by Atar Fire, LLC. This report is intended to supplement the final testing report developed by UL Solutions.

Large-scale fire testing represents one of the most critical layers of safety in an overall BESS fire protection design strategy. The primary purpose of large-scale fire testing is to evaluate the thermal exposure from a developed fire within a battery energy storage system, including non-battery components, to determine propagation or ignition risk to adjacent enclosures and exposures [3]. During a large-scale fire test, BESS enclosures are arranged in a configuration that replicates the intended site installation. This includes the design of the BESS enclosures themselves, as well as planned separation distances between each BESS enclosure. Active fire protection and thermal runway mitigation measures are intentionally disabled to create a worst-case scenario, with the test fire being initiated in a single BESS enclosure. Observations are made to determine the potential for and impacts of fire propagation. Additional data is gathered during the test to validate and substantiate how the product and configuration will perform in a fire event.

[1] The specific code sections provided in this document are in draft form. The section numbers, and section content, may change prior to publication of a final draft.

Referenced Codes and Standards

Both NFPA 855 [3], and the International Fire Code (IFC) [4], provide requirements for the safe design and installation of stationary energy storage systems. Within both NFPA 855 and the IFC, provisions exist for large scale fire testing of energy storage systems. For example:

Section 9.2.1 of NFPA 855 prescribes: "*Where required elsewhere in this standard, fire testing in accordance with Section 9.2 shall be conducted on a representative ESS in accordance with UL 9540A and large-scale fire testing to collect data for gas production at a cell level, thermal runaway propagation at a module level, and thermal runaway propagation potential between ESSs.*

NFPA 855 further clarifies the large-scale fire test by stating in Section 9.2.1.2.1: *"The large-scale fire testing in accordance with 9.2.1.2 shall be conducted or witnessed by and reported by an approved testing laboratory to characterize the composition of gases generated and show that a fire involving one ESS unit will not propagate to an adjacent unit.*

Section 1207.1.7 of the IFC similarly states: *"Large-scale fire test. Where required elsewhere in Section 1207, large-scale fire testing shall be conducted on a representative ESS in accordance with UL 9540A. The testing shall be conducted or witnessed and reported by an approved testing laboratory and show that a fire involving one ESS will not propagate to an adjacent ESS, and where installed within buildings, enclosed areas, and walk-in units will be contained within the room, enclosed area or walk-in unite for the duration of the test."*

The intent of the test is specifically discussed in the Official Code and Commentary to the IFC [5] in Section 1207.1.5: *"A large-scale fire test is essential to documenting that unit-to-unit propagation will not occur as well as generating additional data for necessary risk assessments for varied installation locations and arrangements relative to exposures."*

The testing performed on the CATL C04285P10L0, and summarized in this report, was designed and performed to meet the requirements of a large-scale fire test as noted in both NFPA 855 and the IFC.

Laboratory test reports that are produced from the large-scale fire test are required to be accompanied by a supplemental report generated by a registered design professional. The report must interpret the test results as required by NFPA 855 §9.2.2.2: "*The test report shall be accompanied by a supplemental report by a registered design professional with expertise in fire protection engineering that provides interpretation of the test data in relation to the installation requirements for the ESS".* This Large-Scale Fire Test Summary Report has been developed to fulfill this NFPA 855 requirement, as Atar Fire, LLC is staffed by licensed Fire Protection Engineers / Professional Engineers with specific expertise in energy storage system safety.

Product Information

The CATL C04285P10L0 is comprised of lithium-ion battery cells, modules and racks. The following table summarizes the product information.

Item	Value/Comment
Cell Chemistry	Lithium Iron Phosphate
Cell Model	CBDC0
Cell Capacity	285 Ah
Cell Voltage, Nominal	3.2 V
Cell Construction	Prismatic
Module Model	M01285P10L01
Module Capacity	285 Ah
Module Voltage, Nominal	166.4 Vdc
Unit Model	C04285P10L01-R
Unit Rated Capacity	285 Ah
Unit Voltage, Nominal	1331.2 Vdc
Enclosure Model	C04285P10L0 (also referred to as 'C1P')
Enclosure Capacity	3.79 MWh
UL 9540A Cell Report	UL Solutions Project 4791943570 Dated 2025-10-24
UL 9540A Module Report	UL Solutions 4791943679 Dated 2025-10-29
UL 9540A Unit Report	UL Solutions 4791943683 Dated 2025-10-28

Table 1 - Manufacturer's Specifications of BESS

In the CATL C04285P10L0, cells are combined into modules and modules are combined into racks. Each rack is comprised of 8 modules and contains a high voltage combiner box which is located beneath the lowest module. Ten racks are combined within a singular noncombustible enclosure to create the ESS enclosure. Five individual doors are provided on one side of the enclosure. The ESS enclosure is provided with liquid cooling. All control equipment including the battery management system, energy management system, and fire alarm control panel is located in a compartment on one end of the enclosure with exterior access.

The following figures provide images of the CATL C04285P10L0 from the test site for reference:



Figure 1 – CATL C04285P10L0 - Overview

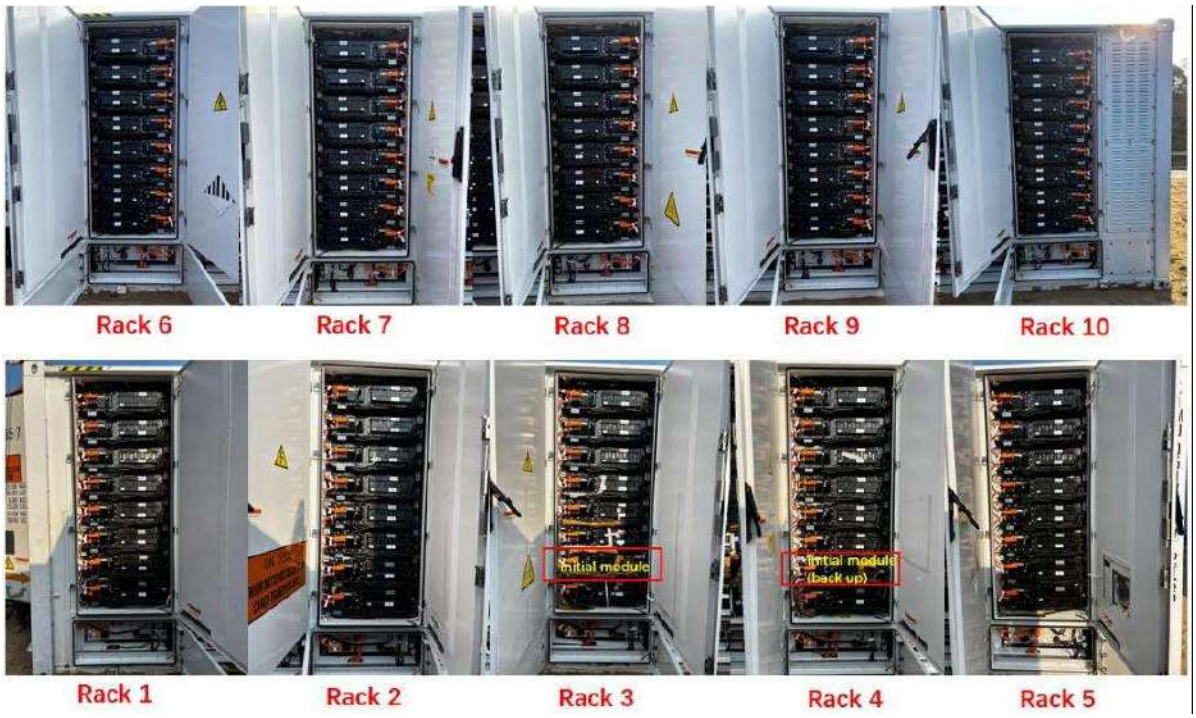

Figure 2 - CATL C04285P10L0 Enclosure – Front and Back View – Doors Open



Figure 3 - Product 'Electrical Room



Figure 4 - Sample Battery Rack (8 Modules)

The CATL C04285P10L0 is equipped with NFPA 68 deflagration vents [10], and an NFPA 69 [7] combustible concentration reduction system. The deflagration venting system consists of eight deflagration vent panels mounted on the roof of the enclosure, as shown in Figure 5, each with an area of 3.65 cm^2. The design of the deflagration venting system in accordance with NFPA 68 was independently evaluated by a registered design professional. The associated report is included in reference [10].



Figure 5 - Deflagration Vents (8 Total)



Figure 6 - Deflagration Vents (Four Shown)

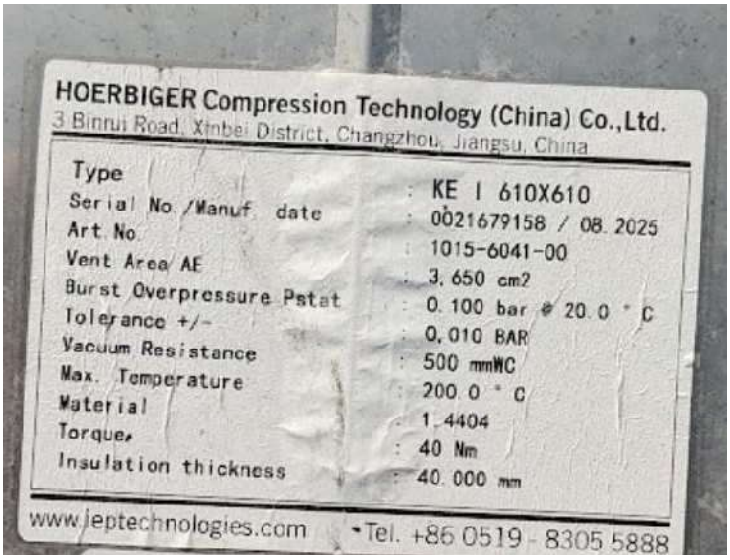

Figure 7 - Deflagration Vent Design Data

The NFPA 69 combustible concentration reduction system is comprised of a mechanical exhaust fan and a make-up air opening. The mechanical exhaust system is activated by gas sensors located within the enclosure. Separately, a fire detection system is provided utilizing smoke and heat detectors collocated within the enclosure. An evaluation of the suitability of the NFPA 69 system is reviewed in reference [11].

Test Plan and Background Information

For this large-scale fire test, the enclosures were arranged in an as-installed site configuration. Three enclosures were placed on the test site under a dedicated smoke collection hood. The layout of the enclosures and associated separation distances are shown below in Figure 8 and tabulated in Table 2 for reference:

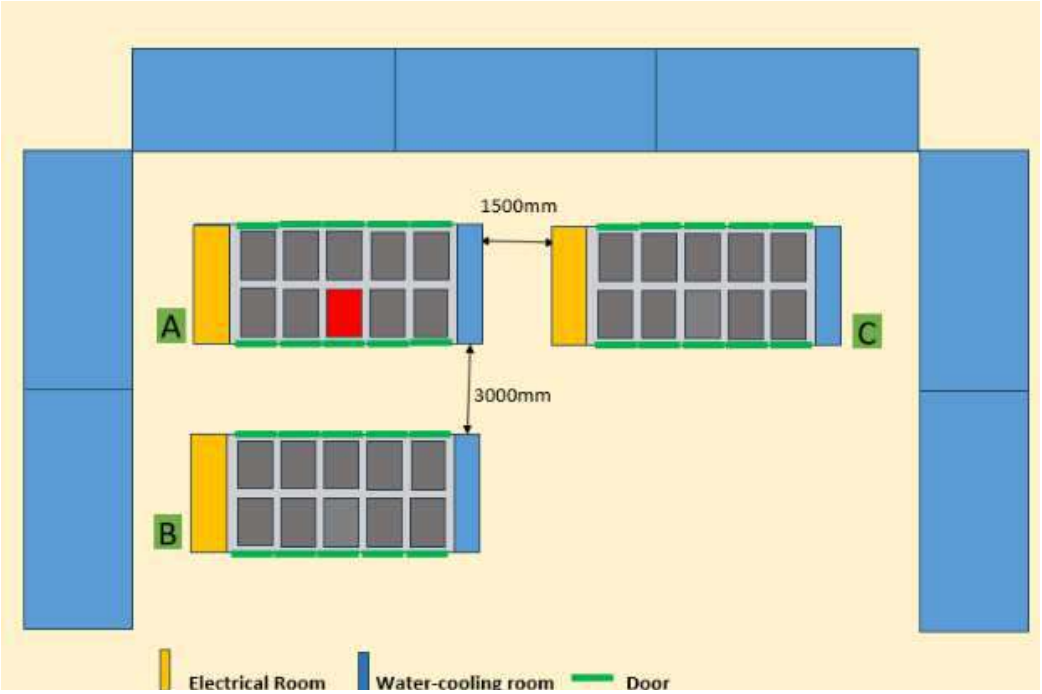

Figure 8 - Enclosure Layout, Separation Distances in Millimeters

Items	Distance
A-B	3000 mm (~ 118 inches)
A-C	1500 mm (~59 inches)

Table 2 - Separation Distances of Enclosures During Testing

Atar Fire physically verified each distance on site to ensure distances were in accordance with the test plan.

Module Population

Enclosure A was established as the enclosure of origin. It was a fully populated enclosure, as required by UL 9540A draft, §10.1B.5. The two target enclosures (B, C) were each partially populated. This partial population is permitted by the draft UL9540A language within §4.18A and §10.1E.5.

Within Enclosure B, twelve total modules were live modules. The entire rack (eight total modules) directly opposite the initiating rack in Enclosure A contained live modules. In

addition, the top module of all other racks (four total modules), were live modules. The decision to ensure these modules were live modules was made as these locations were anticipated to receive the greatest fire exposure from Enclosure A. As such, the chosen locations of live modules therefore represent the worst-case fully developed fire exposure from the enclosure of origin. Live modules are shown for Enclosure B in pink below. Areas with unpopulated modules are shown in gray.

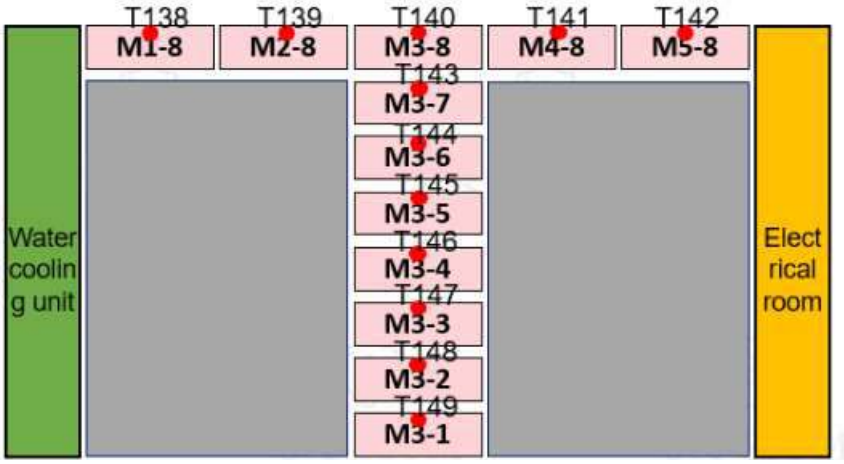

Figure 9 - Enclosure B Live Modules

Within Enclosure C, all eight modules in the rack closest to Enclosure A were live modules. The chosen location of live modules represents the worst-case fire exposure from the enclosure of origin. The remainder of Enclosure C was unpopulated. Populated modules are shown in pink below. Areas with unpopulated modules are shown in gray.

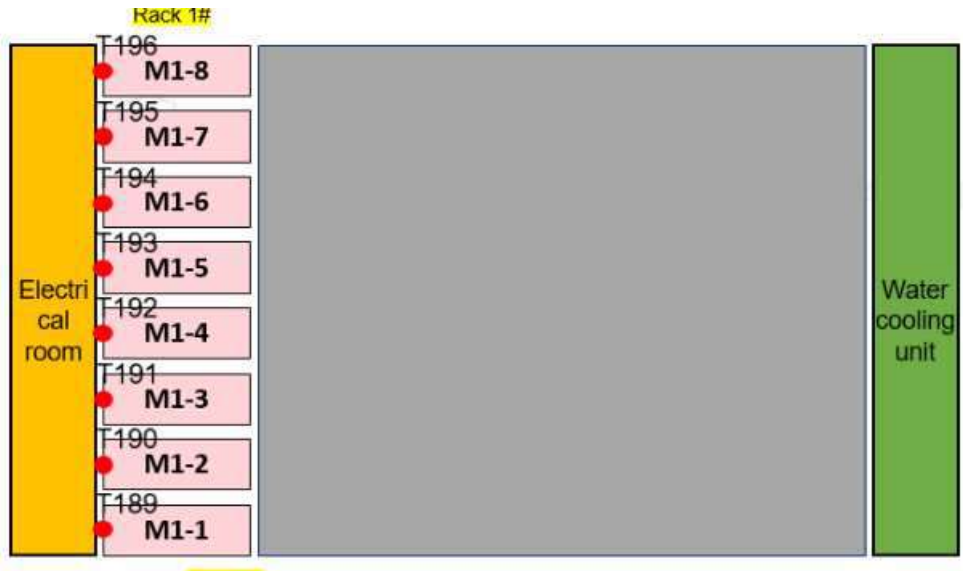

Figure 10 - Enclosure C Live Modules

With respect to CSA/ANSI C800, the module population and chosen locations meet CSA/ANSI C800:25 §9.7.1 to '*have at least one live battery module located in the most likely area to be affected by a large fire.*'

Thermal Runaway Initiation Location

The initiating rack in Enclosure A was selected as the middle rack. This was chosen to ensure that fire spread to multiple racks within the enclosure, to develop anticipated worst-case fire spread conditions and thermal stress to adjacent enclosures. This arrangement satisfies the recommendation of UL 9540A draft, §10.1F.6.

The initiating module was chosen to be in the second lowest vertical position within the rack, to assess both downward and upward fire propagation, as well as to adhere to the recommendation of UL 9540A draft, §10.1F.6.

The selection of both the initiating rack and module satisfies the recommendation of CSA/ANSI C800:25 §9.7.4 such that "*The initiating unit within the ESS Enclosure shall be selected based on criteria that maximize the thermal exposure to target units and other units in the ESS Enclosure.*" The following schematic and image show both the initiating rack and initiating module within Enclosure A. In these images, M3-2 represents the initiating module, and M4-2 represents a backup initiating module.

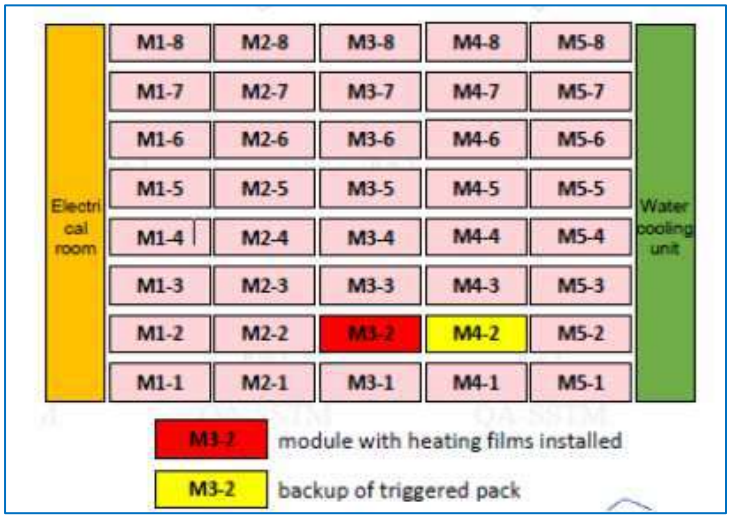

Figure 11 – Enclosure A - Initiating and Backup Initiating Modules

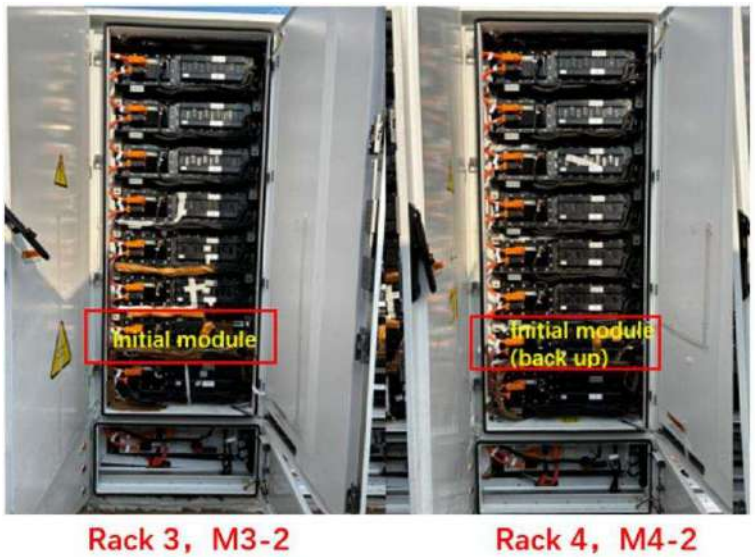

Figure 12 - Enclosure A - Initiating and Backup Modules – Test Photos

Within the module, heating elements were placed at the locations shown in Figure 13. The heating elements were in contact with a total of eight cells. The red line in the following figure represents the heater, and the orange/pink color represents the heated cells. Heater locations were chosen to maximize the potential for cell-to-cell thermal runaway propagation and ensure fire propagation within the module. An image of an as-installed heater is shown in Figure 14.

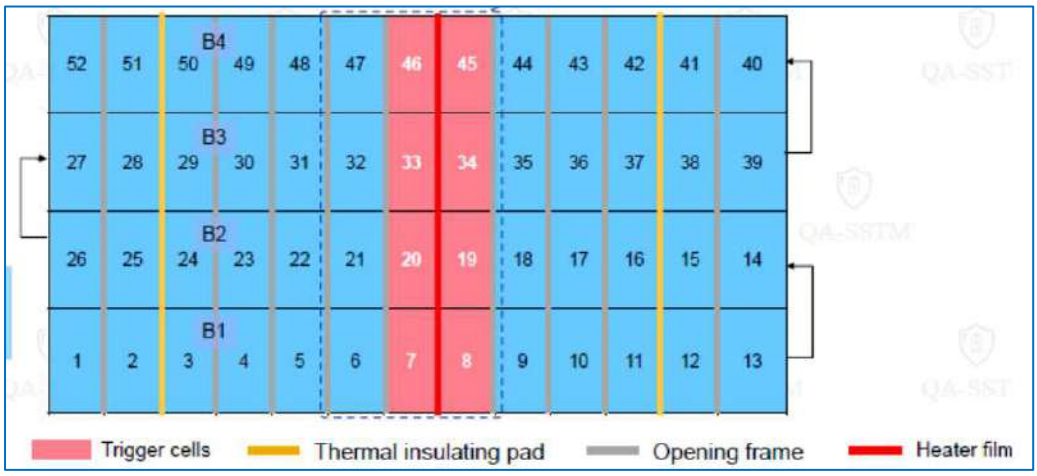

Figure 13 - Heater Locations in Module



Figure 14 - Heating Film on Cell

Thermal Runaway Initiation and Vent Gas Ignition Process

Thermal runaway was initiated using heaters in accordance with UL 9540A draft §10.1F.1. Cells were heated at approximately 4.5 degrees Celsius per minute to replicate the currently published UL 9540A [8] cell level testing conditions. Atar Fire verified the heating rate during the test via visual confirmation of heating rate output from cell thermocouples. The exact heating rate is shown in the formal UL Solutions Report [12]. An electric igniter was used to ignite combustion gases shortly after thermal runaway. The igniter was located external to and in as close a proximity as possible to the vent of the initiating module. Atar Fire inspected the igniter and observed the timing of ignition of the vent gases. The igniter was left on until it was mutually determined among testing staff that the fire was self-propagating. A photo of the igniter is shown in Figure 15.



Figure 15 – Igniter (Seen in White)

Voltage Verification

Prior to the initiation of the large-scale fire test, Atar Fire observed and confirmed voltage level checks by test technicians to ensure the voltage drop was in accordance with UL 9540A draft, §10.1B.13. The CATL C04285P10L0 was verified to be charged to the maximum state of charge in accordance with UL 9540A draft, §10.1B.12. Atar Fire observed technicians with voltmeters confirm voltages at module and rack levels were at or exceeded the nameplate value of 100% state of charge. Charging was performed within 72 hours of the test and at least one hour was allowed for rest time per UL 9540A draft, §10.1B.12 and §10.1B.14. Charging also met the requirements of CSA/ANSI C800-25 §9.7.2. Charging curves and states of charge prior to testing are included in the formal UL Solutions Report [12] and validate the open circuit voltages for modules and racks meets or exceed the maximum state of charge.



Figure 16 - Sample Confirmation of Module Voltage

Environmental Conditions

Environmental conditions were determined to be suitable and in accordance with UL 9540A draft, §10.1B.11, as well as CSA/ANSI C800:25, §9.7.2. Specifically, the wind speed was less than 19.3 km/hr (≤12 miles/hour), the temperature was more than 10 °C (50 °F) and less than 40 °C (105 °F) for the majority of the test, humidity was less than 90%, and there was no precipitation. Environmental conditions remained within the above bounds during the entire test, though there were natural variations in wind, temperature, and humidity due to the testing duration. Exact environmental conditions changed during the duration of the test. Environmental condition data is published in the formal UL Solutions Report [12].

Ventilation Conditions – Enclosure A

Prior to the start of the test, the roof mounted NFPA 68 deflagration vents were removed. The purpose of this was to encourage a fully developed fire, as well as to comply with CSA/ANSI C800-25 §9.7.1, "*During testing, these systems shall remain open in the initiating unit and closed on the target units.*" This approach also met UL 9540A draft, §10.1C.2, "*Deflagration pressure relief areas in the enclosure shall be open from the beginning of the test. Openings that are not deflagration pressure relief areas shall remain closed.*" Furthermore, UL 9540A draft §10.1A.4 states "*The developed fire condition is assumed to occur after the operation*

and dissipation of single-use, non-continuous operation systems designed to protect the BESS enclosure of origin.” The opening of the deflagration vents is intended to replicate a scenario in which an explosion occurred, the deflagration vents have opened, and a fire subsequently occurs. The chosen ventilation conditions meet the requirements of CSA/ANSI C800-25 and the referenced UL 9540A draft.



Figure 17 - Deflagration Vents Open - Enclosure A

Ancillary Systems

Enclosure A (enclosure of origin): The NFPA 69 combustible concentration reduction system was disabled. This decision was made to meet the intention of UL 9540A draft, §10.1A.5 and §10.1C.2. The heat detectors, smoke detectors, gas detectors, and battery management systems within Enclosure A were all active during the test; however, the outputs were disabled. The liquid coolant was retained in Enclosure A to represent an as-installed configuration, and to best represent the total combustible loading. The coolant is comprised of a mixture of water and ethylene glycol, a combustible liquid.

Enclosures B and C (target enclosures): Within the target enclosures, the NFPA 69 system was disabled. Similarly, additional systems (battery management systems, fire alarm/detection, gas detection) were disabled. The exclusion of these systems in the target containers is not anticipated to affect test results. No coolant was included in target enclosures. This represents a worse-case situation as the coolant (if included) would be expected to absorb heat and potentially mitigate cell and module temperature rise from thermal exposure.

Thermocouple Locations

More than 200 thermocouples were installed across all three enclosures, with the placement of the thermocouples meeting the intent of UL 9540A, draft, §10.1E. Additionally, CSA/ANSI C800-25 §9.7.3 requires documentation of the temperatures of modules in

adjacent ESS units, as well as temperatures of any connections between the initiating units and adjacent units. Atar Fire verified that the thermocouple type, wire type, and thermocouple locations were all in accordance with the test plan. The data collection rate cycle was approximately 1 Hz.

Within the enclosures, selected cells and modules were outfitted with thermocouples, to meet the intent of UL 9540A draft, §10.1E.7 and 10.1E.8. Cell level thermocouples were included in the initiating module within Enclosure A, as well as select cells in both Enclosures B and C in areas expected to receive the greatest thermal exposure. Additionally, thermocouples were placed on the module casings, and strategic locations such as inner enclosure surfaces, outer enclosure surfaces, deflagration vent openings, louvers, and more. Thermocouple locations were chosen to adequately assess as well as capture the maximum thermal stress from a fire originating in Enclosure A. A sample of some of these locations is shown in the following figures.

A detailed review of all thermocouple locations is not included in this summary report for brevity. Examples of thermocouple locations at cell, module, and enclosure level are shown as follows:

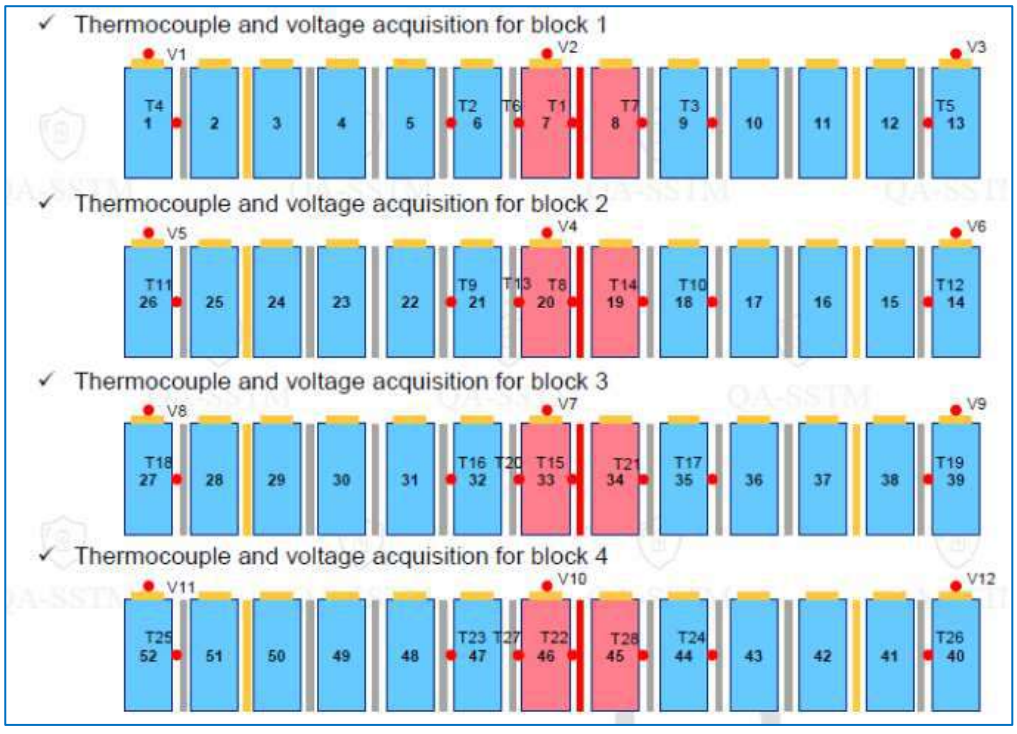

Figure 18 - Enclosure A - Cell Thermocouples in Initiating Module (Thermocouples Denoted 'T1, T2, etc...')

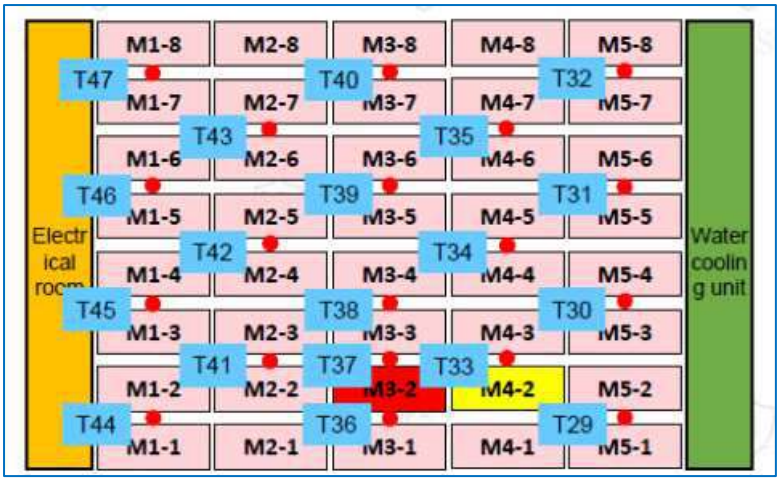

Figure 19 – Enclosure A - Module Thermocouples Example Locations

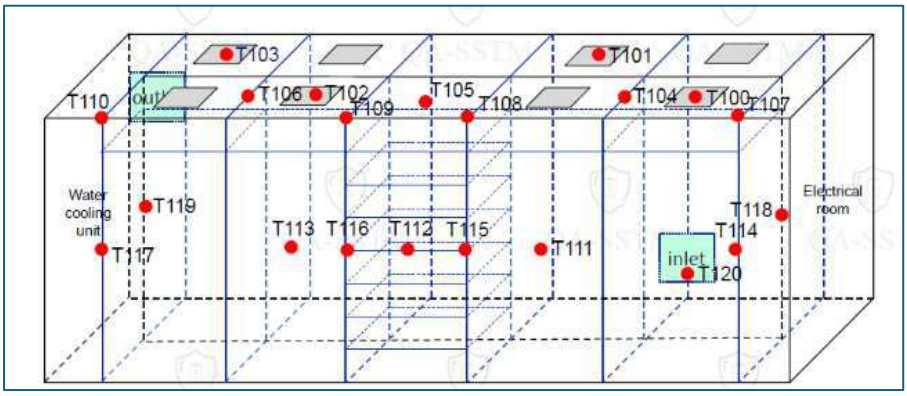

Figure 20 - Enclosure B – Inner Enclosure Surface Thermocouples

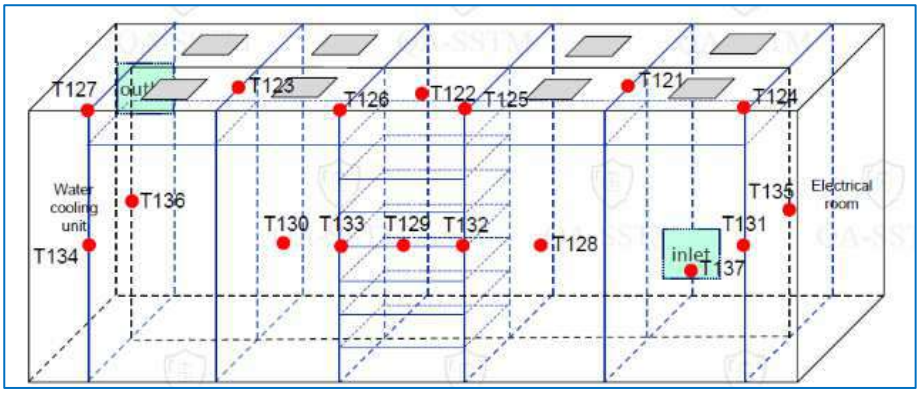

Figure 21 - Enclosure C – Outer Enclosure Surface Thermocouples

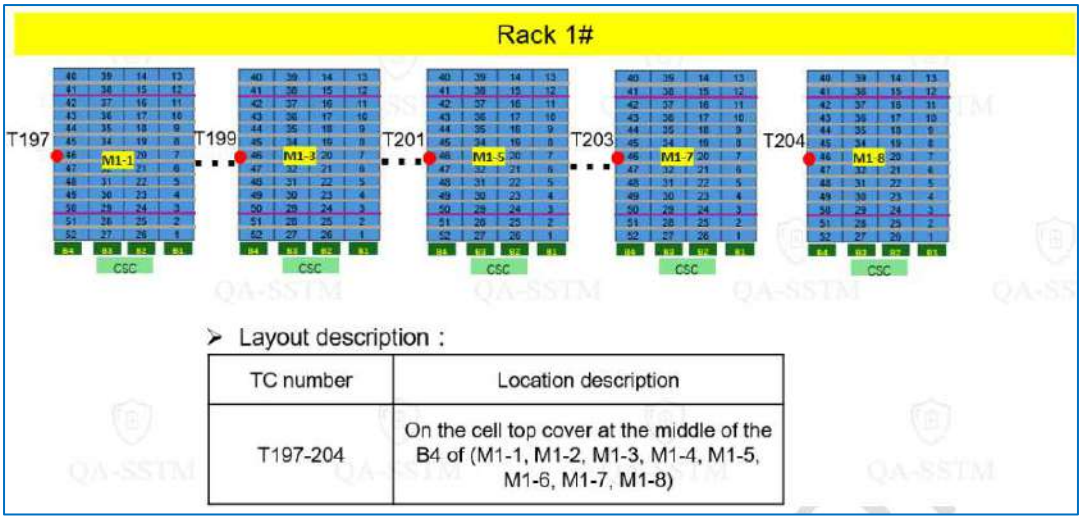

Figure 22 – Enclosure C - Sample Cell Thermocouples

Heat Flux Gauges

Heat flux gauges were placed throughout the testing area to obtain data for use in evaluating exposures and associated distances. Seven heat flux gauges were utilized. Atar Fire verified exact placement and orientation of gauges prior to test. Heat flux gauge locations are graphically represented as follows, with distances specified in the subsequent Table.

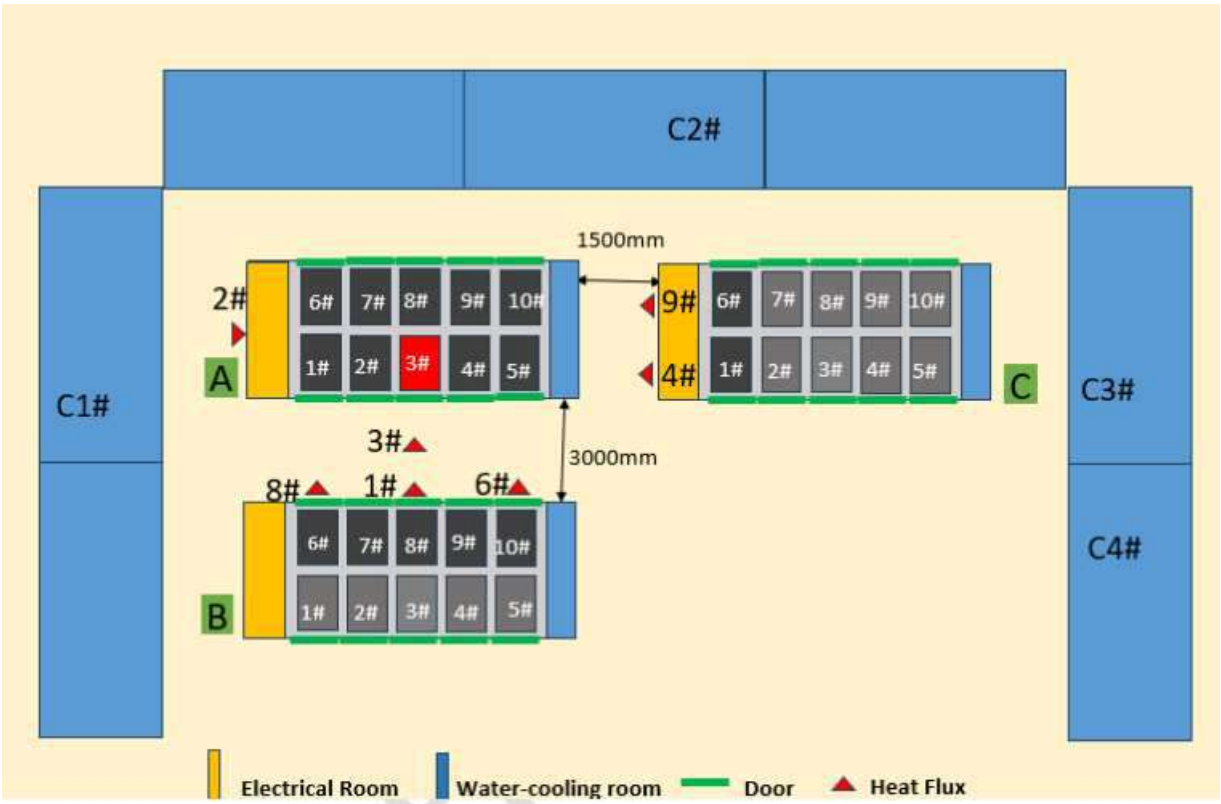

Figure 23 - Heat Flux Gauge Locations

Gauge Number	Height	Distance From Enclosure A / Position
1	2896 mm	3000 mm (~ 118 inches) / Face of Enclosure B, Across from Rack 3 on Enclosure A
2	2362 mm	0 mm (0 inches) / Side of Electrical Room Enclosure A – At NFPA 69 Air Outlet
3	1448 mm	1500 mm (~59 inches) / Half Distance Between Enclosure A & B, Across from Rack 3 on Enclosure A
4	2896 mm	1500 mm (~59 inches) / Face of Electrical Room, Enclosure C, Across from Rack 5 on Enclosure A
6	2896 mm	3000 mm (~ 118 inches) / Face of Enclosure B, Across from Rack 5 on Enclosure A
8	2896 mm	3000 mm (~ 118 inches) / Face of Enclosure B, Across from Rack 1 on Enclosure A
9	2896 mm	1500 mm (~59 inches) / Face of Electrical Room, Enclosure C, Across from Rack 10 on Enclosure A

Table 3 - Heat Flux Gauge Positions

Analysis

Fire Development & Enclosure Consumption

On-site witnessing observed and confirmed that a fully developed fire resulted from the testing procedure. Enclosure A was completely consumed by fire. Fire continued without any intervention until the test was terminated. Images of the fully developed fire, as well as full enclosure consumption, are shown as follows:



Figure 24 - Fully Developed Fire



Figure 25 - Full Enclosure A Consumption



Figure 26 - Fully Consumed Rack – Detail View – Enclosure A

Enclosure Propagation

Atar Fire did not observe any sustained fire propagation between enclosures, although some heat damage was observed. The absence of fire propagation to the battery cells of target enclosures meets the fundamental requirement and intent of NFPA 855 and the IFC, as outlined in the codes and standards section of this report. Images of the exterior of Enclosure B and C post-test are shown as follows:



Figure 27 - Enclosure B Soot Damage Post-Test



Figure 28 - Enclosure C Soot Damage Post Test

Deflagrations

During on-site witnessing of the test by Atar Fire, a partial volume deflagration was observed in Enclosure A. This event was observed approximately 1 hour and 36 minutes after the fire was initiated. This deflagration did not appear to significantly damage Enclosure A (doors remained closed, no rupture of enclosure, no obvious deformation of enclosure during post-test examination), nor did it appear to impact other Enclosures. However, some flying debris resulted. For example, a piece of debris was observed to be ejected and continued to burn for approximately one minute before self-extinguishing in its landing location. This flying and flaming debris did not lead to fire propagation. An image of the ejected debris is shown as follows:



Figure 29 - Ejected Debris During Test

The significance of a partial volume deflagration event, with vents open and several hours into the LSFT, may be used to inform emergency response planning. Even in the event of visible flaming, a partial volume deflagration may still occur, and extreme caution by first responders should be undertaken. Always observe appropriate standoff distances and use appropriate personal protective equipment. Additionally, flying and flaming debris from a deflagration could lead to spot fires. The responding fire department should be aware of this and respond accordingly.

Fire Characterization

The period of fire growth from ignition to peak heat release rate (HRR) was approximately 90 minutes. The total duration of visible (exterior) flaming was approximately 14.5 hours. The peak HRR observed in the test was approximately 8.1 MWh. The HRR curve is shown in the Figure 30. Note that the blue line represents peak chemical HRR, and the orange line represents peak convective HRR.

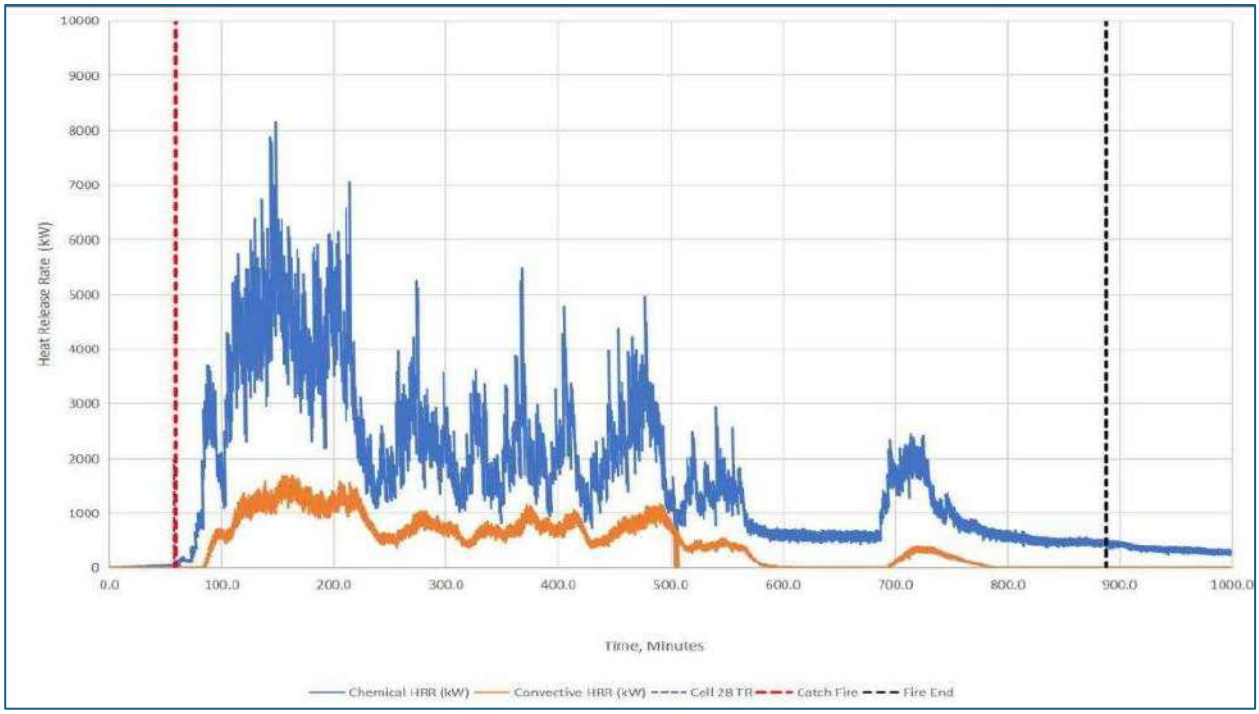

Figure 30 - Heat Release Rate Curve

Flux Data

The observed maximum heat flux at each test gauge is shown in Table 4. Heat Flux Gauge 4, located on Enclosure C, received the highest heat flux, at 35 kW/m^2. This is likely due to a combination of the distance from Enclosure A (1500 mm) and the height, which allowed for a line of sight towards two deflagration vents from which fire was emanating. Heat Flux Gauge 1, located further from Enclosure B (3000 mm away) but also at the height of Enclosure B, received the next highest heat flux, at 17.5 kW/m^2. While this gauge had a higher view factor (with line of sight to four deflagration vents), the larger distance may have contributed to the lower heat flux when compared to Heat Flux Gauge 4. This illustrates that target enclosure heat flux is dependent upon both distance and view factors. Heat Flux Gauges 5 and 6 also received heat flux values just above 12.5 kW/m^2. The value of 12.5 kW/m^2 is often cited as the ignition heat flux for building exposure. This value is referenced in NFPA 80A [11] and is generally accepted as the minimum threshold at which piloted ignition of cellulosic material may occur. Given the lack of cellulosic material on the exterior of each enclosure, this value is less appropriate as

Table 4 - Maximum Heat Flux Values

Heat Flux Gauge	Location	Distance from Enclosure A	Height	Maximum Measured Heat Flux (kW/m²)
1	Aisle between Enclosure A & B	3000 mm (~ 118 inches) / Face of Enclosure B, Across from Rack 3 on Enclosure A	2896 mm	17.5
2	Aisle between Enclosure A & B	0 mm (0 inches) / Side of Electrical Room Enclosure A – At NFPA 69 Air Outlet	2362 mm	1.7
3	Aisle between Enclosure A & C	1500 mm (~59 inches) / Half Distance Between Enclosure A & B, Across from Rack 3 on Enclosure A	1448 mm	4.4
4	Aisle between Enclosure A & C	1500 mm (~59 inches) / Face of Electrical Room, Enclosure C, Across from Rack 5 on Enclosure A	2896 mm	35.0
5	Aisle between Enclosure A & D	3000 mm (~ 118 inches) / Face of Enclosure B, Across from Rack 5 on Enclosure A	2896 mm	14.9
6	Aisle between Enclosure A & D	3000 mm (~ 118 inches) / Face of Enclosure B, Across from Rack 1 on Enclosure A	2896 mm	15.1
7	Aisle between Enclosure A & E	1500 mm (~59 inches) / Face of Electrical Room, Enclosure C, Across from Rack 10 on Enclosure A	2896 mm	11.0

Thermocouple Temperatures

With respect to thermocouple temperatures, a complete overview of all thermocouple temperatures, including time-temperature curves, is provided in the UL Solutions Report [12]. For the purposes of this report, it is noted that cell thermocouple temperatures inside target Enclosures B/C did not exceed the cell vent temperature of 161 ℃ [6] at any time. A complete summary of cell, module, interior, and exterior peak temperatures for Enclosures B and C is shown in Table 5.

It can be seen that Enclosure B, at 3000 mm from Enclosure A, and located in a face-to-face orientation with respect to Enclosure A, experienced higher cell, module, and interior temperatures than Enclosure A. This could potentially be attributed to the longer duration exposure that Enclosure B received compared to Enclosure C, resulting from the face-to-face orientation. Enclosure C, at 1500 mm from Enclosure A, did observe a higher peak exterior temperature. It is postulated this is due to the closer distance to Enclosure A, and corresponding higher received heat flux as previously described. Due to its end-end

location, the duration of fire exposure was likely shorter, therefore, interior, module, and cell temperature remained lower than Enclosure B.

Table 5 - Peak Observed Temperatures

Enclosure	Peak Cell Temperature (℃)	Peak Module Temperature (℃)	Peak Interior Temperature (℃)	Peak Exterior Temperature (℃)
B	43.9 Location: T151	85.0 Location: T138	106.4 Location: T107	225.6 Location: T129
C	29.5 Location: T220	42.5 Location: T212	97.7 Location: T171	255.4 Location: T184

Venting & Thermal Runaway

Atar Fire observations indicated the test did not lead to venting or thermal runaway of cells in any adjacent enclosures, meeting the criteria of UL 9540A draft, §10.1J.1. Cell temperatures in adjacent enclosures remained below the 90% of the average cell vent temperature in the UL 9540A cell level report [6], as required by draft UL 9540A, Table 10.1.

Acceptance & Reporting Criteria

The following summary table is provided for reference as it pertains to test acceptance criteria in the April 29 draft UL 9540A.

Table 6 - UL 9540A Draft Acceptance Criteria

Item Number	Description and Conditions	Atar Fire Comments
10.1J.1.1	There shall be no venting in any cells or modules in the target enclosures.	No venting was observed.
10.1J.1.2	There shall be no thermal runaways in any cells or modules in the target enclosures.	No thermal runaway was observed
10.1J.1.3	If target enclosures are not populated with cells or modules, there shall be no penetration of flames through existing interconnection paths that result in breaches from the enclosure of origin into the target enclosure.	N/A. There are no interconnection paths
10.1J.1.4	The temperature criteria in 10.1J.1.5 – 10.1J.1.9 shall not be exceeded, as summarized in Table 10.1. Temperature measurements shall be evaluated with 60-second averaging. The selected criterion shall correspond to the test instrument placement for target BESS. Performance criteria shall be evaluated at the nearest representation to the location to where cells are installed. For example, if the enclosure interior and cell locations are both instrumented, the cell location shall be used to evaluate the performance criteria. Similarly, if the enclosure interior and module surfaces are both instrumented, the module surfaces shall be used to evaluate the performance criteria.	Temperature criteria not exceeded
10.1J.1.5	With reference to 10.1J.1.4, the temperatures measured by thermocouples placed on cells within the targets per 10.1E.7 shall not exceed 90% of the average temperature of venting temperature from the Cell Level test, Section 7	Compliant. Highest Cell Temperature 106 ℃.
10.1J.1.6	With reference to 10.1J.1.4, the temperatures measured by thermocouples placed on dummy modules within the targets per 10.1E.8 shall not exceed the average temperature at which thermally initiated cell venting occurs according to the Cell Level testing as specified in Section 7.	Compliant. Highest Module Temperatures 162.7 ℃.
10.1J.1.7	With reference to 10.1J.1.4, the temperatures measured by thermocouples placed on the interior surface of target enclosures per 10.1E9 shall not exceed the average temperature at which thermally initiated cell venting occurs according to the Cell Level testing as specified in Section 7.	No Cell Venting or Thermal Runaway Observed. See 10.1K.1.5
10.1J.1.8	With reference to 10.1J.1.4, surface temperature measurements along instrumented wall surfaces shall not exceed a temperature rise of 97 °C (175 °F) above ambient when used as target BESS enclosures.	N/A – No Instrumented Wall
10.1J.1.9	Heat flux measurements shall not exceed 12.5 kW/m2 where used to determine separation distances to combustible structures. Heat flux measurements shall be evaluated with 60-second averaging.	The heat flux data generated may be used to inform site specific analysis.

The following summary table is provided for reference as it pertains to the required reporting items in CSA/ANSI C800:25 §9.7.6.

Table 7 - Summary Table of CSA/ANSI C800 Reporting Requirements

Item Number	Description and Conditions	Atar Fire Comments
a)	Any penetrations of flames or flammable gas into the adjacent target units.	No penetration of flames or flammable gases was observed in target units
b)	Thermal Runaway Events of Cells in the Adjacent Target Units	No cell thermal runaway was observed
c)	Status And Loss of BMS Communication During Test	Data Not Recorded
d)	Status and Loss of Fire Detection, and Any Other Alarm Systems, During the Test	Data Not Recorded
e)	Damage to the Initiating Unit and any Damage (Soot, smoke, or otherwise) to target adjacent units	Soot and smoke staining occurred on target units
f)	Pictures of the initiating unit every 10 minutes from post-fire detection up to 2 hours	Video footage continuous for duration of test
g)	Temperature data at the following locations: i) external faces of the target units and initiating units, ii) various internal points of the target units, initiating unit, and adjacent battery racks, iii) HVAC system, cabling, wiring, switchgear, and other combustibles	Temperature data recorded. Data summary provided by UL Solutions Report [12]
h)	Heat Flux gauges installed on all target units and exposures per the manufacturer's installation instructions	Heat flux gauges confirmed to be installed per test plan
i)	Peak heat release rate from the main initiating unit	The peak heat release rate documented in UL Solutions Report [12] and this Report
j)	Size, duration, and location of the largest flames seen during the test	Documented in the UL Solutions Report [12]
k)	Pre- and post-test adjacent module voltages	Documented in the UL Solutions Report [12]
l)	Deflagration events observed during the test	On deflagration observed in Enclosure A and discussed in this report
m)	Visual and IR video footage of the test	Video and IR recording was for the duration of the test.

Conclusion

It is the engineering opinion of Atar Fire that the testing has been performed in accordance with the UL 9540A draft dated June 29, 2025, as well as CSA/ANSI C800-25, and as such, meets the intent of both NFPA 855 and the IFC for large-scale fire testing. The testing demonstrated that for the products evaluated, under the specific test conditions, fire will not propagate from enclosure to enclosure even when one enclosure is fully involved in a fire.

It is recognized that this test cannot account for every situation that may occur, including varied environmental conditions. It is recommended that the results of this test be utilized by CATL and any constituents to inform emergency response planning efforts that can be closely coordinated with local Fire Departments.

References

[1] UL 9540A, Standard for the Safety for Test Method for Evaluating Thermal Runaway Fire Propagation in Energy Storage Systems. Date of Proposal: June 27, 2025. UL Standards & Engagement.

[2] CSA/ANSI C800:25, *Testing Protocol for Energy Storage System Reliability and Quality Assurance Program*.

[3] NFPA 855, *Standard for the Installation of Energy Storage Systems,* 2026 Edition.

[4] International Code Council, *International Fire Code*, 2024 Edition.

[5] International Code Council, *International Fire Code and Commentary, 2021 Edition*

[6] UL 9540A Cell Level Report, UL Solutions, Project Number 4791943570. Date of Issue 2025-10-24.

[7] NFPA 69, *Standard on Explosion Prevention Systems*, 2024 Edition.

[8] UL 9540A, Standard for the Safety for Test Method for Evaluating Thermal Runaway Fire Propagation in Energy Storage Systems, 4th Edition, 2019. UL Standards & Engagement.

[9] NFPA 68, *Standard on Explosion Protection By Deflagration Venting*, 2023 Edition.

[10] CFD Modeling Report for Battery Energy Storage System. Analysis of Explosion Venting in Accordance with NFPA 68. Atar Fire, LLC. Report 20251005. Dated 2025-11-03.

[11] CFD Modeling Report for Battery Energy Storage System. Analysis of Explosion Prevention in Accordance with NFPA 69. Atar Fire, LLC. Report 20251004. Dated 2025-11-03.

[12] Large Scale Fire Test Report. Battery Energy Storage System model C04285P10L01 (3.779 MWh)

Appendix D

CATL USER MANUAL

This Appendix is protected under a confidentiality agreement and has been redacted from this version of the report.

Appendix E

SAFETY DATA SHEET

SAFETY DATA SHEET

Conforms to Regulation (EC) No. 1907/2006 (REACH), Annex II, as amended by Commission Regulation (EU) 2015/830

SECTION 1: Identification of the substance/mixture and of the company/ undertaking

1.1 Product identifier

Product identifier : 2025004937099

Product name : AE30017704220
TEODUR AP
RAL 7042 TRAFFIC GREY A
MATT SMOOTH

Product type : Powder.

Other means of identification : Not available.

Date of issue : 6 March 2020

Version : 2

Date of previous issue : 15 December 2019

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Powder coating for industrial use.

Uses advised against : For industrial use only by trained professionals. Not for sale to or use by consumers.

1.3 Details of the supplier of the safety data sheet

Axalta Coating Systems Germany GmbH & Co. KG
Christbusch 25
DE 42285 Wuppertal
+49 (0)202 529-0

e-mail address of person responsible for this SDS : sds-competence@axalta.com

National contact

Axalta Powder Coating Systems UK Ltd.
Whessoe Road
GB Darlington, County Durham. DL3 0XH
+44 (0)1325 355371

1.4 Emergency telephone number

Supplier

+(44)-870-8200418

SECTION 2: Hazards identification

2.1 Classification of the substance or mixture

Product definition : Mixture

Classification according to Regulation (EC) No. 1272/2008 [CLP/GHS]

Aquatic Chronic 3, H412

The product is classified as hazardous according to Regulation (EC) 1272/2008 as amended.

See Section 16 for the full text of the H statements declared above.

See Section 11 for more detailed information on health effects and symptoms.

2.2 Label elements

Hazard pictograms : Not applicable.

Signal word : No signal word.

Hazard statements : H412 - Harmful to aquatic life with long lasting effects.

Precautionary statements

Prevention : P273 - Avoid release to the environment.

Response : Not applicable.

Storage : Not applicable.

Disposal : P501 - Dispose of contents and container in accordance with all local, regional, national and international regulations.

Supplemental label elements : Not applicable.

Supplemental label elements (CEPE) :

Annex XVII - Restrictions on the manufacture, placing on the market and use of certain dangerous substances, mixtures and articles : Not applicable.

2.3 Other hazards

Product meets the criteria for PBT or vPvB according to Regulation (EC) No. 1907/2006, Annex XIII : This mixture does not contain any substances that are assessed to be a PBT or a vPvB.

Other hazards which do not result in classification : May form explosible dust-air mixture if dispersed.

SECTION 3: Composition/information on ingredients

3.2 Mixtures : Mixture

SECTION 3: Composition/information on ingredients

Product/ingredient name	Identifiers	%	Regulation (EC) No. 1272/2008 [CLP]	Type
BIS(2,4-DI-T-BUTYLPHENYL) PENTAERYTHRITOL DIPHOSPHITE	REACH #: 01-2119977073-34 CAS: 26741-53-7	≤1	Aquatic Chronic 1, H410 (M=1) **See Section 16 for the full text of the H statements declared above.**	[1]

There are no additional ingredients present which, within the current knowledge of the supplier and in the concentrations applicable, are classified as hazardous to health or the environment, are PBTs, vPvBs or Substances of equivalent concern, or have been assigned a workplace exposure limit and hence require reporting in this section.

Type

[1] Substance classified with a health or environmental hazard
[2] Substance with a workplace exposure limit
[3] Substance meets the criteria for PBT according to Regulation (EC) No. 1907/2006, Annex XIII
[4] Substance meets the criteria for vPvB according to Regulation (EC) No. 1907/2006, Annex XIII
[5] Substance of equivalent concern
[6] Additional disclosure due to company policy

Occupational exposure limits, if available, are listed in Section 8.

SECTION 4: First aid measures

4.1 Description of first aid measures

General : In all cases of doubt, or when symptoms persist, seek medical attention. Never give anything by mouth to an unconscious person. If unconscious, place in recovery position and seek medical advice.

Eye contact : Remove contact lenses, irrigate copiously with clean, fresh water, holding the eyelids apart for at least 10 minutes and seek immediate medical advice.

Inhalation : Remove to fresh air. Keep person warm and at rest. If not breathing, if breathing is irregular or if respiratory arrest occurs, provide artificial respiration or oxygen by trained personnel.

Skin contact : Remove contaminated clothing and shoes. Wash skin thoroughly with soap and water or use recognised skin cleanser. Do NOT use solvents or thinners.

Ingestion : If swallowed, seek medical advice immediately and show the container or label. Keep person warm and at rest. Do NOT induce vomiting.

Protection of first-aiders : No action shall be taken involving any personal risk or without suitable training. It may be dangerous to the person providing aid to give mouth-to-mouth resuscitation.

4.2 Most important symptoms and effects, both acute and delayed

There are no data available on the mixture itself. The mixture has been assessed following the conventional method of the CLP Regulation (EC) No 1272/2008 and is classified for toxicological properties accordingly. See Sections 2 and 3 for details.

This takes into account, where known, delayed and immediate effects and also chronic effects of components from short-term and long-term exposure by oral, inhalation and dermal routes of exposure and eye contact.
Coating powders can cause localised skin irritation in folds of the skin or under tight clothing.

SECTION 4: First aid measures

4.3 Indication of any immediate medical attention and special treatment needed

Notes to physician : In case of inhalation of decomposition products in a fire, symptoms may be delayed. The exposed person may need to be kept under medical surveillance for 48 hours.

Specific treatments : No specific treatment.

See toxicological information (Section 11)

SECTION 5: Firefighting measures

5.1 Extinguishing media

Suitable extinguishing media : Recommended: alcohol-resistant foam, CO_2 blanket, water spray or mist.

Unsuitable extinguishing media : Do not use water jet.
Do not use inert gas under high pressure (e.g. CO2).

5.2 Special hazards arising from the substance or mixture

Hazards from the substance or mixture : Fire will produce dense black smoke. Exposure to decomposition products may cause a health hazard.

Hazardous combustion products : Decomposition products may include the following materials: carbon monoxide, carbon dioxide, smoke, oxides of nitrogen.

5.3 Advice for firefighters

Special protective actions for fire-fighters : Cool closed containers exposed to fire with water. Do not release runoff from fire to drains or watercourses.

Special protective equipment for fire-fighters : Appropriate breathing apparatus may be required.

SECTION 6: Accidental release measures

6.1 Personal precautions, protective equipment and emergency procedures

For non-emergency personnel : Exclude sources of ignition and ventilate the area. Avoid breathing dust. Refer to protective measures listed in sections 7 and 8.

For emergency responders : If specialised clothing is required to deal with the spillage, take note of any information in Section 8 on suitable and unsuitable materials. See also the information in "For non-emergency personnel".

6.2 Environmental precautions : Do not allow to enter drains or watercourses. If the product contaminates lakes, rivers, or sewers, inform the appropriate authorities in accordance with local regulations.

6.3 Methods and material for containment and cleaning up : Contain and collect spillage with an electrically protected vacuum cleaner or by wet-brushing and place in container for disposal according to local regulations (see section 13). Do not use a dry brush as dust clouds or static can be created.

6.4 Reference to other sections : See Section 1 for emergency contact information.
See Section 8 for information on appropriate personal protective equipment.
See Section 13 for additional waste treatment information.

SECTION 7: Handling and storage

The information in this section contains generic advice and guidance. The list of Identified Uses in Section 1 should be consulted for any available use-specific information provided in the Exposure Scenario(s).

Advice should be taken from a competent occupational health practitioner on the assessment of employees with skin or respiratory complaints before the individual is exposed to the uncured product.

7.1 Precautions for safe handling : Precautions should be taken to prevent the formation of dusts in concentrations above flammable, explosive or occupational exposure limits.
Electrical equipment and lighting should be protected to appropriate standards to prevent dust coming into contact with hot surfaces, sparks or other ignition sources.
Mixture may charge electrostatically: always use earthing leads when transferring from one container to another.
Operators should wear antistatic footwear and clothing and floors should be of the conducting type.
Keep away from heat, sparks and flame.
Avoid contact with skin and eyes. Avoid the inhalation of dust, particulates, spray or mist arising from the application of this mixture. Avoid inhalation of dust from sanding.
Eating, drinking and smoking should be prohibited in areas where this material is handled, stored and processed.
Put on appropriate personal protective equipment (see Section 8).
Always keep in containers made from the same material as the original one.
Comply with the health and safety at work laws.
Do not allow to enter drains or watercourses.

7.2 Conditions for safe storage, including any incompatibilities

Store in accordance with local regulations.

Additional information on storage conditions

Observe label precautions. Store in a dry, cool and well-ventilated area. Keep away from heat and direct sunlight. Keep container tightly closed.
Keep away from sources of ignition. No smoking. Prevent unauthorised access. Containers that have been opened must be carefully resealed and kept upright to prevent leakage.

7.3 Specific end use(s)

Recommendations : Not available.

Industrial sector specific solutions : Not available.

SECTION 8: Exposure controls/personal protection

The information in this section contains generic advice and guidance. Information is provided based on typical anticipated uses of the product. Additional measures might be required for bulk handling or other uses that could significantly increase worker exposure or environmental releases.

8.1 Control parameters

Occupational exposure limits

No exposure limit value known.

SECTION 8: Exposure controls/personal protection

Recommended monitoring procedures : If this product contains ingredients with exposure limits, personal, workplace atmosphere or biological monitoring may be required to determine the effectiveness of the ventilation or other control measures and/or the necessity to use respiratory protective equipment. Reference should be made to monitoring standards, such as the following: European Standard EN 689 (Workplace atmospheres - Guidance for the assessment of exposure by inhalation to chemical agents for comparison with limit values and measurement strategy) European Standard EN 14042 (Workplace atmospheres - Guide for the application and use of procedures for the assessment of exposure to chemical and biological agents) European Standard EN 482 (Workplace atmospheres - General requirements for the performance of procedures for the measurement of chemical agents) Reference to national guidance documents for methods for the determination of hazardous substances will also be required.

DNELs/DMELs

Product/ingredient name	Type	Exposure	Value	Population	Effects
BIS(2,4-DI-T-BUTYLPHENYL) PENTAERYTHRITOL DIPHOSPHITE	DNEL	Long term Oral	0.275 mg/ kg bw/day	General population	Systemic
	DNEL	Long term Dermal	0.275 mg/ kg bw/day	General population	Systemic
	DNEL	Long term Dermal	0.55 mg/ kg bw/day	Workers	Systemic

PNECs

No PNECs available

8.2 Exposure controls

Appropriate engineering controls : Avoid breathing dust. Where reasonably practicable, this should be achieved by the use of local exhaust ventilation and good general extraction. If these are not sufficient to maintain exposure to dusts below the OEL, suitable respiratory protection must be worn.

Individual protection measures

Hygiene measures : Wash hands, forearms and face thoroughly after handling chemical products, before eating, smoking and using the lavatory and at the end of the working period. Appropriate techniques should be used to remove potentially contaminated clothing. Wash contaminated clothing before reusing. Ensure that eyewash stations and safety showers are close to the workstation location.

Eye/face protection : Safety eyewear should be used when there is a likelihood of exposure.

Skin protection

Body protection : Personnel should wear protective clothing. Care should be taken in the selection of protective clothing to ensure that inflammation and irritation of the skin at the neck and wrists through contact with the powder are avoided.

Other skin protection : Appropriate footwear and any additional skin protection measures should be selected based on the task being performed and the risks involved and should be approved by a specialist before handling this product.

SECTION 8: Exposure controls/personal protection

Respiratory protection : If workers are exposed to concentrations above the exposure limit, they must use appropriate, certified respirators.

Dry sanding, flame cutting and/or welding of the dry paint film will give rise to dust and/or hazardous fumes. Wet sanding/flatting should be used wherever possible. If exposure cannot be avoided by the provision of local exhaust ventilation, suitable respiratory protective equipment should be used.

Environmental exposure controls : Do not allow to enter drains or watercourses.

SECTION 9: Physical and chemical properties

9.1 Information on basic physical and chemical properties

Appearance

Physical state	: Solid.
Colour	: Not available.
Odour	: Not available.
Odour threshold	: Not available.
pH	: Not applicable.
Melting point/freezing point	: Not available.
Initial boiling point and boiling range	: Not applicable.
Flash point	: Closed cup: Not applicable. [Product does not sustain combustion.]
Evaporation rate	: Not available.
Flammability (solid, gas)	: Not available.
Lower and upper explosive (flammable) limits	: Lower: 40 g/m³
Vapour pressure	: Not available.
Vapour density	: Not available.
Relative density	: 1.571 g/cm³
Solubility(ies)	: Partially soluble in the following materials: cold water.
Partition coefficient: n-octanol/ water	: Not available.
Auto-ignition temperature	: Not available.
Decomposition temperature	: Not applicable.
Viscosity	: Not available.
Explosive properties	: Not available.
Oxidising properties	: Not available.
Weight volatiles	: 0 % (w/w)
VOC content	: 0 % (w/w)

9.2 Other information

Solubility in water : Not available.

room temperature (=20°C)

SECTION 10: Stability and reactivity

10.1 Reactivity : No specific test data related to reactivity available for this product or its ingredients.

10.2 Chemical stability : Stable under recommended storage and handling conditions (see Section 7).

10.3 Possibility of hazardous reactions : Under normal conditions of storage and use, hazardous reactions will not occur.

10.4 Conditions to avoid : When exposed to high temperatures may produce hazardous decomposition products.

10.5 Incompatible materials : Not applicable.

10.6 Hazardous decomposition products : Decomposition products may include the following materials: carbon monoxide, carbon dioxide, smoke, oxides of nitrogen.

Not applicable

SECTION 11: Toxicological information

11.1 Information on toxicological effects

There are no data available on the mixture itself. The mixture has been assessed following the conventional method of the CLP Regulation (EC) No 1272/2008 and is classified for toxicological properties accordingly. See Sections 2 and 3 for details.

This takes into account, where known, delayed and immediate effects and also chronic effects of components from short-term and long-term exposure by oral, inhalation and dermal routes of exposure and eye contact.
Coating powders can cause localised skin irritation in folds of the skin or under tight clothing.

Acute toxicity

Product/ingredient name	Result	Species	Dose	Exposure
BIS(2,4-DI-T-BUTYLPHENYL) PENTAERYTHRITOL DIPHOSPHITE	LD50 Oral	Rat	5580 mg/kg	-

Conclusion/Summary : Not available.

Acute toxicity estimates

Product/ingredient name	Oral (mg/kg)	Dermal (mg/kg)	Inhalation (gases) (ppm)	Inhalation (vapours) (mg/l)	Inhalation (dusts and mists) (mg/l)
BIS(2,4-DI-T-BUTYLPHENYL) PENTAERYTHRITOL DIPHOSPHITE	5580	N/A	N/A	N/A	N/A

Irritation/Corrosion

SECTION 11: Toxicological information

Product/ingredient name	Result	Species	Score	Exposure	Observation
BIS(2,4-DI-T-BUTYLPHENYL) PENTAERYTHRITOL DIPHOSPHITE	Skin - Severe irritant	Rabbit	-	0.5 Grams	-

Conclusion/Summary : Not available.

Sensitisation

Conclusion/Summary : Not available.

Mutagenicity

Conclusion/Summary : Not available.

Carcinogenicity

Conclusion/Summary : Not available.

Reproductive toxicity

Conclusion/Summary : Not available.

Teratogenicity

Conclusion/Summary : Not available.

Specific target organ toxicity (single exposure)

Not available.

Specific target organ toxicity (repeated exposure)

Not available.

Aspiration hazard

Not available.

Other information : Not available.

SECTION 12: Ecological information

12.1 Toxicity

There are no data available on the mixture itself.
Coating powder residues should not be allowed to enter drains or watercourses or be deposited where they could affect ground or surface waters.

The mixture has been assessed following the summation method of the CLP Regulation (EC) No 1272/2008 and is classified for eco-toxicological properties accordingly. See Sections 2 and 3 for details.

Product/ingredient name	Result	Species	Exposure
BIS(2,4-DI-T-BUTYLPHENYL) PENTAERYTHRITOL DIPHOSPHITE	LC50 70.7 mg/l	Fish	96 hours
	NOEC 0.1 mg/l	Daphnia	21 days

Conclusion/Summary : Not available.

12.2 Persistence and degradability

SECTION 12: Ecological information

Product/ingredient name	Test	Result	Dose	Inoculum
BIS(2,4-DI-T-BUTYLPHENYL) PENTAERYTHRITOL DIPHOSPHITE	OECD 301 B	9 % - 28 days	-	-

Conclusion/Summary : Not available.

Product/ingredient name	Aquatic half-life	Photolysis	Biodegradability
BIS(2,4-DI-T-BUTYLPHENYL) PENTAERYTHRITOL DIPHOSPHITE	-	-	Not readily

12.3 Bioaccumulative potential

Not available.

12.4 Mobility in soil

Soil/water partition coefficient (K_{OC}) : Not available.

Mobility : Not available.

12.5 Results of PBT and vPvB assessment

This mixture does not contain any substances that are assessed to be a PBT or a vPvB.

12.6 Other adverse effects : No known significant effects or critical hazards.

SECTION 13: Disposal considerations

The information in this section contains generic advice and guidance. The list of Identified Uses in Section 1 should be consulted for any available use-specific information provided in the Exposure Scenario(s).

13.1 Waste treatment methods

Product

Methods of disposal : The generation of waste should be avoided or minimised wherever possible. Disposal of this product, solutions and any by-products should at all times comply with the requirements of environmental protection and waste disposal legislation and any regional local authority requirements. Dispose of surplus and non-recyclable products via a licensed waste disposal contractor. Waste should not be disposed of untreated to the sewer unless fully compliant with the requirements of all authorities with jurisdiction.

Hazardous waste : Within the present knowledge of the supplier, this product is not regarded as hazardous waste, as defined by EU Directive 2008/98/EC.

Disposal considerations : Do not allow to enter drains or watercourses.
Dispose of according to all federal, state and local applicable regulations.
If this product is mixed with other wastes, the original waste product code may no longer apply and the appropriate code should be assigned.
For further information, contact your local waste authority.

European waste catalogue (EWC)

SECTION 13: Disposal considerations

The European Waste Catalogue classification of this product, when disposed of as waste, is:

Waste code	Waste designation
08 02 01	waste coating powders

Packaging

Methods of disposal : The generation of waste should be avoided or minimised wherever possible. Waste packaging should be recycled. Incineration or landfill should only be considered when recycling is not feasible.

Disposal considerations : Using information provided in this safety data sheet, advice should be obtained from the relevant waste authority on the classification of empty containers.
Empty containers must be scrapped or reconditioned.
Dispose of containers contaminated by the product in accordance with local or national legal provisions.

Type of packaging	European waste catalogue (EWC)	
CEPE Paint Guidelines	15 01 10*	packaging containing residues of or contaminated by hazardous substances

Special precautions : This material and its container must be disposed of in a safe way. Care should be taken when handling emptied containers that have not been cleaned or rinsed out. Empty containers or liners may retain some product residues. Avoid dispersal of spilt material and runoff and contact with soil, waterways, drains and sewers.

SECTION 14: Transport information

	ADR/RID	ADN	IMDG	IATA
14.1 UN number	Not regulated.	9005	Not regulated.	Not regulated.
14.2 UN proper shipping name	-	ENVIRONMENTALLY HAZARDOUS SUBSTANCE, SOLID, N.O.S.	-	-
14.3 Transport hazard class(es)	-	9	-	-
14.4 Packing group	-	-	-	-
14.5 Environmental hazards	No.	Yes.	No.	No.

Additional information

ADN : The product is only regulated as a dangerous good when transported in tank vessels.

14.6 Special precautions for user : **Transport within user's premises:** always transport in closed containers that are upright and secure. Ensure that persons transporting the product know what to do in the event of an accident or spillage.

SECTION 14: Transport information

14.7 Transport in bulk according to Annex II of Marpol and the IBC Code : Not applicable.

The actual shipping description for this product may vary based several factors including, but not limited to, the volume of material, size of the container, mode of transport and use of exemptions or exceptions found in the applicable regulations. The information provided in Section 14 is one possible shipping description for this product. Consult your shipping specialist or supplier for appropriate assignment information.

SECTION 15: Regulatory information

15.1 Safety, health and environmental regulations/legislation specific for the substance or mixture

EU Regulation (EC) No. 1907/2006 (REACH)

Annex XIV - List of substances subject to authorisation

Annex XIV

None of the components are listed.

Substances of very high concern

None of the components are listed.

Annex XVII - Restrictions on the manufacture, placing on the market and use of certain dangerous substances, mixtures and articles : Not applicable.

Other EU regulations

Seveso Directive

This product is not controlled under the Seveso Directive.

National regulations

Industrial use : The information contained in this safety data sheet does not constitute the user's own assessment of workplace risks, as required by other health and safety legislation. The provisions of the national health and safety at work regulations apply to the use of this product at work.

15.2 Chemical safety assessment : No Chemical Safety Assessment has been carried out.

SECTION 16: Other information

CEPE code : 3

Indicates information that has changed from previously issued version.

Abbreviations and acronyms : ATE = Acute Toxicity Estimate
CLP = Classification, Labelling and Packaging Regulation [Regulation (EC) No. 1272/2008]
DMEL = Derived Minimal Effect Level
DNEL = Derived No Effect Level
EUH statement = CLP-specific Hazard statement
N/A = Not available
PBT = Persistent, Bioaccumulative and Toxic
PNEC = Predicted No Effect Concentration
RRN = REACH Registration Number
vPvB = Very Persistent and Very Bioaccumulative

Procedure used to derive the classification according to Regulation (EC) No. 1272/2008 [CLP/GHS]

Classification	Justification
Aquatic Chronic 3, H412	Calculation method

Full text of abbreviated H statements

H410	Very toxic to aquatic life with long lasting effects.
H412	Harmful to aquatic life with long lasting effects.

Full text of classifications [CLP/GHS]

Aquatic Chronic 1, H410	LONG-TERM (CHRONIC) AQUATIC HAZARD - Category 1
Aquatic Chronic 3, H412	LONG-TERM (CHRONIC) AQUATIC HAZARD - Category 3

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Date of previous issue : 15 December 2019
Version : 2

Notice to reader

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Appendix F

NFPA 69 TEST REPORT

**CFD MODELING REPORT FOR BATTERY ENERGY STORAGE SYSTEM

ANALYSIS OF EXPLOSION PREVENTION IN ACCORDANCE WITH NFPA 69**

PREPARED FOR:	
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List of Acronyms

CATL	Contemporary Amperex Technology Co., Ltd.
BESS	Battery Energy Storage Systems
SOC	State of Charge
SOH	State of Health
BMS	Battery Management System
PCS	Power Conversion System
FDS	Fire Dynamics Simulator
CFD	Computational Fluid Dynamics
LFL	Lower Flammability Limit
NFPA	National Fire Protection Association
NIST	National Institute of Standards and Technology
UFL	Upper Flammability Limit
UL	Underwriters Laboratories

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Executive Summary

This study evaluates the performance of the NFPA 69 [1] combustible concentration reduction (CCR) system for the Contemporary Amperex Technology Co., Ltd. (CATL) Battery Energy Storage System (BESS) enclosure, specifically the model C1P Battery Energy Storage System. The primary function of the CCR system is to mitigate the risk of explosion following a thermal runaway event by maintaining battery gas concentrations within established safety limits. To assess the effectiveness of the CCR system in achieving this objective, a computational fluid dynamics (CFD) analysis was conducted.

Thermal runaway events in BESS pose a safety hazard due to the potential release of flammable gases. The accumulation of these gases within the BESS enclosure can create an explosion risk upon ignition. Therefore, CCR systems are critical for mitigating this risk through the effective removal of these flammable gases.

NFPA 855 [2] requires that UL 9540A [3] be used to evaluate the fire and explosion characteristics of a BESS during a thermal runaway event. This data is then utilized to inform the design of explosion control systems. Accordingly, an approach to determine a conservative battery gas release rate to assess the adequacy of the CCR system design has been developed based on UL 9540A data. Information from the Cell [4], Module [5], and Unit [6] level UL 9540A test reports are used to inform the composition, properties, volume, release rate and duration of the battery gas release.

CFD analysis was employed to evaluate the proposed CCR system's ability to maintain the global concentration of flammable gases within the enclosure below 25% of the Lower Flammable Limit (LFL), a requirement stipulated by both NFPA 855 [2] and NFPA 69 [1]. This analysis utilized the National Institute of Standards and Technology (NIST) Fire Dynamics Simulator (FDS) software (FDS Version: 6.10.1), a widely recognized tool for simulating fire dynamics, as well as smoke and gas dispersion phenomena. The modeled CCR system is comprised of an exhaust fan responsible for extracting air from the enclosure and a makeup air inlet providing fresh air to the enclosure. This explosion prevention system is designed to mitigate flammable battery gas releases resulting from thermal runaway events and does not address potential fire hazards or toxic gas exposures. Moreover, the analysis does not consider the activation of any extinguishing systems that might influence the performance of the detection or CCR systems. Appropriate programming of these systems is essential by the manufacturer to prevent adverse effects on the operation of the CCR system. Information provided as part of this analysis indicates that the CCR system is latching, cannot be overridden, and requires manual reset.

The CFD simulation incorporated the detection time of vented battery gases, as well as the activation and ramp-up characteristics of the exhaust fan. A conservative gas release

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scenario was modeled to determine the time required for detecting hydrogen and other flammable gases. Based on this detection time, additional safety factors, including a 15-second delay in ventilation system activation and a conservative fan ramp-up time, were incorporated into the model. The exhaust fan modeled within the CFD simulation utilized client-specified input from actual measured airflow rates on a BESS enclosure.

Simulation results indicate that the CCR system design removes flammable battery gases from the enclosure as designed, maintaining the average flammable gas concentration below 25% of the LFL following ventilation system activation for the modeled failure scenarios. Transiently, the global concentration of battery gases exceeded 25% LFL at the assumed leakage location and in other localized areas along the path from the release location to the exhaust outlet; such localized exceedances were anticipated. Overall, the design evaluated in this study complies with the intent of NFPA 855 (2026), and NFPA 69, ensuring that, during steady-state operation for all considered failure scenarios, the average battery gas concentration remains below 25% of the LFL. This analysis, in line with the realistic expectations of NFPA 855 (2026), recognizes that a complete elimination of explosion hazard is not possible with a CCR system. A residual volume of gas over 25% of the LFL will remain. As such, a partial volume deflagration analysis has also been performed in a supplementary report [10] to assess the design of the complementary deflagration venting system. This evaluation is mandated by NFPA 855 (2026).

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1.0 Introduction

1.1 Purpose

The primary objective of this report is to present the CFD analyses performed to evaluate the design of the proposed CCR system intended to mitigate flammable gas concentrations within BESS enclosure. This evaluation aims to ascertain whether the system prevents the accumulation of combustible gas concentrations, maintaining them below acceptable limits, in compliance with pertinent provisions outlined in NFPA 855 (2026) and NFPA 69.

1.2 Scope

The scope of this analysis is limited to evaluating the performance of the CCR system for a single, representative BESS enclosure, independent of specific site configurations. This report does not constitute a comprehensive assessment of overall BESS compliance with NFPA 855, the International Fire Code, or any other applicable codes and standards. Instead, this analysis focuses solely on the CCR system's performance and its conformity to pertinent provisions within NFPA 855 and NFPA 69. The specific tasks undertaken within this focused scope include:

1) Identification of a credible worst case battery gas release scenario based on UL 9540A test results obtained from cell, module, and unit-level testing.
2) Assessment of the manufacturer-designed CCR system's capability to meet the requirements stipulated by NFPA 855 and NFPA 69, utilizing the identified battery gas release scenarios as parameters for the CFD simulations.

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2.0 System Description

2.1 System Overview

BESS can be categorized into three fundamental levels: the cell, the module, and the unit/rack. The cell represents the smallest component. Multiple cells are assembled in series and/or parallel to form a module, and several modules are then integrated to constitute a unit/rack. The unit/rack also incorporates a Battery Management System (BMS), which provides real-time monitoring of the system's operational status and overall health. The BMS tracks critical parameters, including state of charge, operating temperature, and the detection of any anomalous occurrences. Based on these monitored parameters, the BMS also executes safety functions to ensure safe and reliable operation.

The CATL C1P Battery Energy Storage System is housed within a non-combustible enclosure with overall product dimensions of 20 feet [6.058 m] (width) x 8 feet [2.478 m] (depth) x 9.5 feet [2.896 m] (height). This BESS has a rated energy capacity of 3.8 MWh and operates at a rated voltage of 1331.2 V. The BESS accommodates up to 80 battery modules configured as model M01285P10L01, each with a rated voltage of 166.4 Vdc and an energy capacity of 47.4 kWh. Each module is comprised of 52 lithium iron phosphate (LFP) battery cells (model:CBDC0) connected in series, with each cell having a nominal voltage of 3.2 V. A summary of these specifications is provided in Table 2-1, while Figure 1 presents illustrative images of the BESS enclosure, a module, and individual cell.



Figure 1 C1P Battery Energy Storage System BESS; M01285P10L01 module; CBDC0 cell (Left to Right)

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Table 2-1: BESS Specifications		
BESS	Model	C1P Battery Energy Storage System
	Manufacturer	Contemporary Amperex Technology Co., Ltd.
	Configuration	52 cells per module, 8 modules per rack, 10 total racks.
	Ratings	1331.2Vdc, 3.8MWh
	Enclosure	Metal casing, filled with flame-retardant materials
	Dimensions	6058 mm (20 ft) (W) x 2478 mm (8.0 ft)(D) x 2896 mm (9.5 ft) (H)
Unit	Model	C04285P10L01-R
	Manufacturer	Contemporary Amperex Technology Co., Ltd.
	Configuration	1P8S
	Tested To	UL 9540A unit level
Module	Model	M01285P10L01
	Manufacturer	Contemporary Amperex Technology Co., Ltd.
	Configuration	52S1P
	Ratings	166.4V, 285 Ah
	Dimensions	1150 mm (W)*810 mm (D)*241.5 mm (H)
	Weight	325±10 kg
	Operating Range	Charge temperature range, ° C:0~60 Discharge temperature range, ° C:-20~60
	Tested To:	UL 9540A module level
Cell	Model	CBDC0
	Manufacturer	Contemporary Amperex Technology Co., Ltd.
	Format	Prismatic
	Ratings	3.2Vdc, 285Ah
	Chemistry	$LiFePO_4$
	Tested To:	UL 9540A cell level
	Dimensions	（L*W*T）71.55±0.8 mm×174.3±0. 8 mm×207.3±0.8 mm
	Weight	5.46±0.3 kg

2.2 Design Features

The C1P Battery Energy Storage System containerized BESS incorporates a suite of safety mechanisms to mitigate potential electrical and operational anomalies. This section provides a high-level overview of these mechanisms.

2.2.1 System Overview

C1P Battery Energy Storage System integrates the power electronic equipment, control systems and safety components required for the DC side of the battery energy storage system. The layout of C1P Battery Energy Storage System and an overview of the key components are shown in Figure 2.

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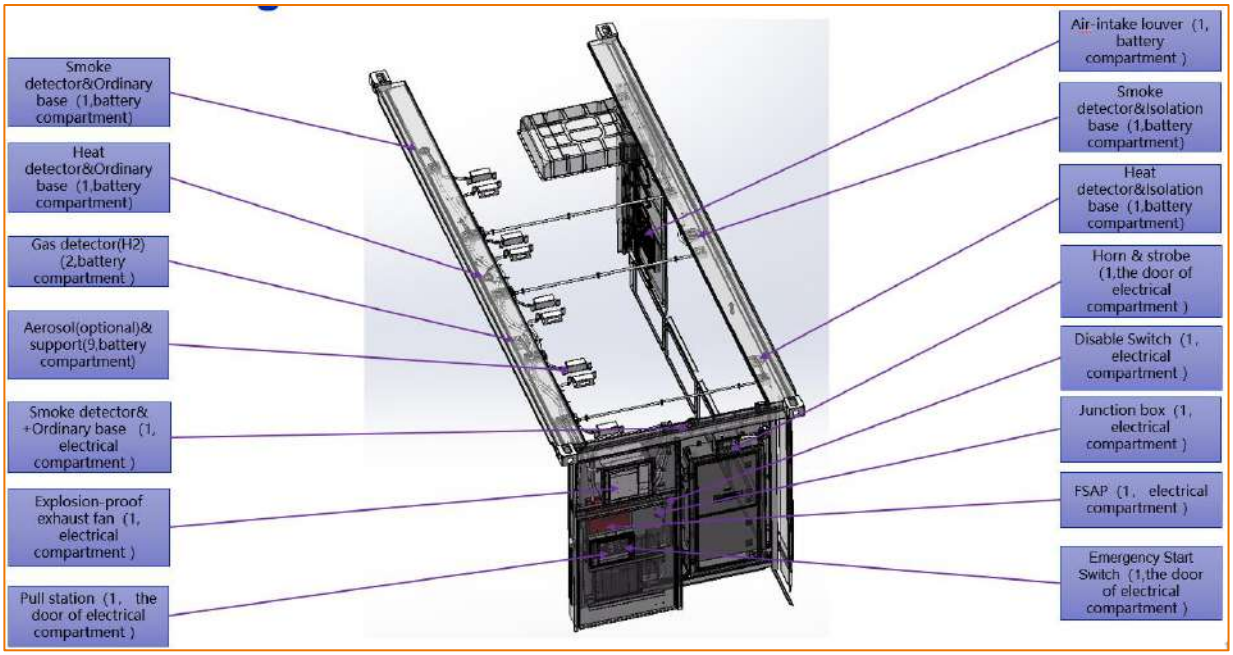

Figure 2 Key Components of C1P Battery Energy Storage System

2.2.2 Battery Management System (BMS)

The battery management system is a real-time monitoring system composed of electronic circuit devices, which can effectively monitor battery voltage, battery current, battery cluster insulation status, battery SOC, manage system charging and discharging safety, alarm and emergency protection for possible faults, optimize control of the battery system, and ensure safe, reliable, and stable operation of the battery.

2.3 C1P Fire Protection Systems

2.3.1 Conceptual Design

The energy storage fire protection systems include an aerosol fire extinguishing system and a CCR system. When the battery undergoes thermal runaway and produces flammable gases, the CCR system is activated via gas detectors to reduce the concentration of combustible gases in the enclosure. When a fire is detected, the aerosol fire extinguishing system activates.

2.3.2 Combustible Concentration Reduction System

The CCR system is comprised of two gas detectors (two hydrogen), an exhaust fan, and a make-up air inlet. If the gas concentration reaches the trigger thresholds, the detector transmits a signal to the control interface, which then activates the ventilation system to reduce the concentration of gases within the container. The CCR system signals have been designed to latch and require a manual reset. This design is to ensure CCR system signals take precedent, as well as ensure no conflicts with extinguishing or suppression

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systems arise, as required by NFPA 855 (2026), Section 9.7.6.7.4.1: *"where suppression systems other than water based are contained within an ESS, the detection, logic solvers, and sequence of events for discharge shall not impede the CCR system performance"*. This analysis focuses solely on the performance of this system to effectively reduce the combustible gas concentration within the container to within acceptable limits, specifically, those mentioned in NFPA 855 (2026) as well as NFPA 69 (2024), Section 8.3.1. The control logic for the CCR system is shown in the following Figure.

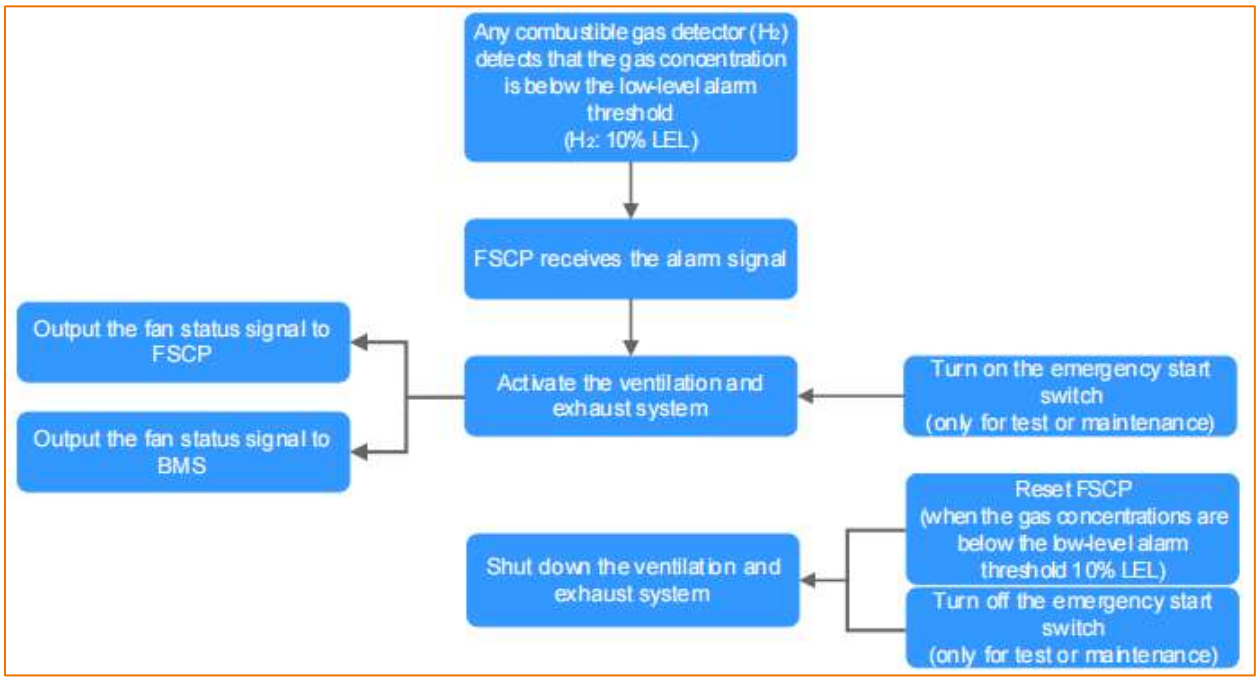

Figure 3 Ventilation system control logic diagram.

2.3.3 Aerosol Fire Extinguishing

The BESS is equipped with an optional aerosol fire extinguishing system. The system is triggered automatically via heat or smoke detection. When the heat and smoke detectors in the container are activated simultaneously, the aerosol fire extinguishing system is automatically activated. An evaluation of the adequacy of the aerosol system, and its compliance with applicable codes and standards, is not part of this evaluation. This analysis assumes that there is no interaction between the aerosol extinguishing system and the CCR system. The OEM is responsible for ensuring appropriate programming is in place. Should an interaction occur between the aerosol system and the CCR system, this analysis is no longer valid. Control logic for the aerosol system is shown in the following Figure. This is provided for reference only:

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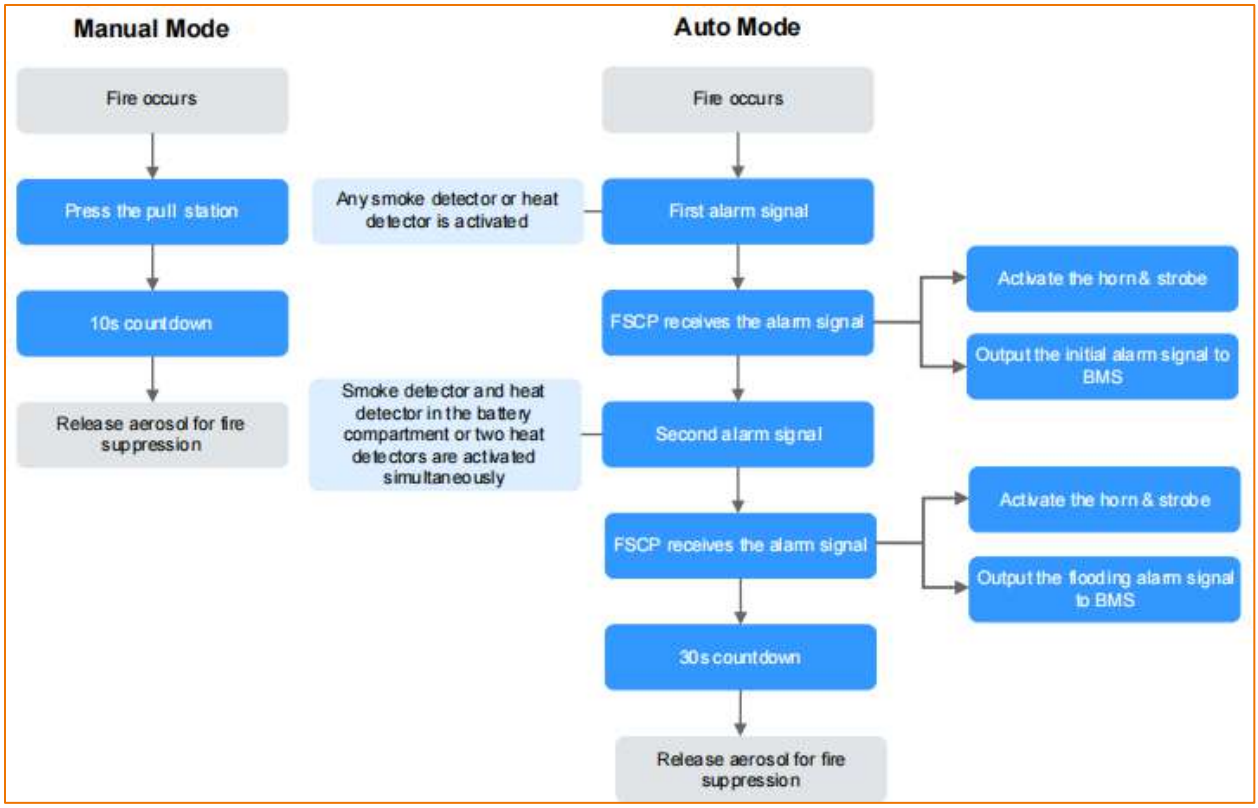

Figure 4 Automatic fire alarm and gas fire suppression system control logic diagram

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3.0 CFD Modeling Approach

3.1 CFD Simulation Tool

The methodology adopted for this analysis utilized Computational Fluid Dynamics (CFD) modeling, employing the software tool called Fire Dynamics Simulator (FDS), (Version 6.10.1). Developed by the National Institute of Standards and Technology (NIST), FDS is a widely recognized tool for simulating fire dynamics, including the transport of smoke and gaseous species. The model geometry was defined by importing a three-dimensional CAD file, provided to Chuweineng Testing Technology (Shanghai) Co., Ltd (CWN) by CATL and subsequently processed using PyroSim, a graphical user interface (GUI) that facilitates FDS model construction and execution.

3.2 Mesh generation and resolution criteria – Sensitivity Discussion

Several limitations were imposed on the geometrical representation within FDS to maintain computational feasibility and stability.

First, small fixtures with characteristic dimensions below 1 cm were excluded from the model to reduce the complexity of the model and eliminate fixtures which would not influence the flow pattern. Moreover, due to the Cartesian mesh utilized and the thickening sub-model, these small fixtures could have an unrealistically high impact on the flow field if not manually preprocessed. The computational domain was discretized using a uniform mesh with a 2.5-centimeter (cm) grid resolution. Any geometrical features smaller than the grid size were effectively thickened to conform to the underlying mesh structure.

The selection of this 2.5 cm grid cell size was justified through a grid convergence study, which compared simulation results obtained using 2.5 cm and 5 cm cell sizes. This analysis indicates that, compared with the coarser 5 cm grid, the finer 2.5 cm grid can achieve a certain degree of higher accuracy and can better represent the internal gaps within the system. The use of a 2.5 cm grid is also consistent with Atar Fire's interpretation of best engineering practices within this industry.

The resulting model within the computational domain, along with its associated mesh representation, is illustrated in Figure 5.

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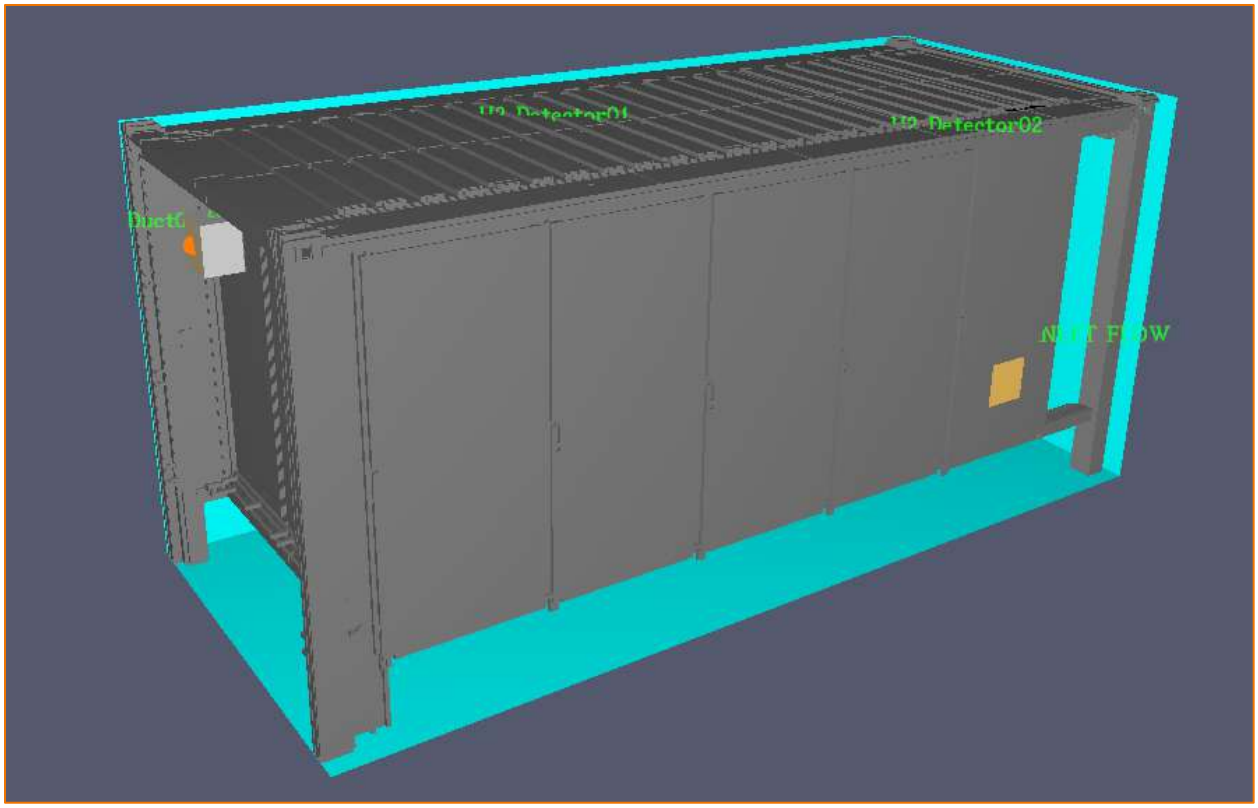

Figure 5 Model in the Computational Domain

3.3 High Level approach

Following the development of a physical model based on the product's actual geometry, a gas release curve and gas release location, informed by UL 9540A data and engineering judgment, was incorporated into the model. An initial simulation was conducted to ascertain the activation times of the gas detectors.

Subsequently, the model was refined to incorporate the exhaust fan and make-up air opening, while simultaneously accounting for additional safety factors (described later) to mitigate potential modeling uncertainties within the as-designed configuration. Results are then derived from this refined model.

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4.0 Model Input Parameters and Assumptions

4.1 Gas Release Assumptions

4.1.1 Location of Gas Release

To ensure a conservative analysis, the simulated thermal runaway event assumes the affected module is located furthest from the CCR exhaust outlet. This placement maximizes gas accumulation and the distance the evolved gases must travel to reach the exhaust fan. A more proximal location to the exhaust outlet would favor the preferential expulsion of battery gases, resulting in a lower overall concentration within the environment.

Consequently, for the purposes of this scenario, the battery module at the base of rack 1# has been designated as the location of the thermal runaway event. Detailed illustrations of this configuration can be found in Figures 6 through 9.

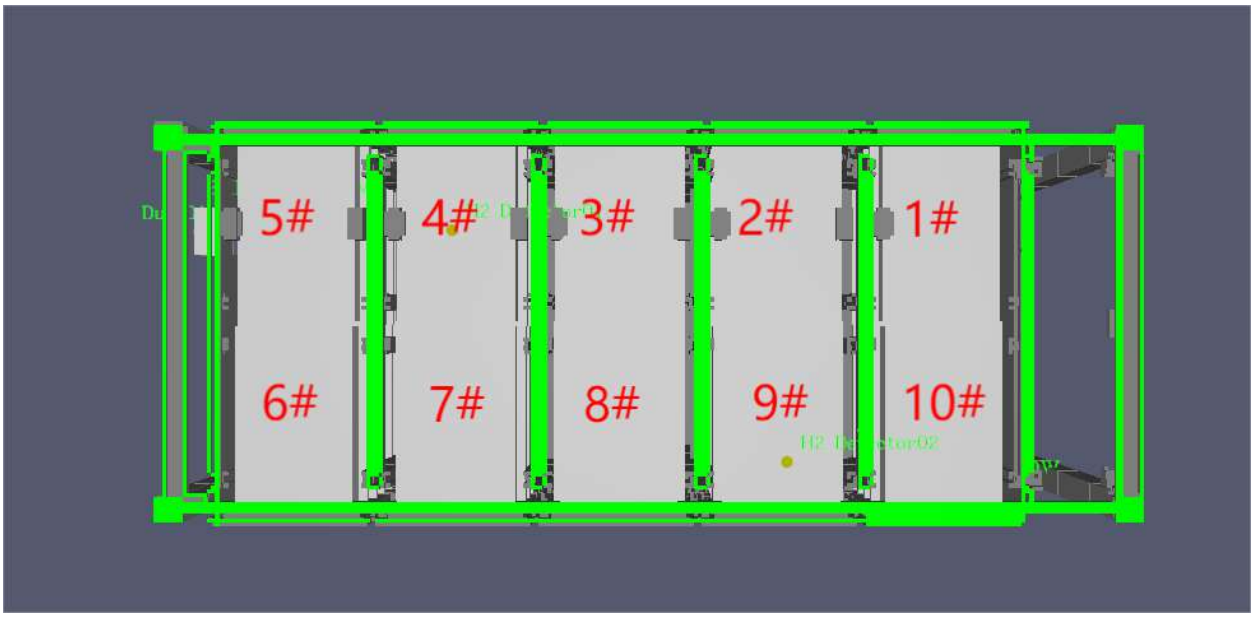

Figure 6 Rack Positions in BESS - Top View

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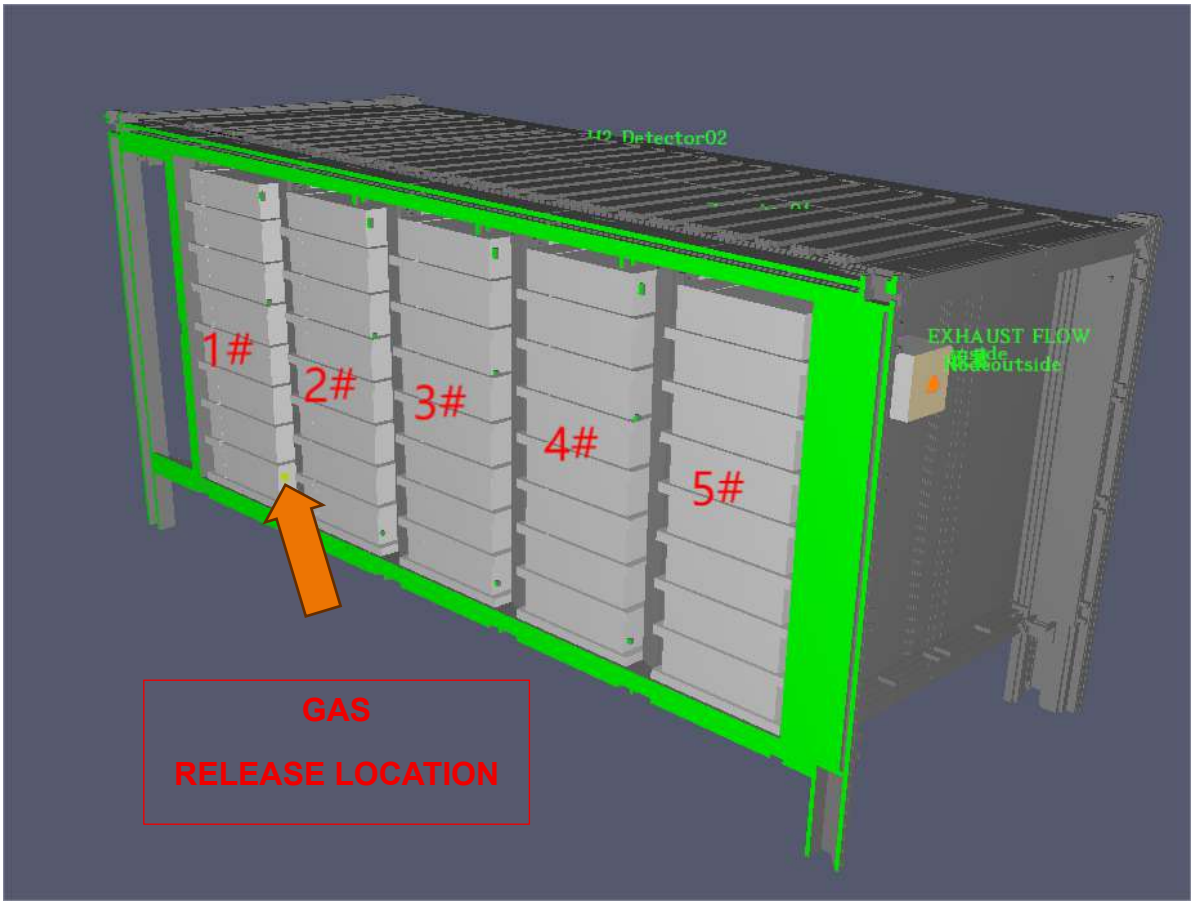

Figure 7 Location of Thermal Runaway Battery Module- (Front View)

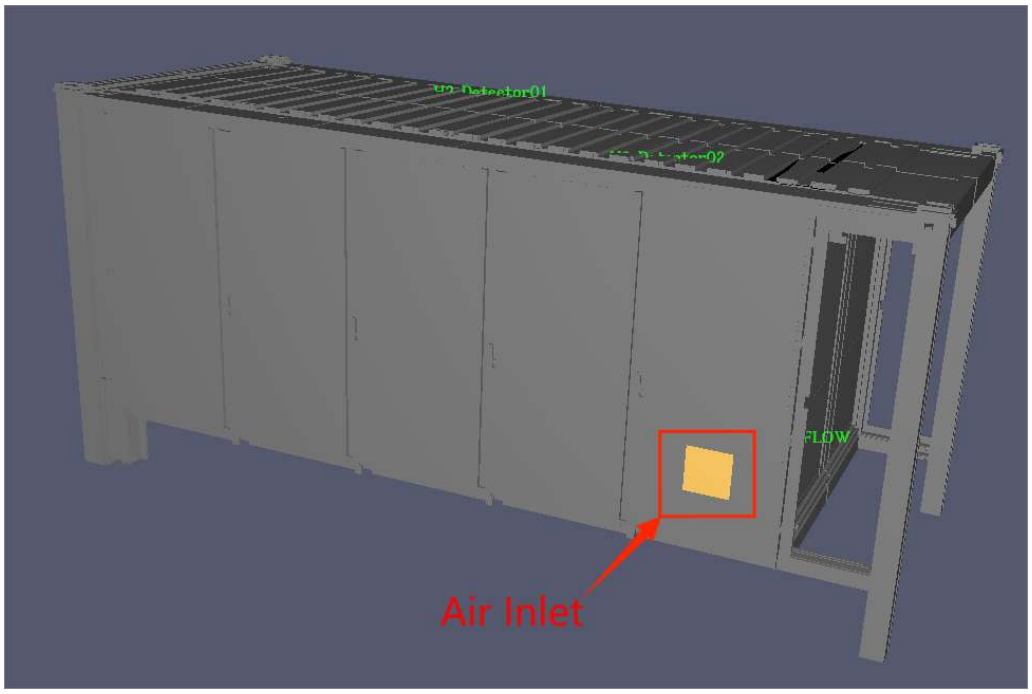

Figure 8 Location of Air Inlet- (Rear View)

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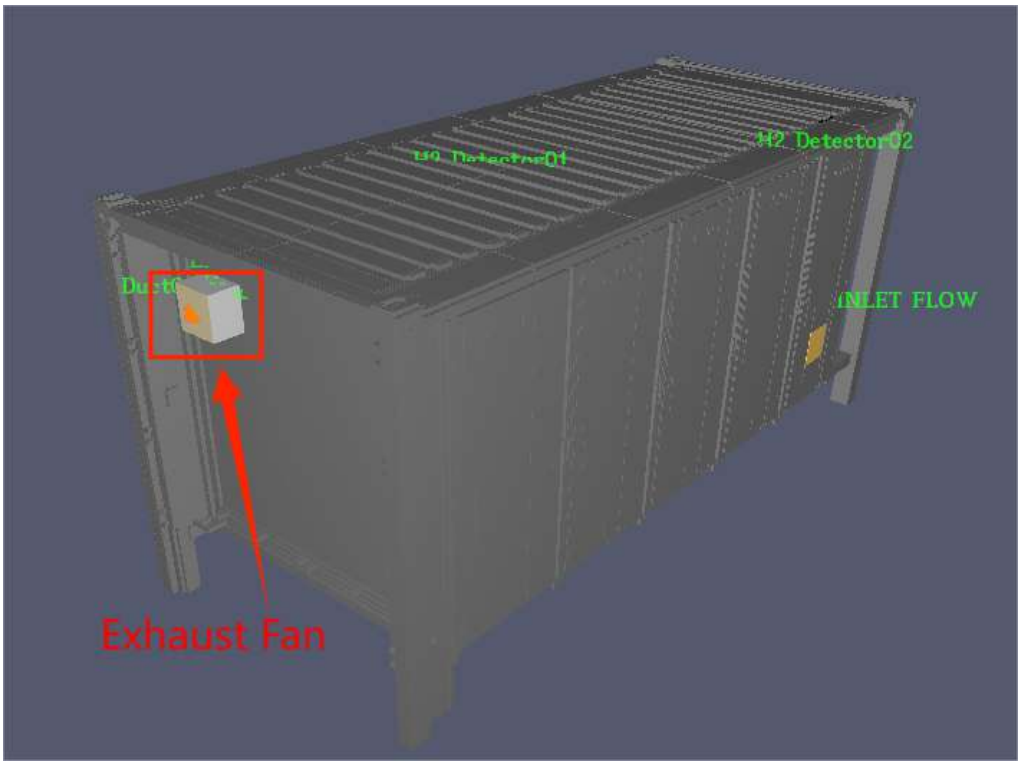

Figure 9 Location of Exhaust Fan- (Side View)

4.1.2 Composition of Battery Gas and LFL

UL 9540A cell-level testing was conducted on a lithium-ion battery cell (Model CBDC0) manufactured by CATL. In this evaluation, a single cell was placed within a 100 L pressure vessel and induced into thermal runaway using flexible film heaters applied to both sides, with heating rates ranging from 4°C/ min to 7° C/ min. Venting commenced at a cell surface temperature of 161°C, with the cell subsequently transitioning into thermal runaway at 220°C. The total volume of gas vented during the event was 176.3 L.

Analysis of the vented thermal runaway gas composition, as shown in the UL 9540A Cell report, revealed the presence of approximately 43.569% hydrogen, 10.610% carbon monoxide, 30.116% carbon dioxide, 6.625% Methane, 4.159% Ethylene, 1.245% Ethane 1.056% Propylene, 0.188% Acetylene and 2.432% total hydrocarbons. Based on this composition, the LFL for the battery gas mixture , as provided by the test laboratory, was approximately 7.545% by volume in air at vent temperature. The LFL for the battery gas mixture at ambient, as provided by the test laboratory, was 8.05% by volume in air. For this analysis, the LFL has been determined based on the CFD simulation results showing that the average temperature in the BESS enclosure is close to ambient. Near the release location, local elevated temperatures are observed. A temperature of 65 ℃ was chosen to maintain some conservatism. At 65 ℃, interpolating the LFL values provided by the test laboratory, an LFL of 7.888% was derived and is utilized in this report. The chemical properties associated with the vented battery gas mixture are detailed in Table 4-1. For

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the purposes of this analysis, the total hydrocarbon component (CxHy) was assumed to be equivalent to propane (C_3H_8) – a conservative assumption due to the relatively low LFL of propane. Finally, data extracted from the UL 9540A cell report indicates a measured gas burn velocity of approximately 0.64 m/s and a maximum pressure (P_{max}) of 6.5 bar (94.29 psi).

Table 4-1: *Gas Composition Derived from UL9540A Cell Test Data*

Component	Volume Fraction (%vol)	Density (at NTP) (kg/m^3)
H_2	43.569	0.0838
C_3H_8	2.432	1.833
CO	10.610	1.165
CO_2	30.116	1.83
CH_4	6.625	0.668
C_2H_4	4.159	1.167
C_2H_6	1.245	1.25
C_3H_6	1.056	1.748
C_2H_2	0.188	1.079
Mixture	100	0.885

4.1.3 Model of Battery Gas Release Rate

To facilitate assessment of CCR system performance, an accurate estimation of the battery vent gas release rate into the enclosure over time is crucial. This study developed a gas release rate model based on test data from UL 9540A standards for Cell [4], Module [5], and Unit [6] level testing. Based on a review of all documents, this analysis adopted a conservative assumption to ensure a robust assessment.

The module level test initiated thermal runway in Cell 20. The test report shows Cell 19 and Cell 21 entering TR within 50 seconds of each other. This indicates it is possible for two cells to be off gassing simultaneously. When the other cells are venting, it can be assumed that Cell 20 is no longer releasing gas, or if it is, it does so at a very low rate. However, to develop a conservative gas release rate, this analysis assumes three cells undergo thermal runaway simultaneously.

For this assessment, a conservative approach has been taken to simply assume all gas (176.3 L) is released from a single cell in one minute. This approach is extremely conservative as gas release rates vary during TR and venting, as well as vary over time, often occurring over many minutes. The selection of three cells going into TR at the exact same time also represents a non-UL 9540A failure condition, such as a multi cell short-circuit. This approach meets the intent of NFPA 855 Annex G, which discusses ensuring

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conservatism is built into gas release rate assumptions. The overall gas release rate calculation is therefore as follows:

$$\frac{176.3\ L}{60\ seconds} = 2.93\ \text{L/s for one cell}$$

2.9383 L/s * 3 cells = 8.815 L/s

This gas release rate was compared to the unit level test, which demonstrated use of the module level test as more conservative. The unit level test demonstrated the potential for TR in two cells simultaneously, but the time difference at which these entered TR was nearly two minutes, as opposed to the 50 seconds observed in the module level test.

Finally, the module and unit level gas release generation rate curves were analyzed. For the module level test, the maximum gas generation rate (refer to Attachment F of the UL 9540A Report) was observed to be 2.38 L/s (CO: 18 L/min; CO2: 46 L/min; H2: 63 L/min; Total Hydrocarbons: 16 L/min). For the module level test, the maximum gas generation rate (refer to Attachment F of the UL 9540A Report) was observed to be 2.65 L/s (CO: 9 L/min; CO2: 25 L/min; H2: 100 L/min; Total Hydrocarbons: 25 L/min). As such, use of 2.93 L/s is more conservative. A representative image of the module venting is shown as follows:

Within the model, the release rate is simulated to increase rapidly over 1 second, subsequently stabilizing at its peak value. While the actual gas release rate is expected to exhibit fluctuations, modeling a continuous peak release introduces yet another conservative assumption. Figure 10 shows the modeled gas release rate.

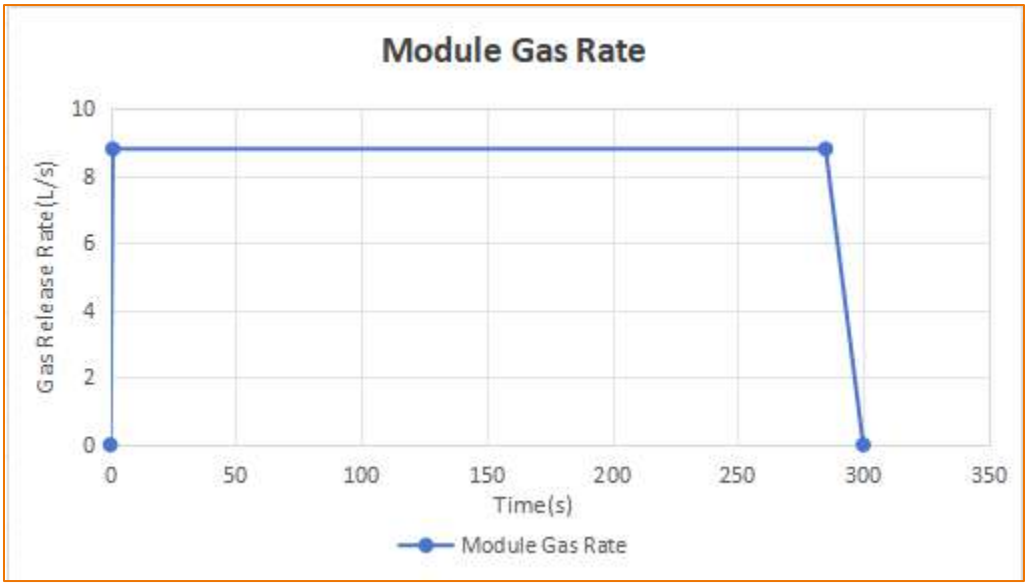

Figure 10 Gas Rate of Module

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4.2 Gas Release Point Assumptions

Rack 1# was designated as the source of gas release, with the bottom module specifically identified as the release location. A small obstacle block was incorporated onto this module, and in the simulation process, the front surface away from the cabinet door is defined as the gas release location, to represent the actual product/module vent location. As depicted in Figure 11, the square area visually represents the gas release location. The exhaust temperature within the Fire Dynamics Simulator (FDS) was set to 161 °C, a value obtained from the UL9540A Cell level testing report.

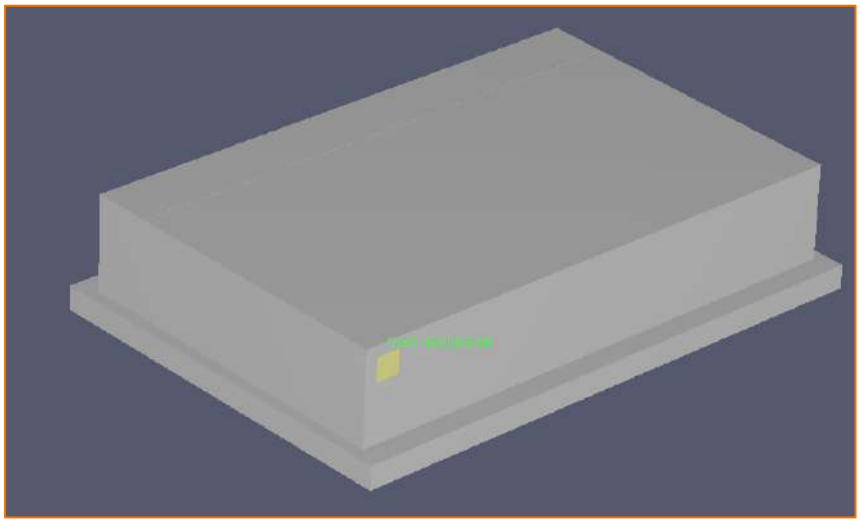

Figure 11 Module Vent Location

4.3 Gas Detection Parameters

The BESS features two gas detectors. The selected gas detectors are manufactured by Honeywell [7] and the model is Sensepoint XCL (hydrogen). The alarm levels are set as 4000 ppm (10% LFL) for hydrogen. The response time for the hydrogen detectors is stated by the manufacturer as 15 seconds or less.

To account for the stated response times, corresponding delays were incorporated to the FDS derived gas detector activation time. This includes a delay of 15 seconds for the hydrogen detector. This delay ensured that CCR system would activate only after a conservative delay, representing an additional precautionary measure.

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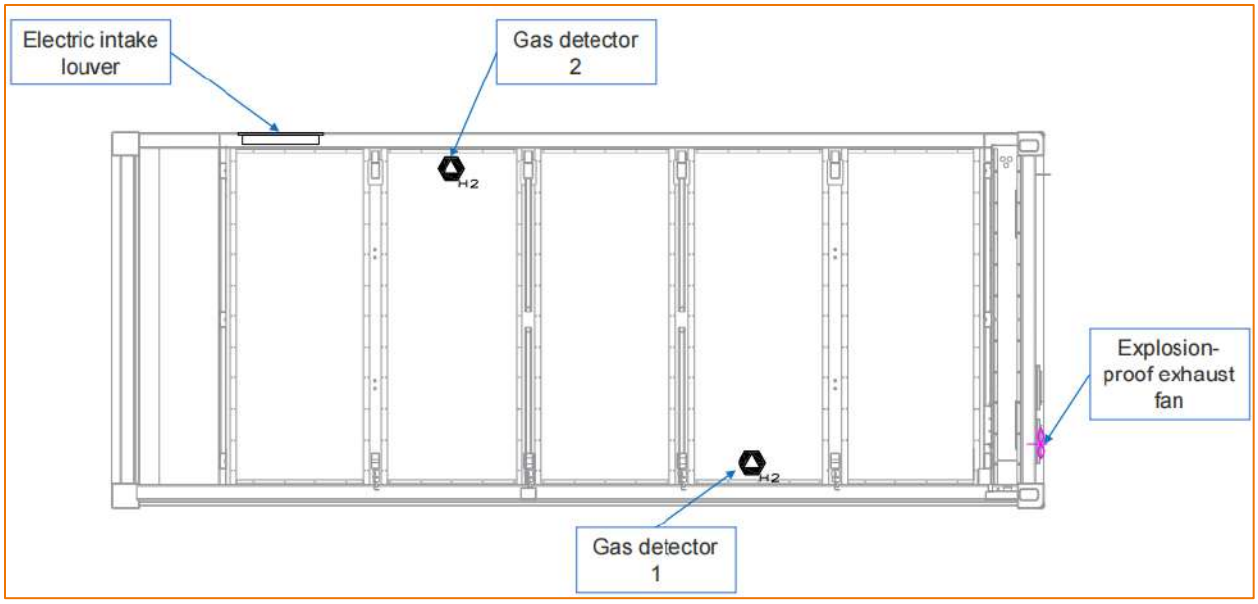

Figure 12 Gas Detector Locations-Top View

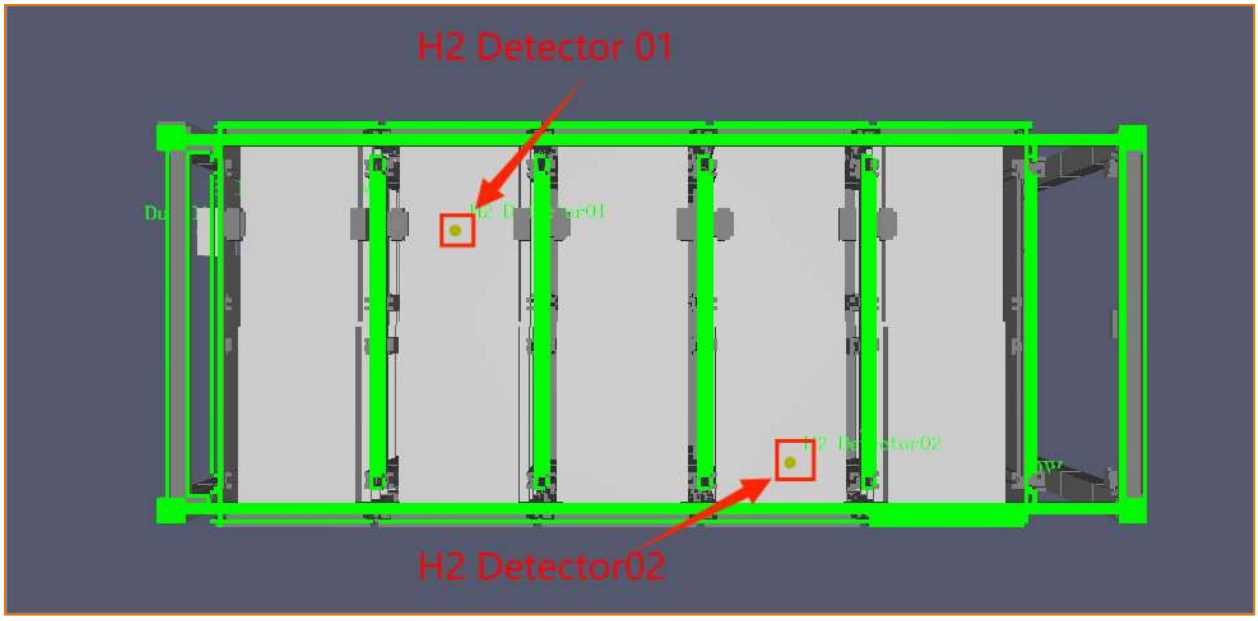

Figure 13 Gas Detector Locations in CFD Model

4.4 Parameters of the Intake and Exhaust System

As-installed airflow data (exhaust fan model TPF03 [8] manufactured by Nanjing Heben M&E Equipment Technology Co., Ltd.[Electro Man]) from Contemporary Amperex Technology Co., Ltd., resulted in a measured air volume of 650 CFM. After reaching an agreement with the client, 0.236m^3/s (500 CFM) was used as the input data for FDS. This airflow rate is significantly less than the maximum rated airflow stated by the manufacturer of 1393.19 m^3/h (820 CFM) and accounts for static pressure drop. As noted earlier, the

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simulation incorporates a 15 second delay between the gas detector signal and the CCR system activation. Furthermore, rather than immediately operating at maximum capacity, the exhaust fan air volume was modeled as increasing linearly from zero to its maximum over a period of 15 seconds. While this ramp-up duration was chosen to provide a conservative estimate, it is important to acknowledge that actual fan ramp-up times are typically shorter, often on the order of five seconds. The parameters governing fan rate within the simulation are detailed in Figure 14.

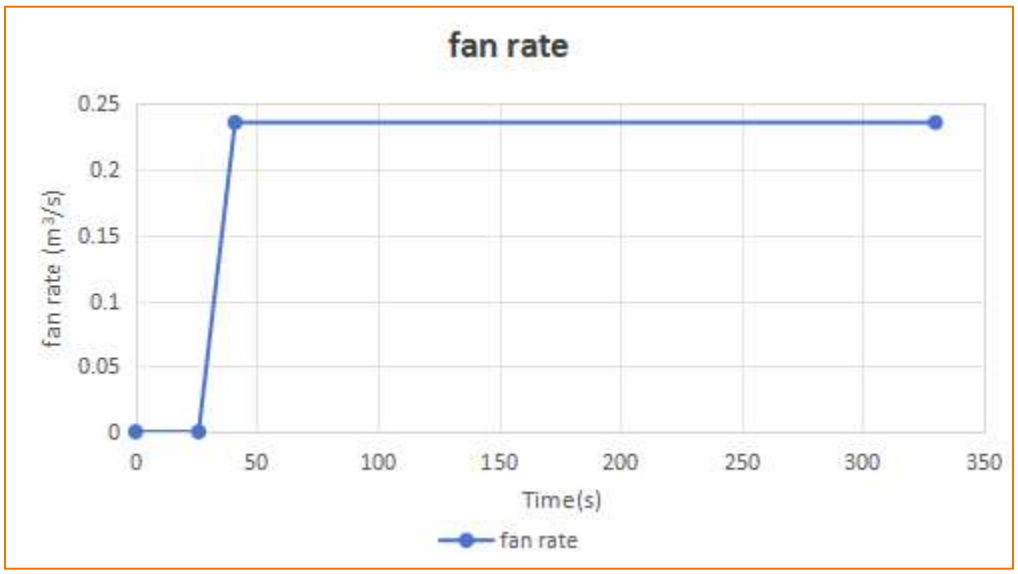

Figure 14 Exhaust Fan Airflow and Ramp Rate

The dimensions of the air inlet and outlet were constrained by the product specifications of the selected fan and the existing make-up air opening. These dimensions were deliberately chosen to closely approximate real-world operating conditions.

4.5 Other Information

The current simulation lacks specific environmental configurations, effectively representing conditions of standard temperature and pressure with negligible wind influence. Consequently, and consistent with the objective of modeling gas dispersion and airflow solely within the enclosure's internal environment, all obstructions present within the simulation have been designated as adiabatic.

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5.0 FDS Model

5.1 BESS Geometry

The three-dimensional CAD geometry of the CATL BESS enclosure was imported into the FDS. The CFD geometry encompassed all essential components, including the battery racks and the CCR system.

Figure 15 illustrates the CATL BESS geometry within the CFD model. More detailed descriptions of specific components within the CFD model are provided in subsequent sections.

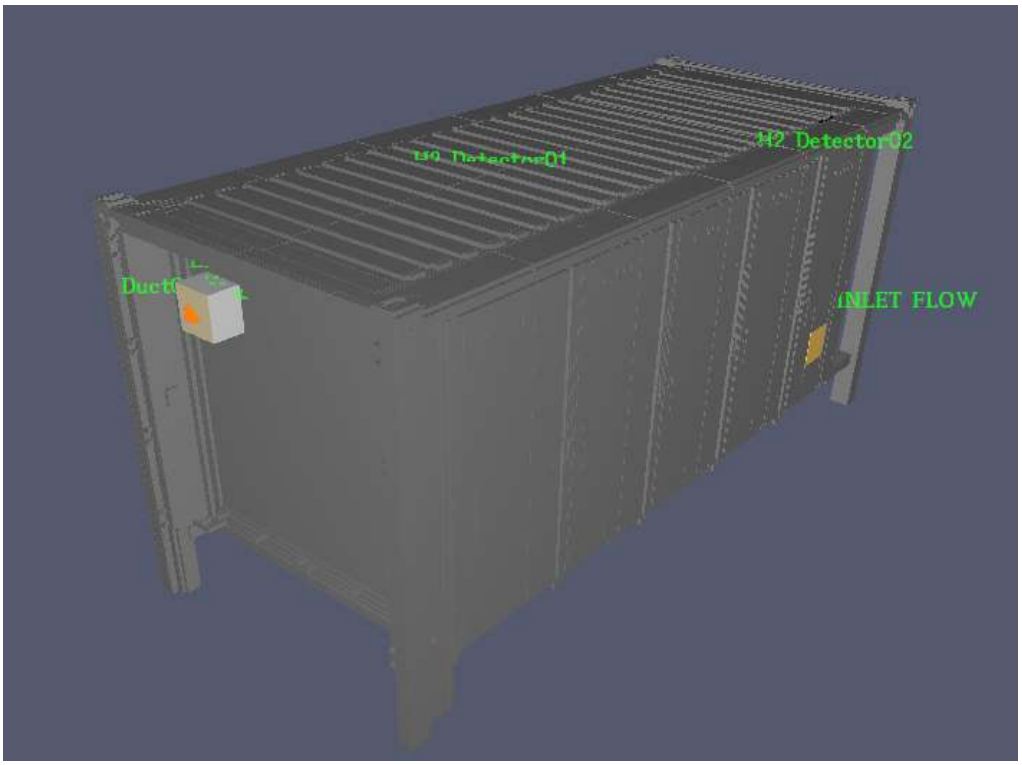

Figure 15 Exterior Images of BESS Model

5.2 Battery Module

The geometric representation of the BESS CFD model, incorporating the battery modules, is detailed in Figure 16.

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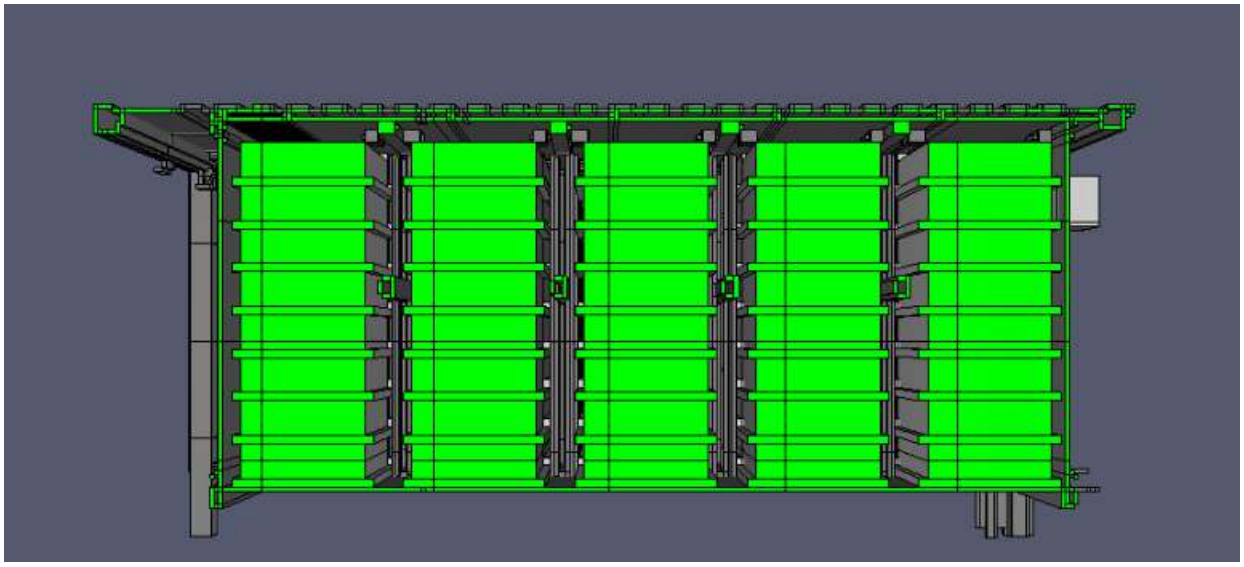

Figure 16 Representation of Modules and Racks in CFD Model

As depicted in Figure 15, the exhaust fan is located at one end of the BESS, while the air intake louvers are situated in an opposing corner. Within FDS, the exhaust fan's operational profile is modeled to linearly increase from zero to the target flow rate over a 15-second period. The input exhaust capacity is 0.236 m^3/s (500 CFM), representing the installed volumetric flow rate.

5.3 Locations of all relevant items within the model

Figure 17 depicts the designated gas release module and the location of the gas release source (indicated in green). This location corresponds to the actual module vent location.

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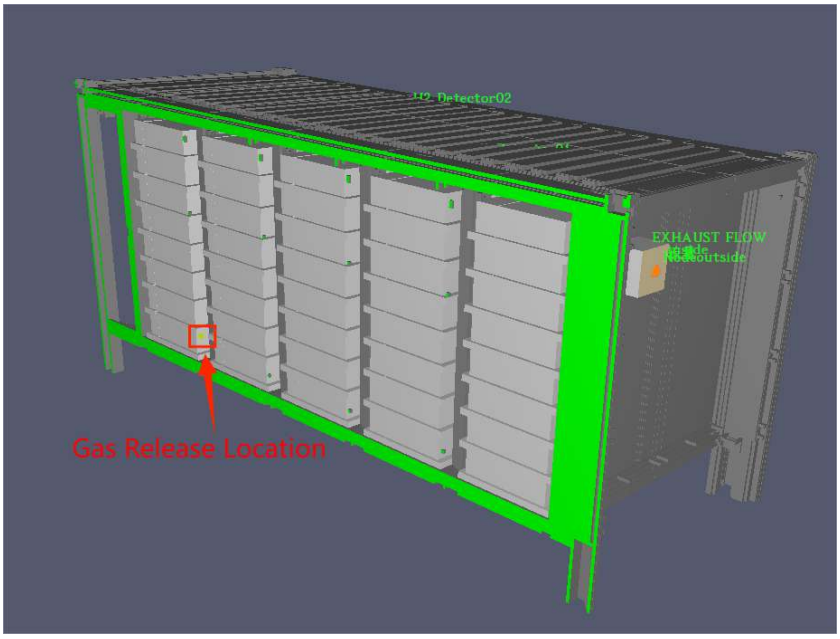

Figure 17 Gas Release Location in CFD Model

5.4 Simulation Scenarios

The modeling strategy involved a two-stage approach as follows:

1) Determine the time at which the gas detectors reach the concentration required to activate the CCR system.
2) Subsequently, simulate the performance of the CCR system in response to this scenario. The CCR system was initiated at the calculated detection time, incorporating a 15-second delay to account for potential uncertainties. Furthermore, acknowledging the response time of the exhaust system, a conservative assumption was made that the system achieves measured air capacity via a linear ramp-up over a period of 15 seconds.

The specific scenarios modeled are summarized in Table 5.1.

Table 5-1: Failure Scenarios Modeled

Scenario No.	Step	Simulation Goals
Scenario 1	Step 1	Simulate the release of gas and measure the response time of the gas detector when the ventilation system is not operational.
Scenario 2	Step 2	Assess the performance of the CCR system, utilizing the gas detection time, delays in fan start up, delays in fan ramp up time, and utilizing the design gas release rate.

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6.0 Results and Analysis

6.1 Results Summary

6.1.1 Detector Activation Study (Step 1)

This step investigated the gas detector alarm activation time in response to the simulated gas release event.

Figure 18 depicts the temporal evolution of hydrogen at the manufacturer specified detector locations during the gas release event.

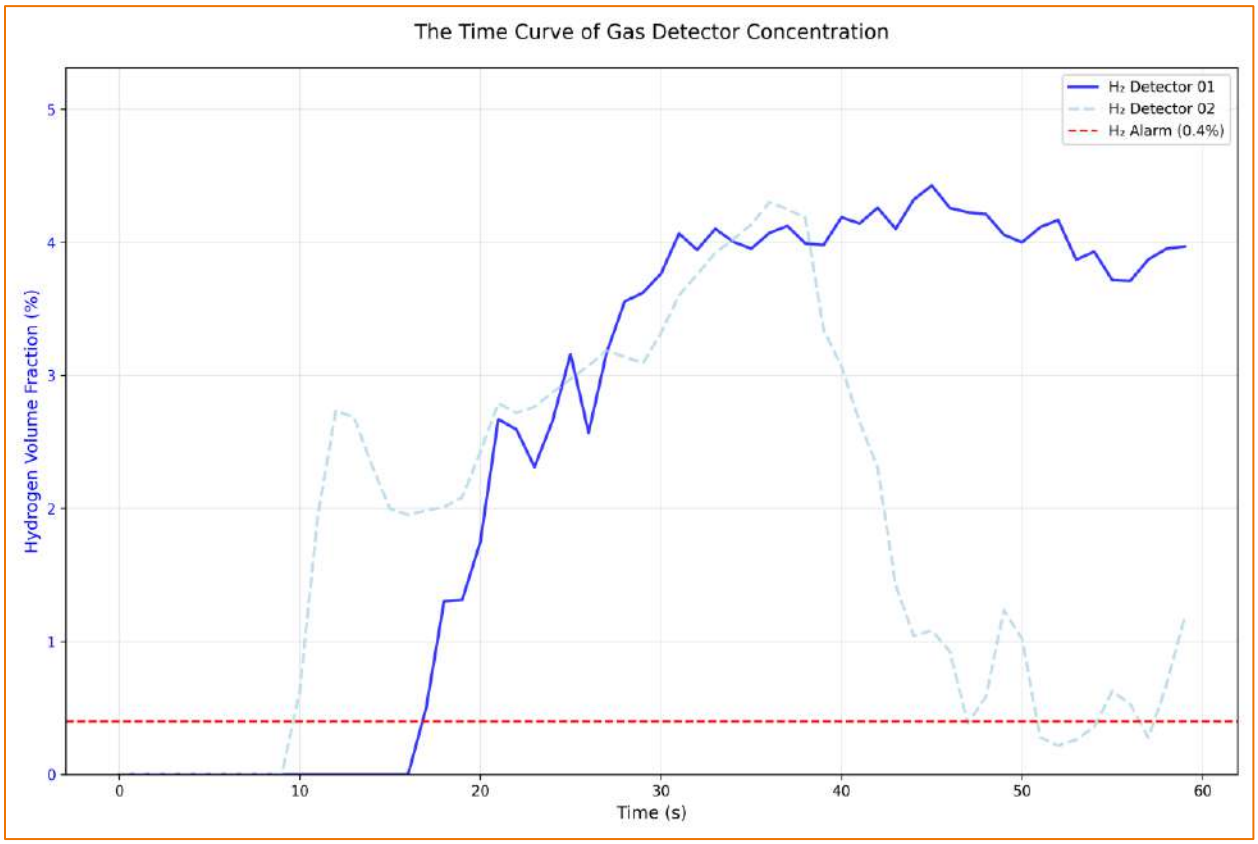

Figure 18 Temporal Variation of Hydrogen at Detector Locations

Based on the CFD results, the activation time for ‘H2 Detector 2’ at 0.4% (10% LFL) was recorded at approximately 10 seconds.

Table 6-1 presents the total assumed detection time, calculated by summing the actual detection duration and a 15 second delay for hydrogen.

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Table 6-1: *Detection Times for Gas Detectors*		
Detector	Detection Time (Seconds)	Total Assumed Detector Activation Time, Including a Safety Margin (Seconds)
H_2 Detector2	10	25

6.1.2 CCR Performance Study (Step 2)

Building upon the detection time of 25 seconds established in Step 1 and presented in Table 6-1, subsequent analysis in Step 2 incorporated this value. As elaborated in Section 5 of this report, the simulation considered the interrelationship between gas detector alarm times and the time required for the exhaust fan to achieve maximum air volume. The key input parameters employed in Step 2 are detailed in Table 6-2.

Table 6-2: *Detection, Exhaust, and Simulation Duration Times*	
Type	Time(s)
H_2 detector 1 alarm time	25
Exhaust system reached full capacity (+15s)	40
Simulation time for the scenarios (seconds)	330

6.2 Results Analysis

6.2.1 Gas concentration

Figures 19 through 27 depict the temporal evolution of gas concentrations within the BESS enclosure during the simulated gas release event. As the gases release, combustible gas concentrations inside the enclosure rapidly increase, triggering an alarm from the detector at a conservative detection time of 25 seconds. This alarm initiates the opening of the air inlet and the operation of the exhaust fan.

Following a 15-second ramp-up period, the fan reaches its measured airflow capacity, evacuating combustible gases generated by the failing battery from the BESS. Simultaneously, fresh air is drawn into the enclosure through the air inlet. The interaction between the inlet and outlet airflows establishes a dynamic equilibrium with the gas generation rate from the battery cells, resulting in the stabilization of gas concentrations within the BESS enclosure.

Specifically, Figure 19 shows that the global concentration of all gases reaches approximately 1.86%, while, according to the UL 9540A Cell level report, 25% of the lower flammability limit (LFL) for the gas mixture is 1.972% at the cell vent temperature.

Similarly, Figure 20 indicates that the global carbon monoxide (CO) concentration reaches 0.2%, compared to a 25% LFL for CO of 3.125%.

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Figure 21 illustrates that the global hydrogen (H_2) concentration reaches approximately 0.81%, while 25% of the LFL for H_2 is established at 1%.

Figure 22 illustrates that the global methane concentration reaches approximately 0.12%, while 25% of the LFL for methane is established at 1.25%.

Figure 23 illustrates that the global ethane concentration reaches approximately 0.02%, while 25% of the LFL for ethane is established at 0.75%.

Figure 24 illustrates that the global ethylene concentration reaches approximately 0.08%, while 25% of the LFL for ethylene is established at 0.675%.

Figure 25 shows that the global propane concentration reaches approximately 0.05%, compared to an estimated 25% LFL for propane of approximately 0.525%.

Figure 26 shows that the global acetylene concentration reaches approximately 0.003%, compared to an estimated 25% LFL for acetylene of approximately 0.625%.

Finally, Figure 27 shows that the global propylene concentration reaches approximately 0.02%, compared to an estimated 25% LFL for propylene of approximately 0.5%.

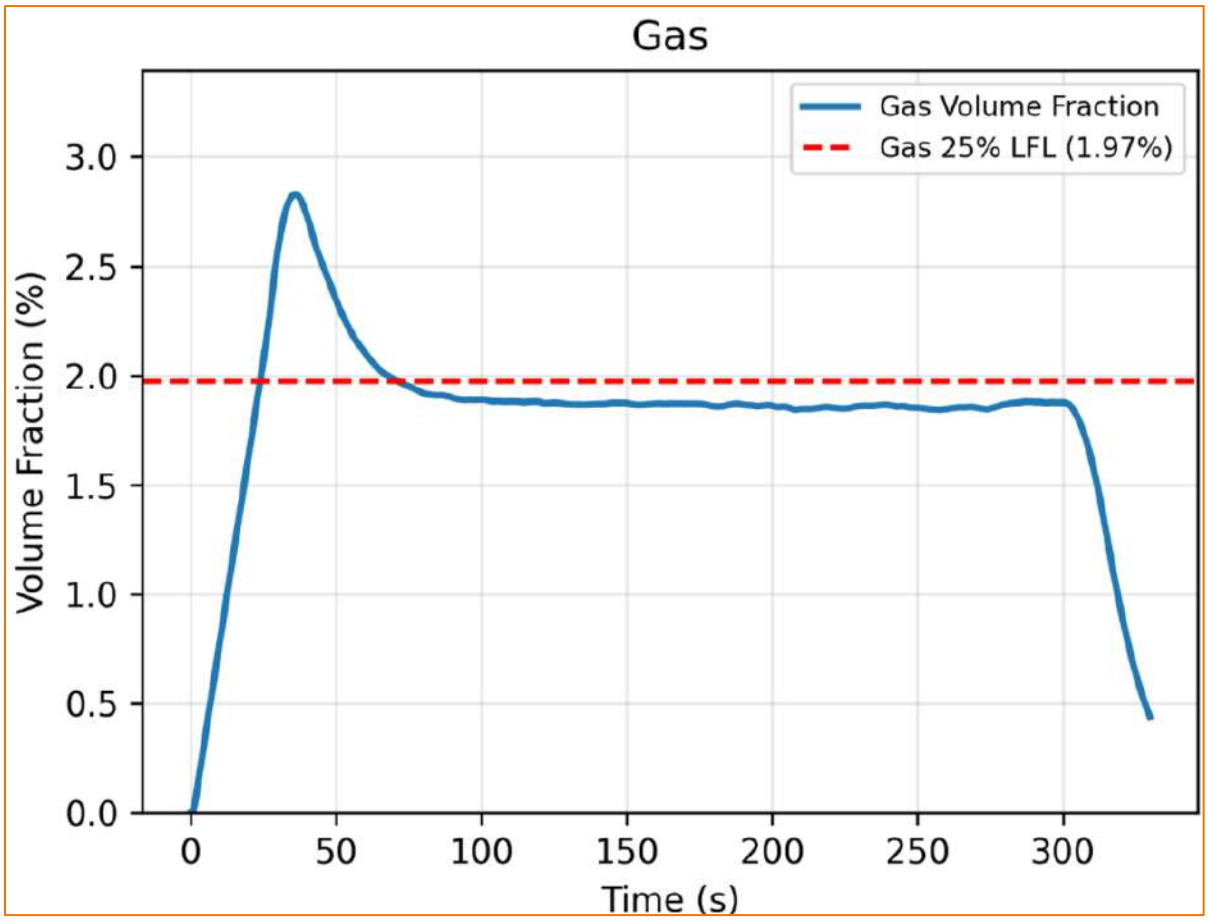

Figure 19 The Temporal Variation of Average Gas Concentration within the BESS Enclosure

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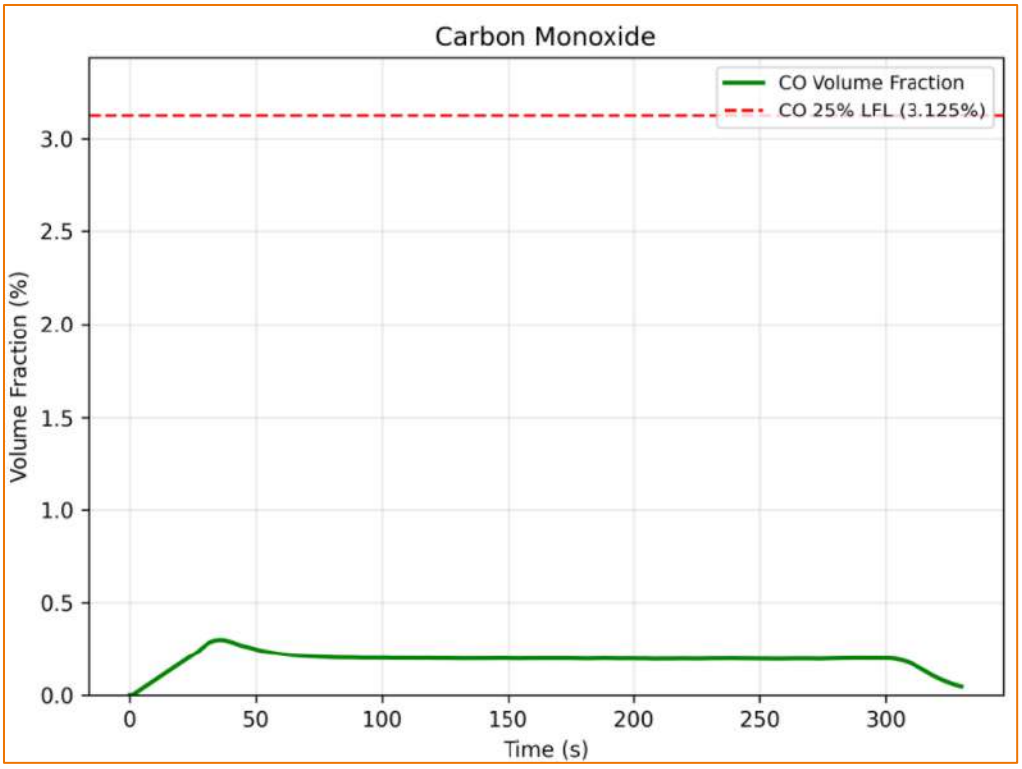

Figure 20 The Temporal Variation of Average Concentration of CO within BESS Enclosure

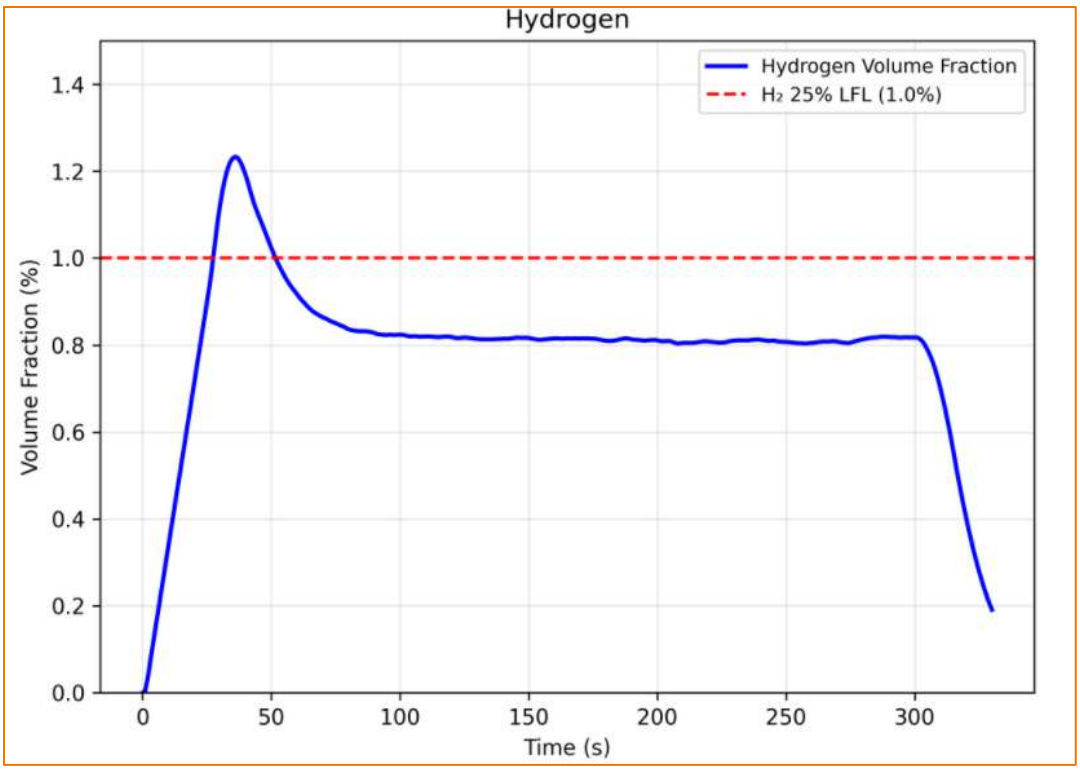

Figure 21 The Temporal Variation of Average Concentration of Hydrogen within BESS Enclosure

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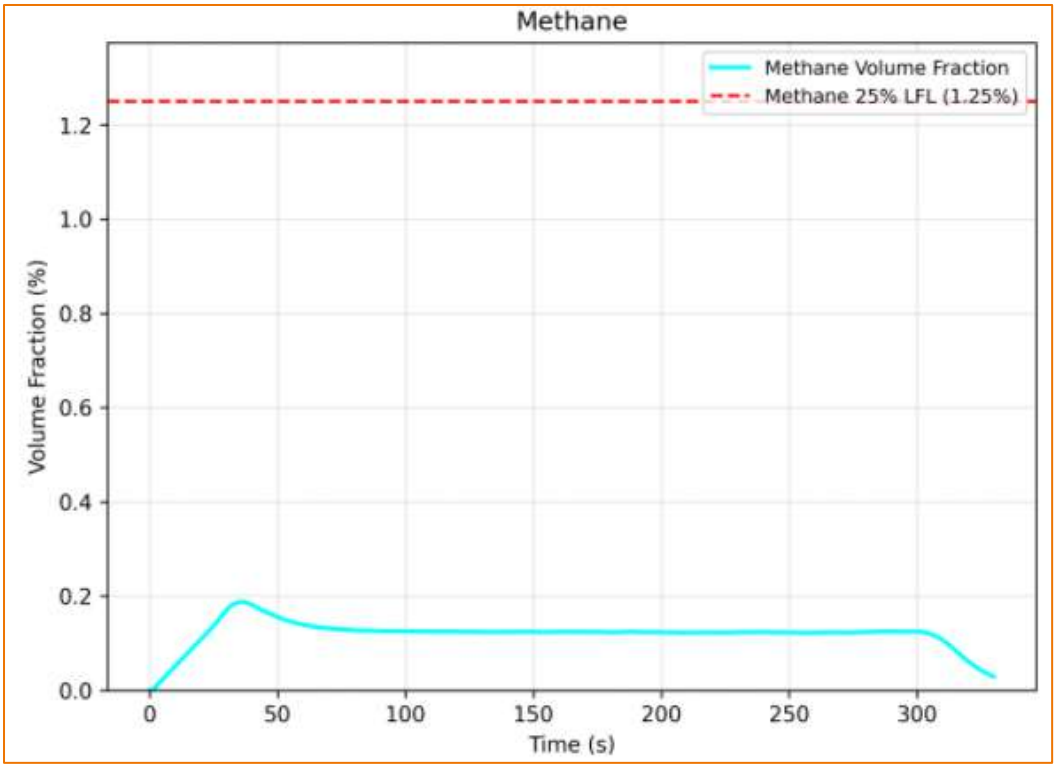

Figure 22 The Temporal Variation of Average Concentration of Methane within BESS Enclosure

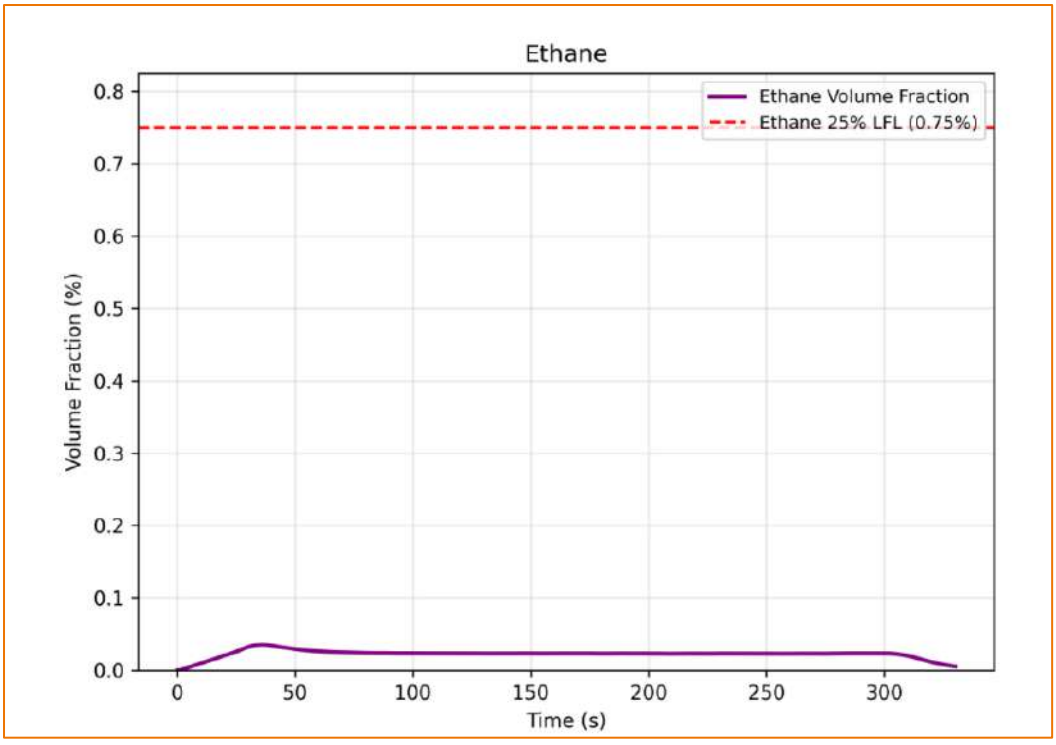

Figure 23 The Temporal Variation of Average Concentration of Ethane within BESS Enclosure

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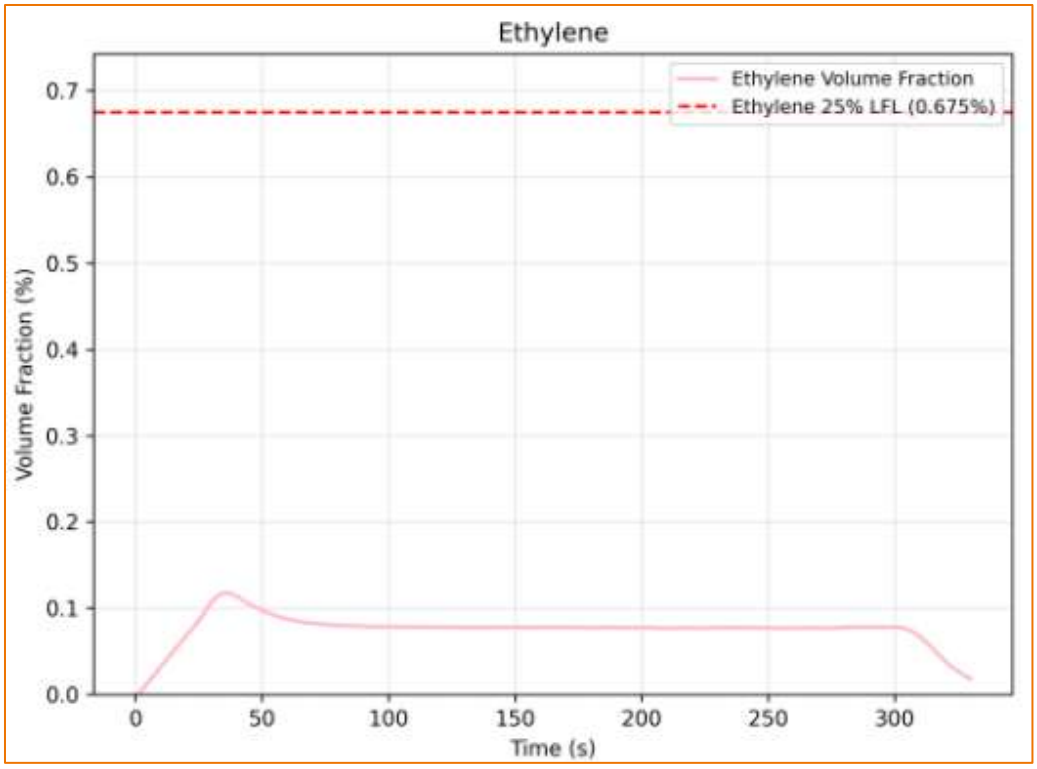

Figure 24 The Temporal Variation of Average Concentration of Ethylene within BESS Enclosure

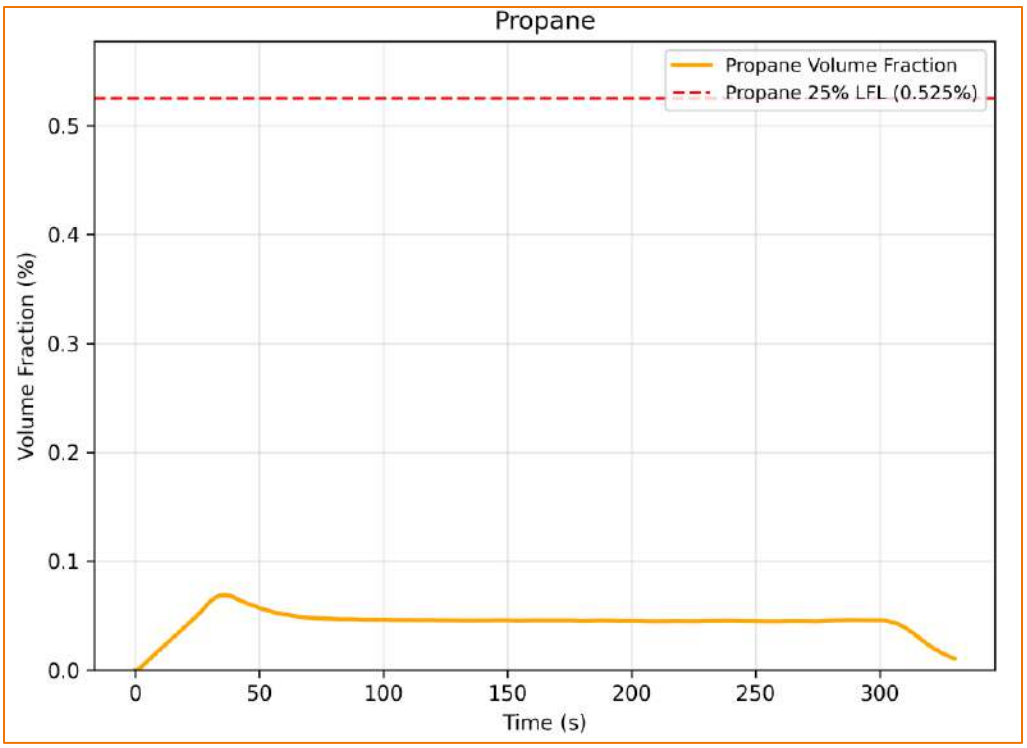

Figure 25 The Temporal Variation of Average Concentration of Propane within BESS Enclosure

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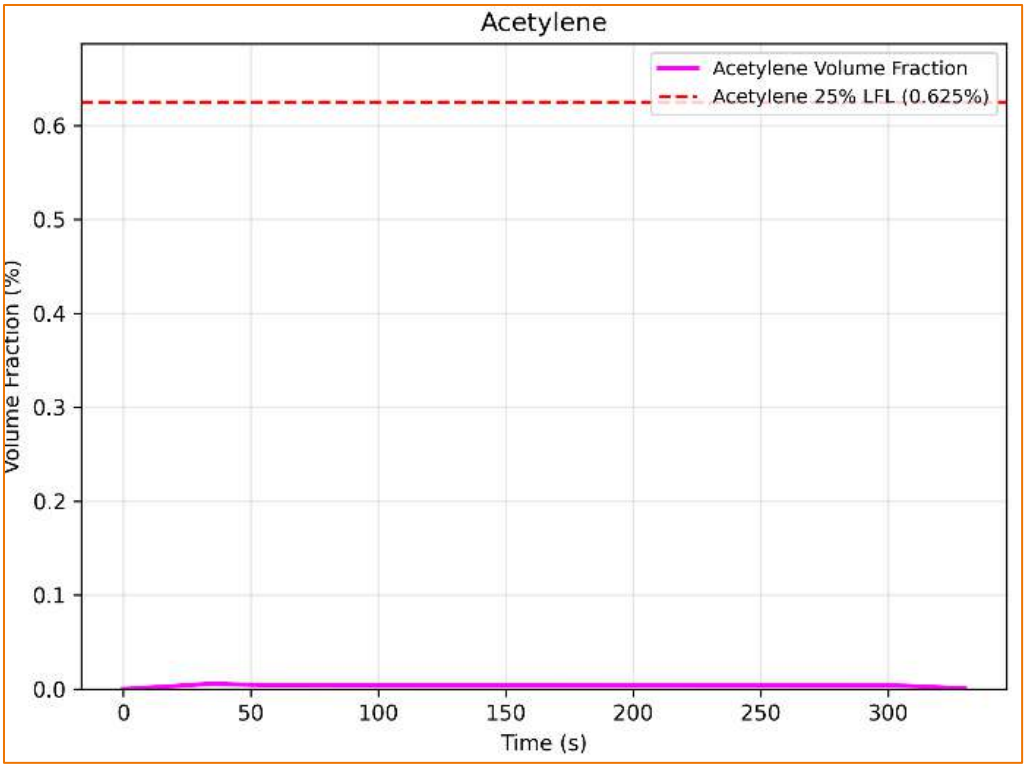

Figure 26 The Temporal Variation of Average Concentration of Acetylene within BESS Enclosure

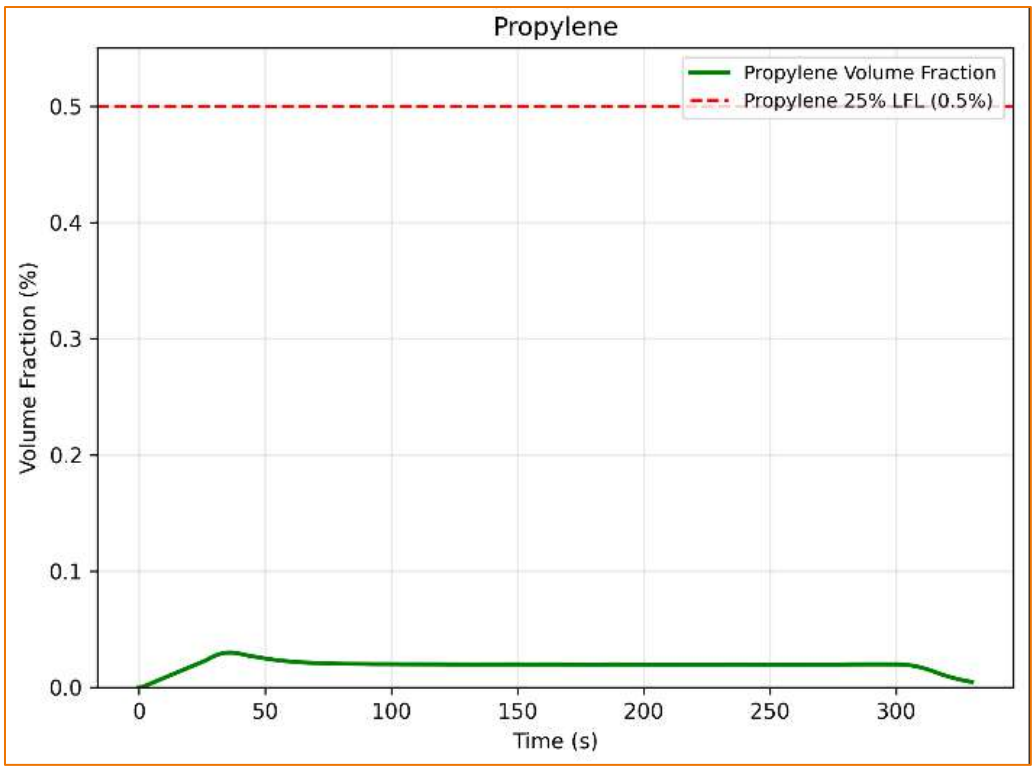

Figure 27 The Temporal Variation of Average Concentration of Propylene within BESS Enclosure

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Combining the chosen credible worst-case gas release with the assumed airflow of the exhaust fan is a conservative assumption, given that temporal fluctuations of gas release are expected in a real-life scenario, as thermal runaway is typically a cascading cell to cell event. Additionally, the modeled flow rate of 0.236 m³/s (500 CFM) is significantly less than the measured flow rate of 0.307 m³/s (650 CFM). Upon cessation of gas release, the gas volume faction rapidly diminishes to negligible levels. As depicted in the preceding figures, the average concentration of all measured gases within the BESS remains below the designated threshold of 25% of their respective Lower Flammability Limits (LFL).

To facilitate a more granular analysis of gas accumulation patterns within the BESS, gas concentrations were measured at strategically positioned detector locations. The temporal variation in concentration at these detectors is illustrated in Figure 28. Notably, H_2-detector 02, situated remote to the gas release point, recorded a stabilized concentration of approximately 0.5%. Conversely, H_2-detector 01, located within the gas release path from release point to exhaust fan, exhibited a concentration of approximately 3.5%, or 87.5% of the hydrogen LFL.

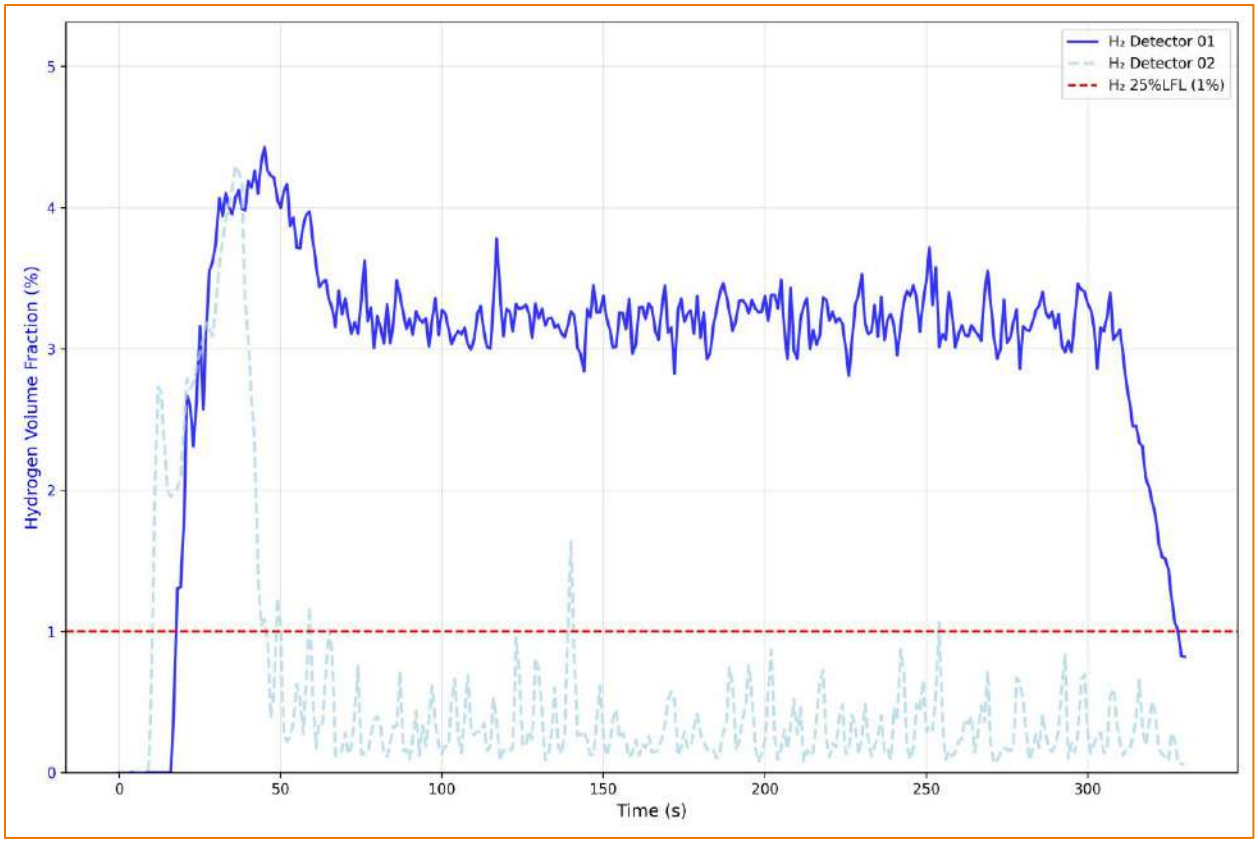

Figure 28 Temporal Variations in Gas Concentrations at the Gas Detectors

To further evaluate gas dispersion dynamics, time-resolved gas concentration measurements were conducted at select, discrete locations. Specifically, Monitoring Point

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1 (MP1), positioned upper right corner of the initiating module (illustrated in Figure 29), was selected due to the anticipated potential for exceeding 25% LFL. This condition could create circumstances conducive to partial volume deflagration. Temporal variations in gas concentration at MP1 are presented in Figures 30 through 38.

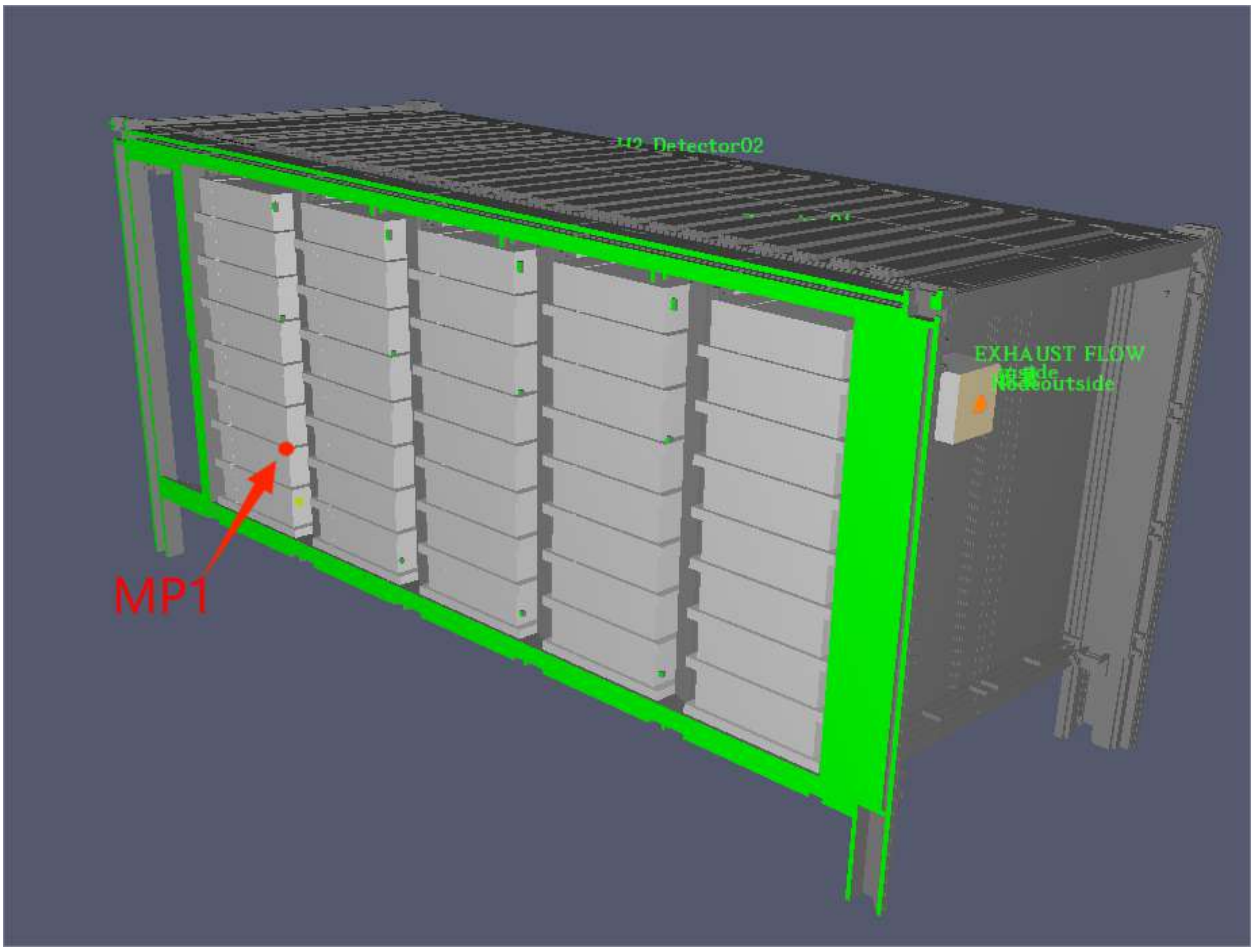

Figure 29 Location of MP1

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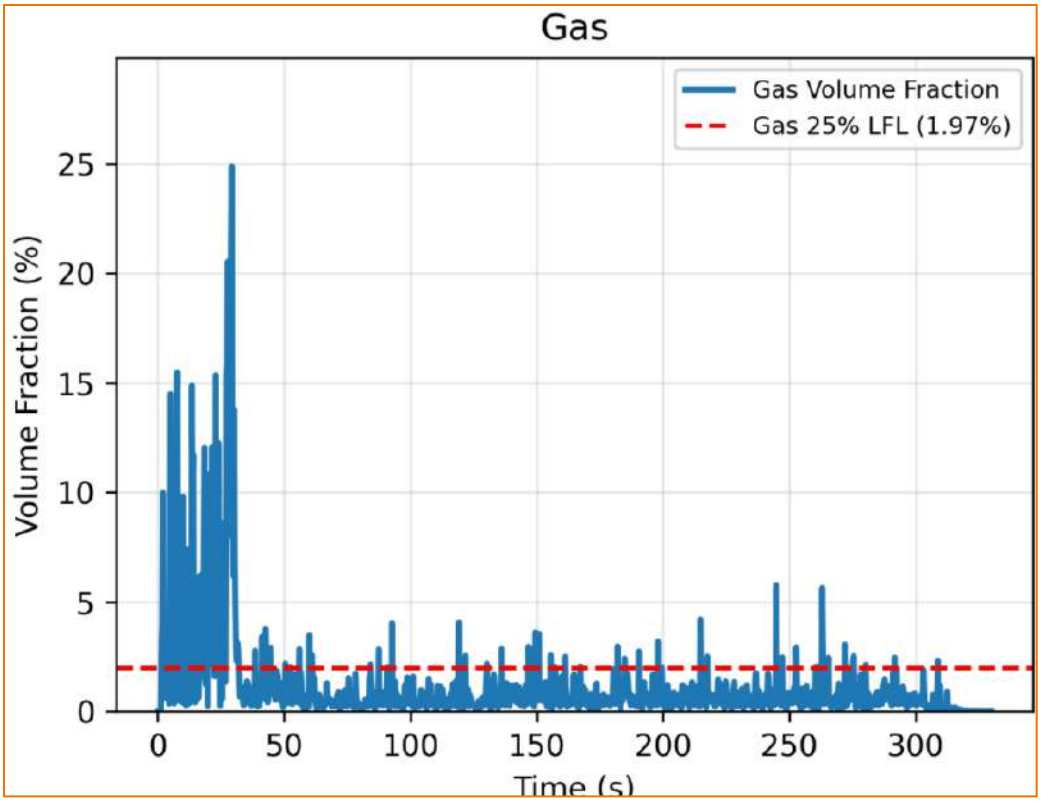

Figure 30 MP1 Temporal Variations in Gas Concentration

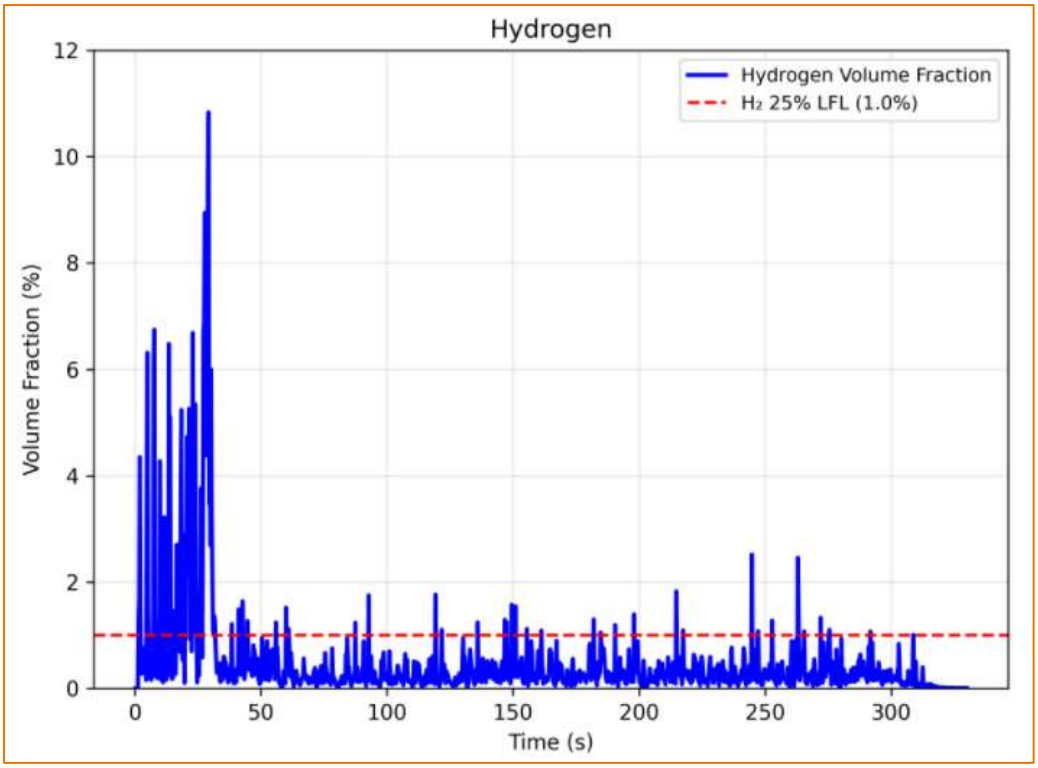

Figure 31 MP1 Temporal Variations in Hydrogen Concentration

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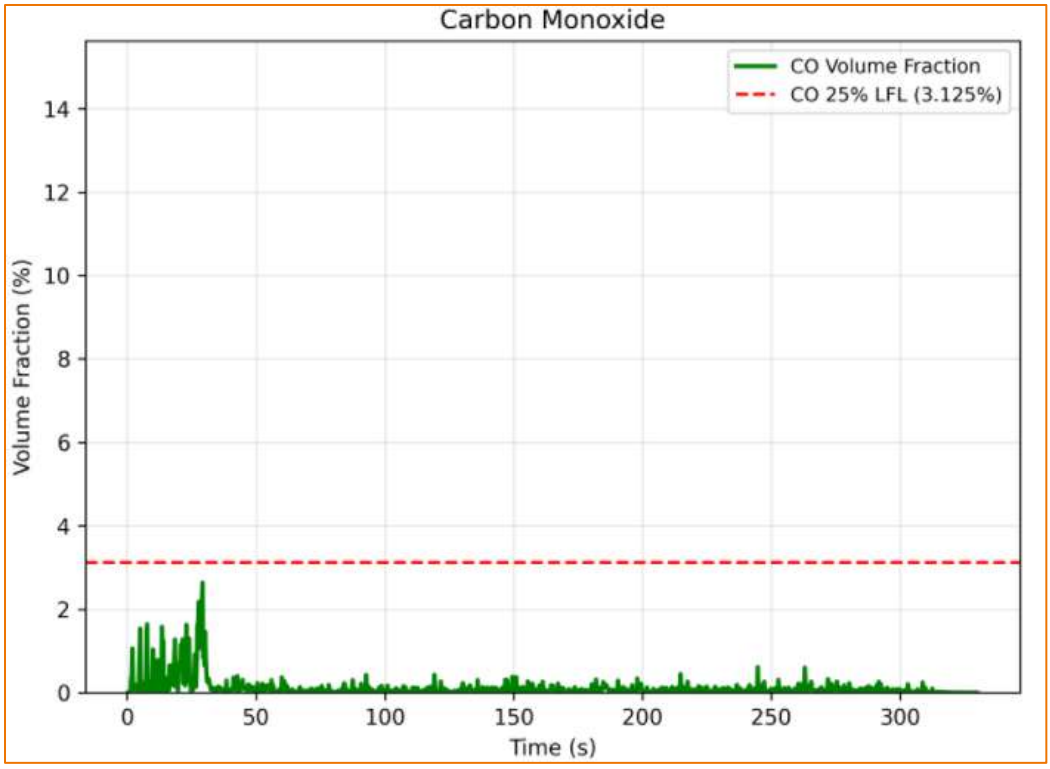

Figure 32 MP1 Temporal Variations in CO Concentration

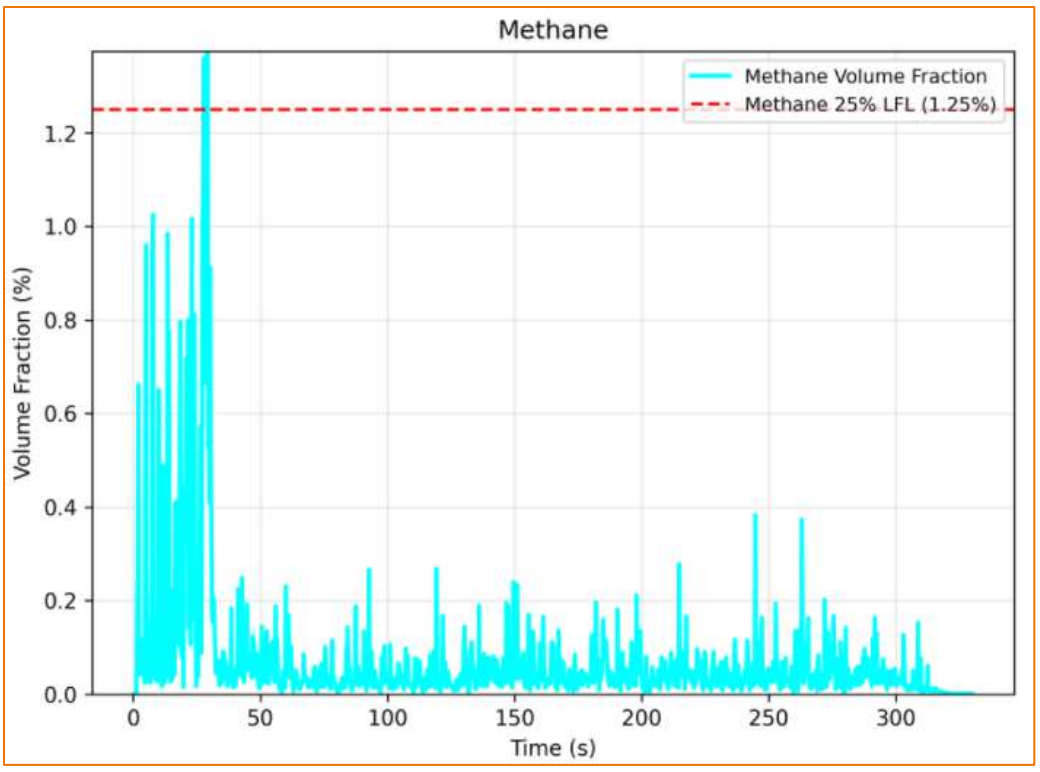

Figure 33 MP1 Temporal Variations in Methane Concentration

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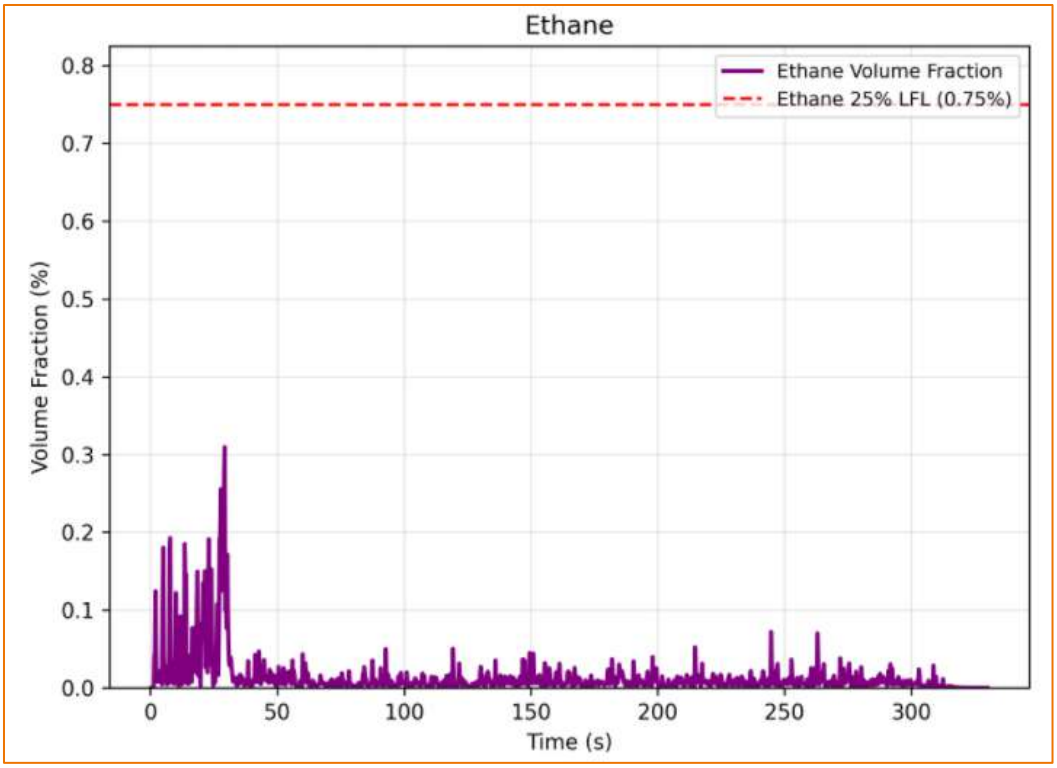

Figure 34 MP1 Temporal Variations in Ethane Concentration

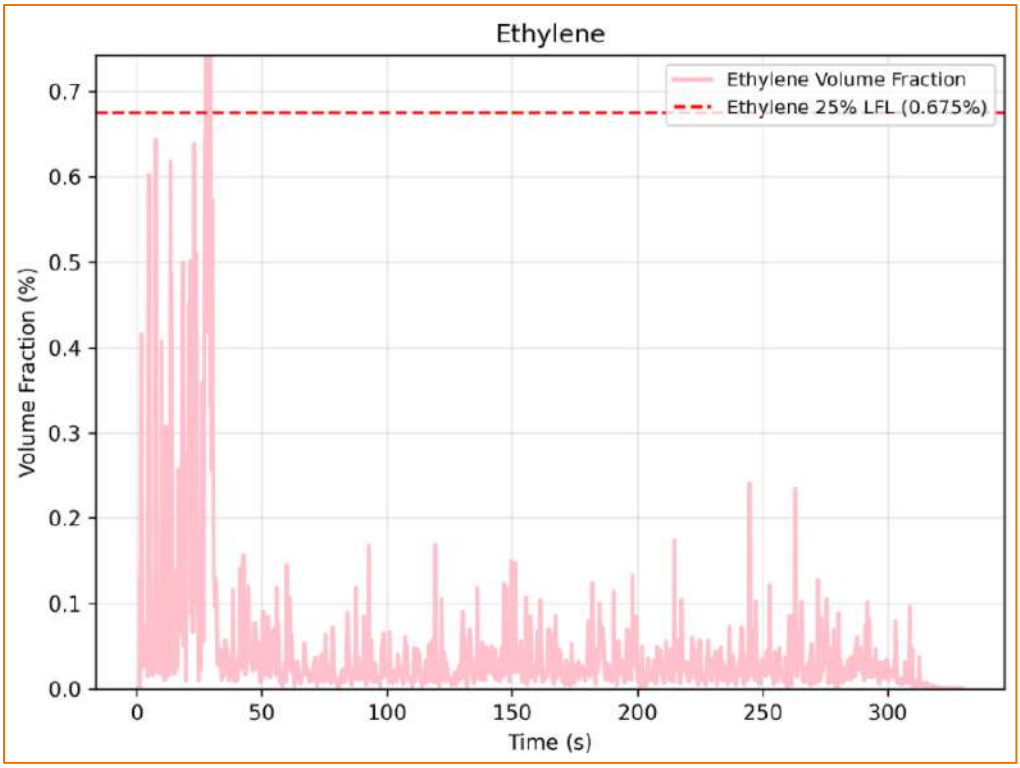

Figure 35 MP1 Temporal Variations in Ethylene Concentration

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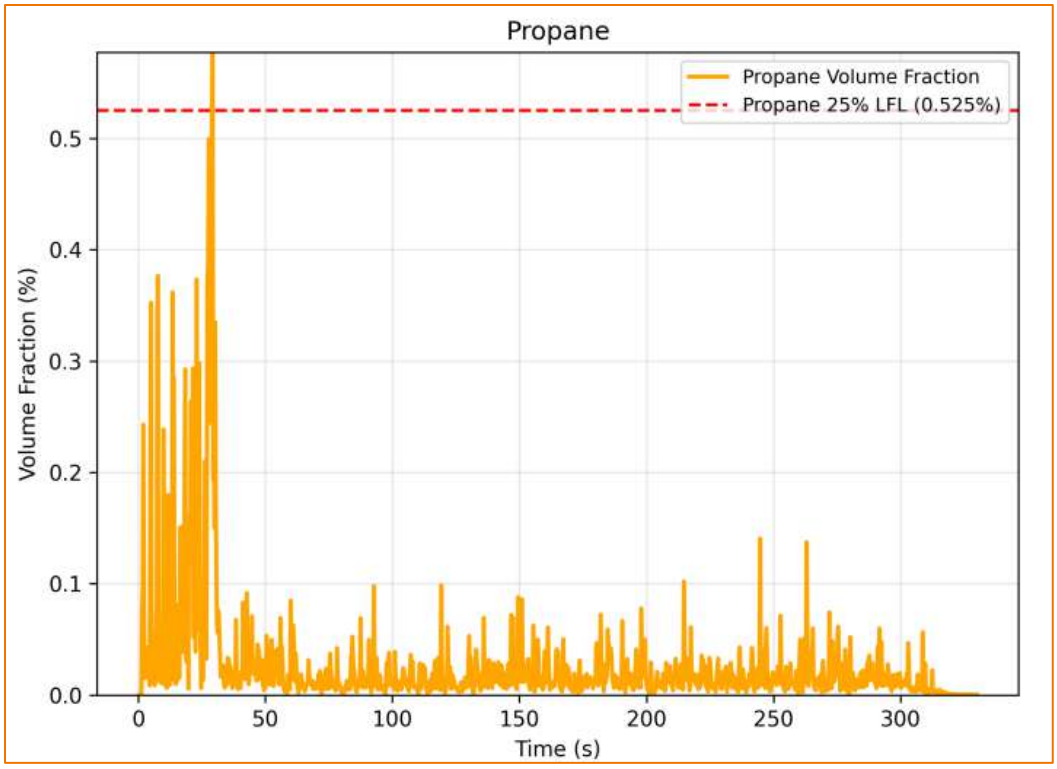

Figure 36 MP1 Temporal Variations in Propane Concentration

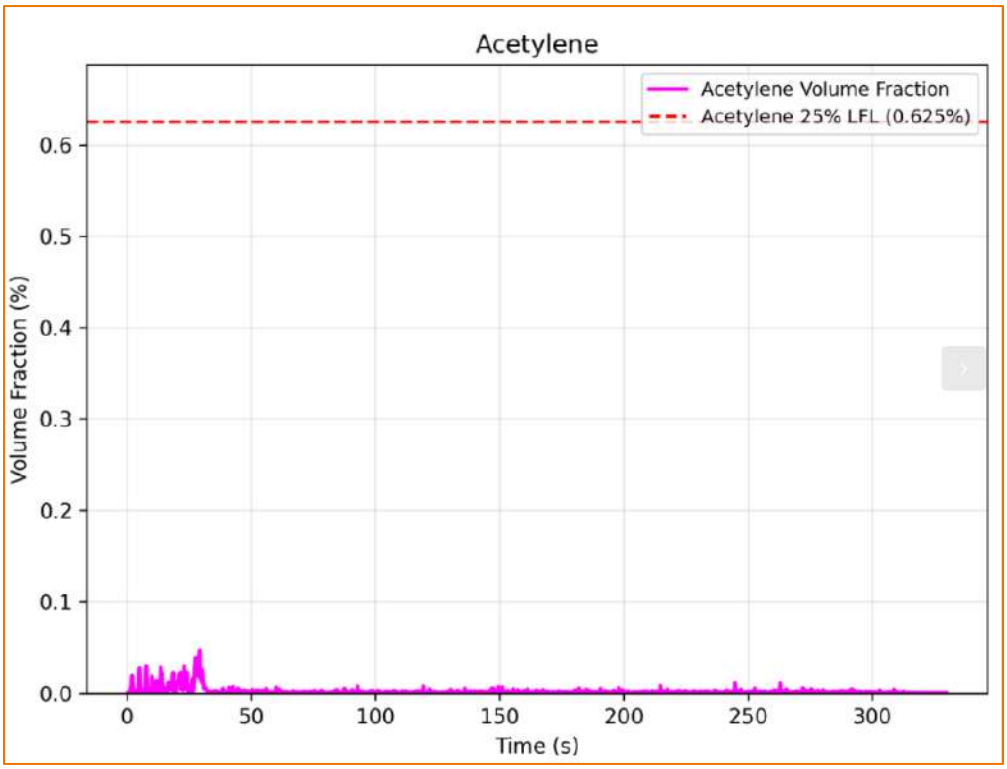

Figure 37 MP1 Temporal Variations in Acetylene Concentration

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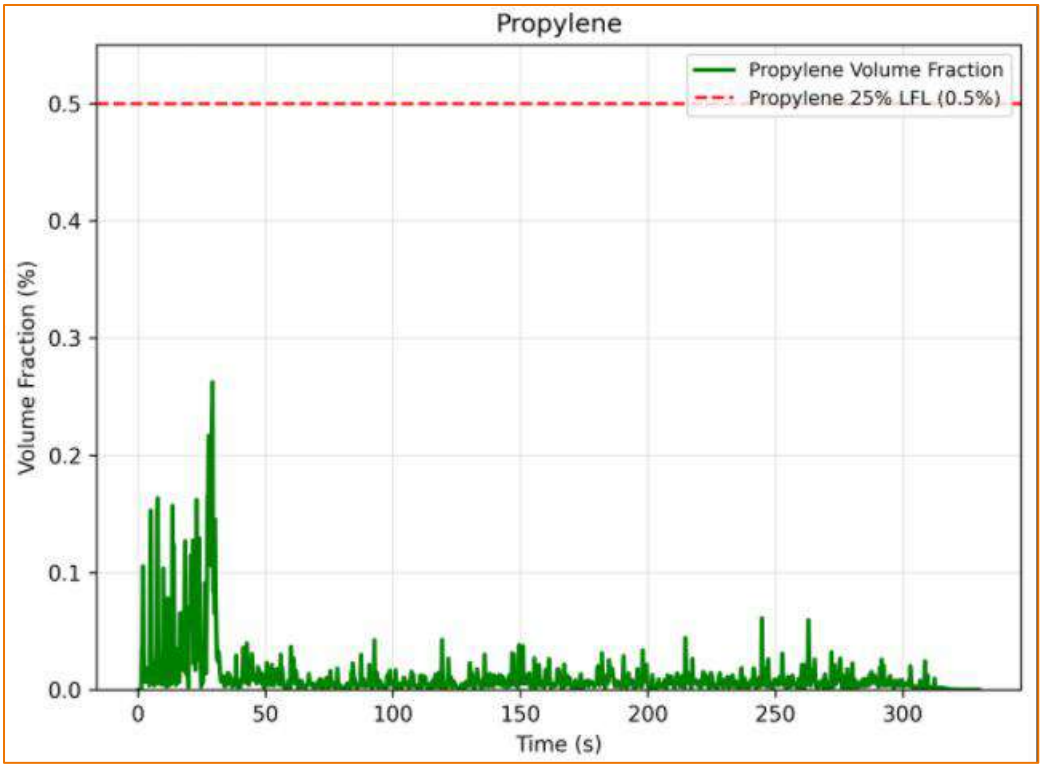

Figure 38 MP1 Temporal Variations in Propylene Concentration

The displayed data indicates that the gas concentration at the monitoring location, both the gas mixture and hydrogen as an individual component, exceeds 25% LFL. The CO content did not exceed 25% LFL because the LFL of the gas itself was relatively high, while the hydrocarbon substances (methane, ethane, ethylene, propane) did not exceed 25% LFL because their proportion in the mixed gas was small. The phenomenon observed here indicates that a partial volume explosion risk remains, even in the presence of the NFPA 69 CCR system.

6.2.2 Slice file

Figure 39 illustrates the distribution of gas within BESS at 26 seconds following the release of gas, prior to the activation of exhaust systems. At this juncture, the released gas has diffused towards the upper regions of BESS. The areas with high concentration are predominantly located in front of and above the initial module. In these zones, gas concentrations can reach or exceed 25% of LFL. This phenomenon is anticipated in proximity to the release site as well as right above the point of origin, given that gas is

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highly concentrated at its point of release and gradually diluted due to buoyancy.

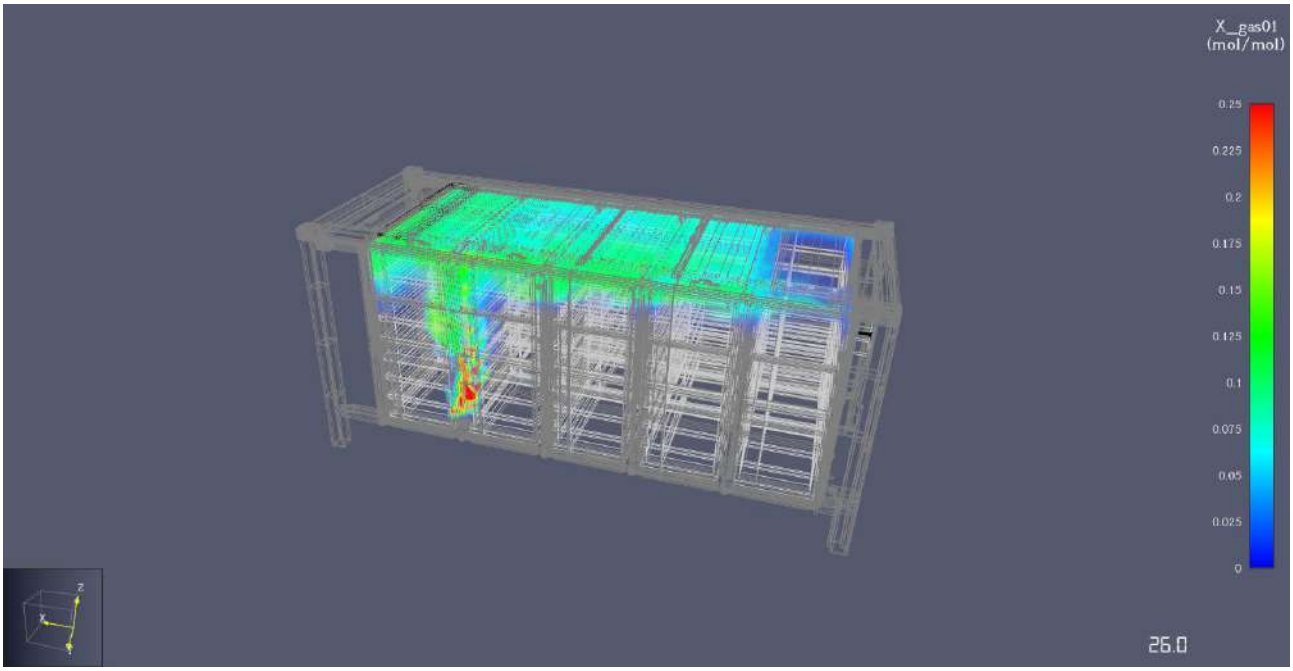

Figure 39 Gas Concentration Measured at 26 Seconds (Exhaust System Inactive)

Figure 40 illustrates the distribution of gas mixture within BESS enclosure one minute after the fan was activated and reached its full operational capacity. At this point, the gas has dispersed from left to right in accordance with the airflow pattern, resulting in varying concentrations across the BESS. The area on the left is situated closer to the gas release source, leading to a higher concentration of gas, while the area on the right is nearer to the fan and exhibits a lower concentration. This graph highlights the effectiveness of the exhaust system in facilitating gas removal from the enclosure.

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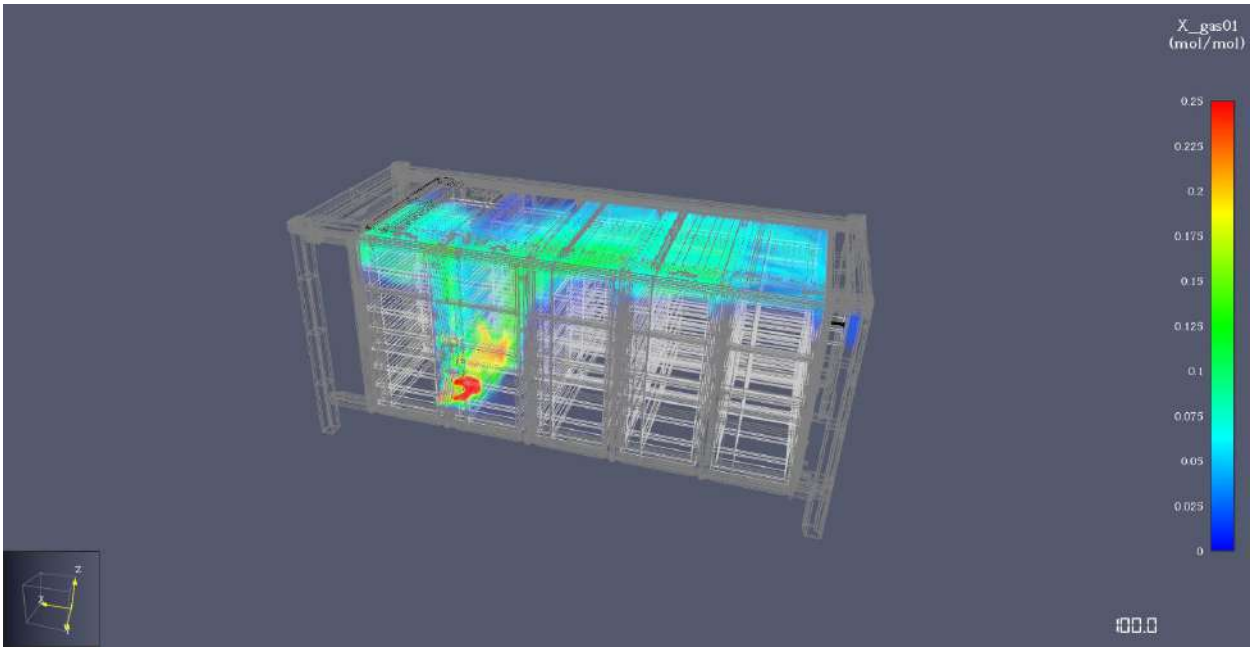

Figure 40 Gas Concentration in BESS After 100 Seconds (Fan Operates for 1 Minute)

Figure 41 illustrates the distribution of battery gas four minutes after the fan has been activated. As anticipated, a high concentration of gas is observed in front of and above of the gas release location, diluting in concentration is it makes its way to the exhaust fan. This overall distribution pattern resembles that depicted in Figure 40 and will persist until the conclusion of the simulation run. After the concentration falls under 25% LFL, it then consistently remains below this level.

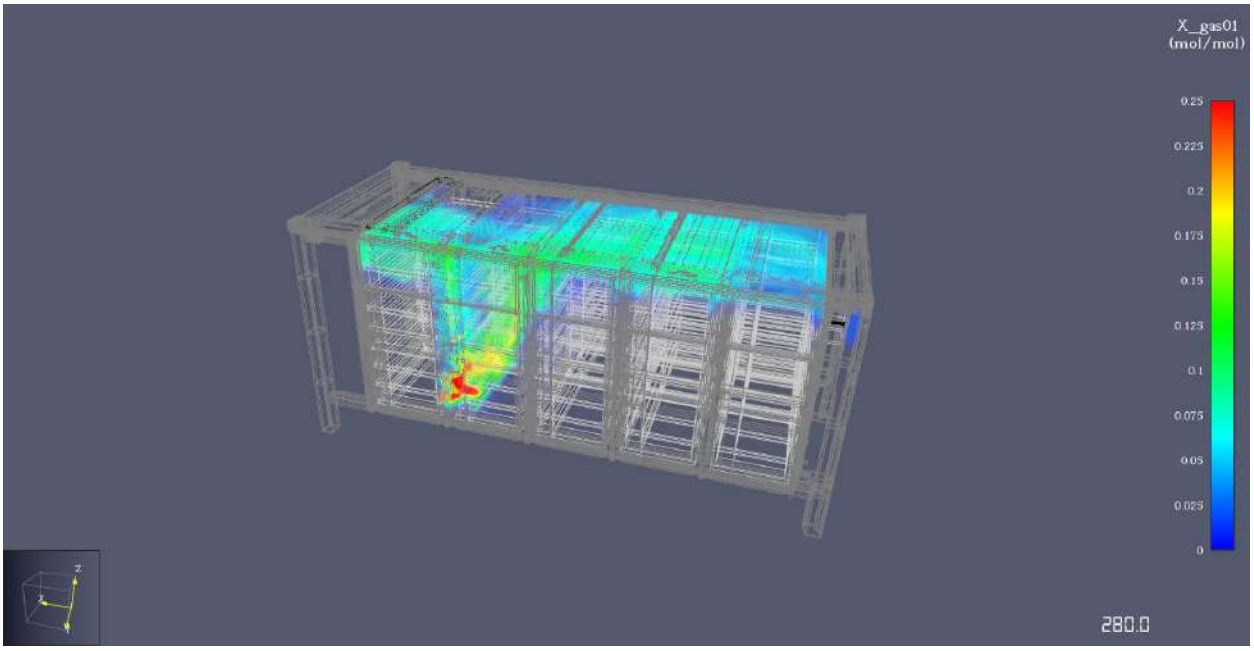

Figure 41 Gas Concentration in BESS After 280 Seconds (Fan Operates for 4 Minutes)

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Figure 42 illustrates the region where the hydrogen concentration exceeds 1% (25% LFL) when the hydrogen gas within BESS container reaches a steady state. Due to adjustments made to the vertical axis, all colored areas in the graph indicate hydrogen concentrations that surpass 1% (25% LFL of hydrogen) at those specific locations. The colorless area represents regions with concentrations below 25% LFL.

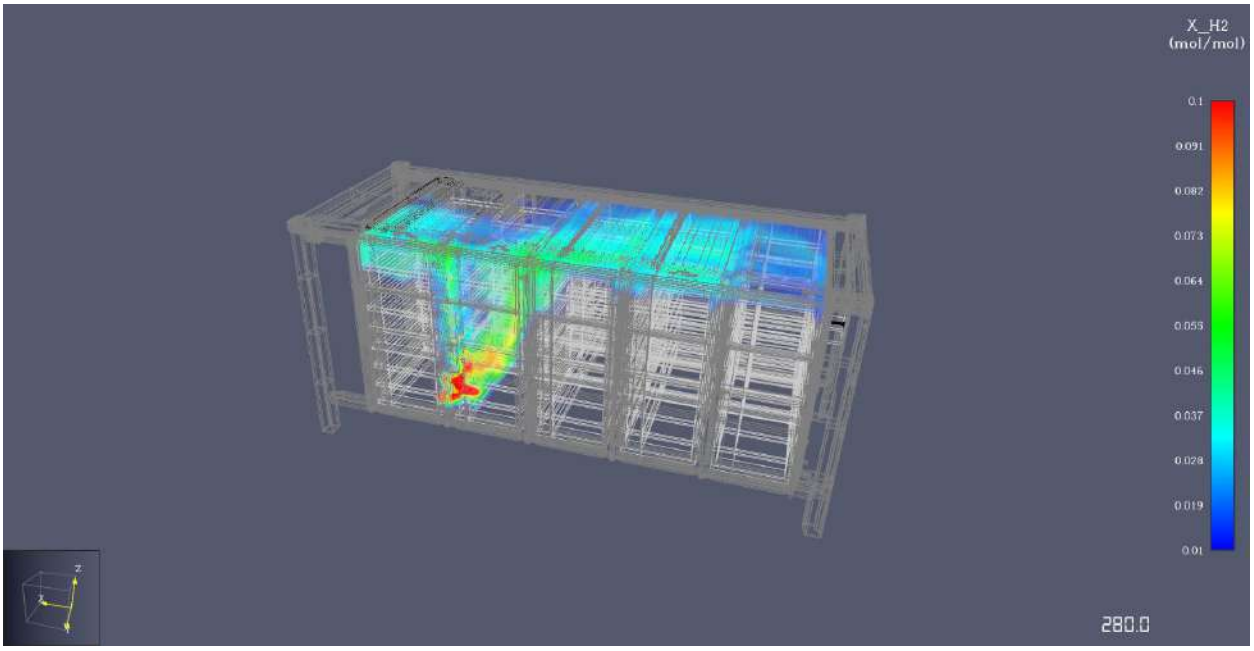

Figure 42 Areas Where Hydrogen Concentration Exceeds 1% After Stabilization within BESS

The areas shown above 25% LFL are anticipated, as the release of a concentrated volume of gas within an enclosure will create a gradient from the point of release to the exhaust location, with the highest concentrations occurring at the release site. The accompanying image illustrates the functionality of gas removal from the enclosure while ensuring that overall average concentrations remain below 25% LFL, in accordance with the intent of NFPA 855 (2026) and NFPA 69 requirements.

The recognition that average concentration is more suitable for BESS design has been incorporated into NFPA 855 (2026). NFPA 855 (2026) states that “flammable gas does not exceed an average of 25 percent of the LFL of the gas mixture...”

Furthermore, NFPA 855 (2026) (where enforced by the local AHJ) mandates that systems provided with an NFPA 69 CCR system be accompanied by a partial volume deflagration analysis in accordance with NFPA 68. This necessity is underscored by the formal substantiation of this new requirement, recognizing that “a partial volume deflagration can occur before and during operation of an NFPA 69 (CCR) system as pockets of gas above the LFL may still exist." Consequently, this validates that results illustrated in Figures 39 through 42, indicating a partial volume deflagration hazard is an anticipated phenomena

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during instances involving gas release and exhaust ventilation. It is expected that certain areas will surpass a threshold exceeding 25% LFL.

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7.0 Assumptions and Limitations of the Study

The assessment of the gas release and CCR system presented herein is predicated on several key assumptions. Alterations to these underlying conditions necessitate further analysis to ensure the continued validity of the conclusions.

Specifically: (1) the cell, module, and unit design employed in the UL 9540A testing must remain consistent; (2) the physical layout and configuration of the BESS must be maintained, as modifications to internal obstructions can significantly impact airflow dynamics; (3) the characteristics of the installed gas detector, including its location, detection threshold, and response time, must conform to (or exceed in response time) the specifications outlined in this report, and the dimensions, placement, and air volume of the inlet and outlet air systems must remain unchanged; (4) this analysis assumes the absence of fire or explosion during operational use; (5) the CCR is commissioned, inspected, tested, and maintained in accordance with NFPA 69; and (6) the analysis does not account for the activation of extinguishing systems or fire sprinkler systems, which could potentially influence the performance of the detection and ventilation systems. The manufacturer has stated that CCR system control logic is such that the CCR system is a manual reset. As such it shall not be overridden by other systems. However, should a conflict arise, for example, the aerosol system discharges during CCR system operation, or the operation of the aerosol system causes the make-up air inlet to close, then the results of this analysis are no longer valid.

The CCR system components (exhaust and air inlet), as well as the activation mechanism of the installed gas detectors, have been modeled in strict accordance with the information provided by CATL. Any deviations from these assumptions will require re-evaluation of system performance. Furthermore, the following limitations are pertinent to the CCR system strategy employed in this simulation project:

(1) The CCR system is not designed to prevent localized gas concentrations from exceeding the Lower Flammable Limit (LFL), particularly in proximity to battery gas release points or areas prone to gas accumulation; localized regions within the BESS may exhibit concentrations exceeding the LFL. It should be noted that NFPA 855 (2026) mandates maintaining the average concentration within the enclosure below 25% of the LFL; and (2) observations indicate that, prior to ventilation system activation, localized gas concentrations at the top of the BESS and near battery gas release sites surpass 25% of the LFL levels.

While the evaluated CCR system contributes to mitigating explosion risks and aligning with the design objectives delineated in NFPA 855 and NFPA 69, it does not eliminate the potential for explosion hazards. The formation of flammable gas mixtures within the enclosure remains possible, potentially leading to a partial volume deflagration. A

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deflagration venting system has been designed by CATL to address this potential. The deflagration venting system is analyzed separately [10]/

8.0 Conclusions

NFPA 855 (2026) mandates that BESS's comply with the requirements in NFPA 69, requiring that the average gas concentration within the BESS enclosure does not exceed 25% LFL.

Given the potential for thermal runaway in lithium-ion batteries to release flammable gases into a BESS enclosure, a gas release model was developed based on UL9540A data to characterize combustible gases according to their potential release rate and compositions.

This model incorporates a conservative gas release rate, utilizing Cell, Module, and Unit level data from UL 9540A to estimate a multi cell failure and incorporating a conservative timeframe for thermal runaway to ensure a robust risk assessment. The modeling scenario includes a conservative assumption of a 15-second delay between gas detector alarm activation and the initiation of fan operation, as well as a 15-second fan ramp-up time. The modeled exhaust flow rate of 500 cfm is significantly less than the as-installed measured exhaust flow rate of 650 cfm. These assumptions introduce a margin of safety to account for inherent uncertainties in the modeling process; in reality, actual fan activation is anticipated to occur immediately upon gas detection, with ramp-up times likely to be five seconds or less, and the actual exhaust flow rate is anticipated to be higher.

The FDS modeling described in this report indicated that the average global concentration of battery gas briefly exceeds 2.8% prior to the CCR system activation, over the LFL of 25% (1.972%) for the gas mixture at vent temperature. Once the exhaust fan system reaches full operational capacity and the gas concentration within the BESS achieves a steady state, the average global concentration of combustible gases was measured at 1.87%, with hydrogen specifically at 0.8%, both remaining below their respective LFL thresholds of 25%.

Although transient localized areas may exhibit elevated gas concentrations exceeding 25% of the LFL, this behavior is anticipated and consistent with the expected performance of the gas release and ventilation system. NFPA 855 (2026), requires that the overall average concentration within the BESS remain below 25% LFL on average to account for this. The potential for partial volume deflagration cannot be entirely dismissed. This concern is also addressed in NFPA 855 (2026), which, where enforced, mandates a partial volume deflagration analysis compliant with NFPA 68 to complement NFPA 69

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CCR systems. A partial volume deflagration analysis has been performed and is discussed in a separate report [10].

Finally, the simulation results presented in this report are applicable solely to the explosion hazards identified based on UL 9540A test data with additional conservatisms; any other scenarios that may present an explosion hazard require independent analysis.

A code compliance crosswalk in accordance with Chapter 6 and Chapter 8 of NFPA 69 is presented in Appendix A for thoroughness.

This analysis does not account for site-specific hazards such as enclosure spacing or separation distances. A comprehensive hazard mitigation analysis must be conducted, and appropriate mitigation strategies developed, to ensure that the BESS does not pose a fire or life safety risk while complying with all applicable local regulations.

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9.0 References

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Appendix A: Prescriptive Analysis of NFPA 69 (2024), Chapters 6 & 8

Section	Text	Comments
6.1	Methods: *The methods recognized in this standard shall be grouped based on the prevention of combustion or on the prevention or limitation of damage after combustion occurs.*	This analysis utilizes 6.1.1(2), Combustible Concentration Reduction, to satisfy the requirements of Section 6.1.
6.2	Limitations: *The limitations specific to each method shall be considered and are specified in the corresponding chapter for each method.*	Limitations of this report are described within the Limitations section of this report.
6.3	Factors to Be Considered: *The following factors shall be considered in the selection of one of the methods and the design of the system:* *1) Effectiveness of each method* *2)Reliability of the system* *3) Personnel hazards inherent in each method*	1. This report considers the effectiveness of the system in meeting the performance objectives described in Section 8.3.1(1) of NFPA 69:2024, NFPA 855 (2023), and NFPA 855 (2026) 2. The reliability of the system is dependent upon required ongoing maintenance, to be performed by the owner or end user. This report does not provide any guarantee of continued reliability which would be ensured by appropriate inspection, testing, and maintenance. A common benchmark for system reliability without automatic monitoring is a probability of failure upon demand 0.1, in accordance with *Guidelines for Initiating Events and Independent Protection Layers in Layer of Protection Analysis* – Center for Chemical Process Safety. Where performance monitoring is provided, in the form of power loss and interlocks to shut down the BESS upon system failure, this PFD can be reduced to .01. 3. Personnel hazards inherent in each method: There are personnel hazards associated with exhausting flammable and toxic gases from a BESS. These hazards should be addressed in an emergency

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		response plan, in addition to any site-specific hazard mitigation analysis, as well as overall site code compliance. NFPA 855 typically requires a clear distance from exhaust outlets such that they are not discharged above public ways.
6.3.1 (1)	System Design Basis	The manufacturer's data was utilized, in addition to UL 9540A data, for assessing the adequacy of the system design. These items are discussed in detail in this report.
6.3.1(2)	Possibility of electrical and mechanical malfunction	Electrical and mechanical failure is possible. See the layers of protection analysis in Section 6.3(2). In the event of electrical or mechanical malfunction, this analysis is no longer valid. The owner or end user must inspect, test, and maintain the system at the required intervals of NFPA 69 to ensure system performance in accordance with industry best practices.
6.3.1(3)	Dependance on sophisticated activating systems:	The successful operation of the system relies on interlocked control systems, including relays and control interfaces. The owner or end user must inspect, test, and maintain the system at the required intervals of NFPA 69 to ensure system performance in accordance with industry best practices.
6.3.1(4)	Need for special installation, training, operating, testing, and maintenance procedures.	System acceptance procedures of Chapter 15 of NFPA 69 shall be adhered to validate adequate installation. End users shall be trained in system operation. Emergency responders shall be informed of the system design intent and its operating characteristics during annual training as required by NFPA 855, the IFC, or other codes, standards, or regulations. The owner or end user must inspect, test, and maintain the system at the required intervals of NFPA 69 to ensure system performance in accordance with industry best practices.
6.3.1(5)	Further limitations as presented in each chapter.	All known limitations are presented in this report.

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6.3.2	In general, explosion prevention systems shall be used to protect processing, storage, and materials-handling equipment	Informational note only provided by NFPA 69.
6.3.3	When explosion prevention techniques are applied to rooms, buildings, or other enclosures where personnel are present, consideration shall be given to the safety of the personnel	BESS is not occupied by personnel. BESS is a non-walk-in unit. Emergency response for BESS incidents is to be addressed in an emergency response plan as required by NFPA 855, IFC, or other codes, standards, or regulations.
6.3.4	Description Omitted for Brevity. Content applies only to NFPA 69 Chapters 10, 11, 12, or 13.	N/A, applies only where Chapter 10, 11 12, or 13 are used. They are not applicable to this analysis.
6.4	Plans	Plans have been used in the development of this report.
6.5	System Acceptance	All acceptance testing shall comply with NFPA 69.
6.6	Inspection and Maintenance	The owner or end user must inspect, test, and maintain the system at the required intervals of NFPA 69 to ensure system performance in accordance with industry best practices.
6.7	Housekeeping	Housekeeping is required in accordance with NFPA 855 or the IFC, which prohibits storage of combustibles inside a BESS enclosure. A BESS is not akin to a combustible dust producing facility, for which this requirement is generally written for.
8.1	Application (*Text not included here, this is a general note for information only)*	-
8.2	All of the following factors shall be considered in the design of a system intended to reduce the combustible concentration below the LFL: 1) Required reduction in combustible concentration 2) Variations in the process, process temperature and pressure, and materials being processed 3) Operating controls 4) Maintenance, inspection and testing 5)	1) This report provides an overall assessment for compliance with sub-item 1. See the full report for more details. 2) This report models thermal runaway the cell vent temperature. Environmental conditions are discussed in the report. 3) Operating controls are discussed in this report. The CCR system is a latching system and must be manually reset once

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	Concentration variation with time and location within the protected enclosure	activated. This report is invalid if the fire extinguishing system overrides or otherwise operates during CCR system operation, or of the CCR system otherwise stops 4) Inspection, testing, and maintenance is required by the owner or end-user to ensure continued system reliability. 5) This report presents concentration variations over space and time within the BESS enclosure.
8.2.2	The LFLs of the combustible components shall be determined at all operating conditions, including startup and shutdown	This analysis considers the LFL of the battery gas mixture as well as individual components. The actual concentrations of gases are tracked over time and space. Results are presented in this report.
8.2.3	Protection System Design and Operation	
8.2.3.1	The owner or operator shall be responsible for a thorough analysis of the process to determine the type and degree of deflagration hazards inherent in the process.	N/A. This is not an industrial process. NFPA 855 regulates prescriptive requirements around BESS, to address the type and degree of known hazards from BESS incidents. This report is intended to satisfy the requirements of NFPA 855 and NFPA 69.
8.2.3.2	Information required for the monitoring and control of the concentration of combustible components shall be compiled and documented. This information shall include but not be limited to: 1) Monitoring and control objectives 2) Monitored and controlled areas of the process. 3) Dimensioned drawings of the process with the following a) Equipment make and model if available, including volumes and diameters and design strengths b)Plan and elevation views with flows indicated. 4) Startup, normal, shutdown, temporary operations, and emergency shutdown process	1) This report covers the objectives of the CCR system, which seeks to control the concentration of combustible gases in an off-normal event 2) The monitored and controlled area is the BESS enclosure. It is described in this report. 3) Drawings have been used as input to this CFD model. 3a) Equipment make and model are described here 3b) Images of the locations of exhaust fan and make up air inlet are included in this report. Images of the airflow during operation are included. 4) The CCR system is to be commissioned in accordance with

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	conditions and ranges for the following: a) Flow b) Temperature c) Pressure d) Oxidant Concentration e) Fuel Concentration. 5) Process Flow diagram and description 6) Ambient temperature in process area 7) Process interlocks	NFPA 69. Startup normal/shutdown/temporary operations, and emergency shutdown procedures are at the discretion of the owner and local AHJ. 5) This is not an industrial process; therefore, no process flow diagram is included 6) The BESS is a temperature-controlled environment. 7) Gas detection is interlocked to activate the exhaust fan and make up air inlet
8.2.3.3	The owner or operate shall disclose any and all process information required for the protection system design.	All information necessary for this analysis has been disclosed by the system manufacturer.
8.2.3.4	The protection system design shall be subject to a documented review by a qualified person	This report provides for an evaluation of the adequacy of the manufacturer's designed CCR system. Atar Fire, LLC, is qualified to perform this evaluation.
8.2.3.5	The owner or operator shall be responsible for the maintenance of the system after installation and acceptance based on procedures provided by the vendor. Maintenance records shall be retained for inspection by the authority having jurisdiction.	The owner or operator shall inspect, test, and maintain system in accordance with NFPA 69 and maintain records of such maintenance.
8.2.3.6	The owner or operator shall be responsible for periodic inspection of the system by personnel trained by the system manufacturer. The inspection frequency shall be in accordance with 15.7.	The owner or operator shall inspect, test, and maintain system in accordance with NFPA 69 and maintain records of such maintenance.
8.2.3.7	Management of Change. The effect of any process change shall be addressed as specified in Section 15.11	Any changes to the BESS and associated components described in this report require a re-evaluation.
8.2.3.8	All documentation relevant to the protection system shall be retained in accordance with Chapter 15.	The owner or site operator shall maintain applicable documentation.
8.3.1	The combustible concentration shall be maintained at or below 25 percent of the LFL for all foreseeable variations in operating conditions and material	This analysis is specific to battery energy storage systems. It is recognized that NFPA 69 was not initially developed with this

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	loadings, unless the following apply: 1) Where continuously monitored and controlled with safety interlocks, the combustible concentration shall be permitted to be maintained at or below 60 percent of the LFL 2) Aluminum powder production systems… (N/A)	application in mind. Recognizing this, the NFPA 855 (2026), permits combustible concentrations to be maintained on average at or below 25 percent of the LFL. This analysis demonstrates this requirement is met.
8.3.2	Catalytic Oxidation	N/A
8.3.3	Ventilation or Air Dilution	
8.3.3.1	If ventilation is used, the outlets from the protected enclosures shall be located so that hazardous concentrations of the exhausted air cannot enter or be drawn into the fresh air intakes of environmental air handling systems	BESS shall be located in a site-specific manner, in accordance with locally adopted codes, which may include location of exhaust vents with respect to air intakes.
8.3.3.2	Air intakes	N/A – this is for air dilution systems.
8.3.3	Filters/Dryers	N/A – there are no filters no filters or dryers
8.4	Instrumentation	
8.4.1	Instrumentation shall be provided to monitor and control process flows	N/A. There are no process flows associated with this BESS. However, gas detectors are provided to monitor off normal conditions.
8.4.2	Instrumentation shall be calibrated according to the requirements of Chapter 15	Gas detectors must be maintained and/or calibrated in accordance with manufacturer's specifications. All other CCR system components must be inspected, tested, and maintained in accordance with NFPA 69.
8.4.3	Where the enclosure being protected presents a personnel hazard, alarms shall be provided to indicate abnormal operation of the system.	Personnel are not allowed to enter the BESS enclosure. However, this normally unoccupied enclosure is provided with gas sensors to detect off-normal events.

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Appendix G

NFPA 68 TEST REPORT

**CFD MODELING REPORT FOR BATTERY ENERGY STORAGE SYSTEM

ANALYSIS OF EXPLOSION VENTING IN ACCORDANCE WITH NFPA 68**

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Revision Record Summary

Date	Rev. Number	Report No.	Summary
2025-11-03	0	20251005	Initial Document
2026-03-14	1	20251005	Minor Editorial Revision: Replaced Figure 2. Specified Aerosol as 'optional'

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List of Acronyms

BESS	Battery Energy Storage System
BMS	Battery Management System
CATL	Contemporary Amperex Technology Co., Ltd
CCR	Combustible Concentration Reduction
CFD	Computational Fluid Dynamics
FLACS	Flame Acceleration Simulator
LFL	Lower Flammability Limit
NFPA	National Fire Protection Association
NIST	National Institute of Standards and Technology
PCS	Power Conversion System
SOC	State of Charge
SOH	State of Health
UFL	Upper Flammability Limit
UL	Underwriters Laboratories

Executive Summary

This study presents an analysis of the deflagration venting solution implemented in the Contemporary Amperex Technology Co., Ltd. (CATL) model C1P Battery Energy Storage System (BESS). The primary objective of this deflagration venting solution is to effectively mitigate overpressure by providing a properly designed and engineered pressure relief system, ensuring that pressures generated during deflagration events remain below the structural limits of the BESS enclosure. A partial volume deflagration analysis was conducted using computational fluid dynamics (CFD) methods to evaluate the overpressures produced during an explosion event involving a defined mixture of air and battery gases that are vented during a thermal runaway event.

Thermal runaway is a hazard posed by BESS installations, potentially leading to the release of flammable gases from the organic battery electrolyte. The ignition of these gas clouds can trigger a deflagration event, resulting in elevated overpressures within the BESS enclosure. Therefore, the deflagration venting system must be designed to mitigate these overpressures through pressure relief panels, thereby reducing explosion-induced pressures and preserving the structural integrity and safety of the BESS enclosure.

The CFD model employed in this analysis incorporates a conservative gas cloud design scenario to evaluate the effectiveness of the deflagration venting system. This approach is informed by battery off gas data developed and documented during corresponding UL 9540A [1] tests, which include assessments at the Cell [2], Module [3], and Unit [4] levels. It is also informed by a corresponding NFPA 69 CFD model [5].

The CFD analysis assesses the ability of the proposed deflagration venting system to maintain pressures below levels that could compromise BESS enclosure strength in the event of a flammable gas cloud ignition within the enclosure. This CFD evaluation and accompanying report aligns with NFPA 855 [6], which refers to NFPA 68 [7], as an accepted methodology for explosion control design. The CFD analysis was performed using Flame Acceleration Simulator (FLACS) Version: 24.1, a software package utilized for simulating dispersion and explosion scenarios involving flammable gases. More specifically, the overall strategy utilized within this report is the performance-based methodology of NFPA 68, outlined in Chapter 5 of the Standard. Concurrent with NFPA 855 (2026) [8], a partial volume deflagration analysis has been utilized, as the primary explosion protection system is the NFPA 69 combustible concentration reduction (CCR) system provided in this BESS equipment. For reference, a full volume deflagration analysis is also included as Appendix material. Safety factors have been incorporated within the modeling process to account for modeling uncertainty.

1.0 Introduction

1.1 Purpose

This report details a CFD analysis conducted to evaluate the design of a deflagration venting system intended to mitigate overpressure resulting from flammable gas explosions within a BESS container. The primary objective of this analysis is to determine whether the proposed deflagration venting system effectively limits the pressure generated by such explosions to levels below the structural integrity threshold of the BESS enclosure, in compliance with the relevant requirements of NFPA 855 (2023), NFPA 855 (2026), and NFPA 68 (2023).

1.2 Scope

This analysis is limited to an evaluation of the deflagration venting system for a single, representative BESS enclosure, considered independently of site-specific installation configurations. Consequently, this study should not be interpreted as a comprehensive assessment of the overall compliance of the BESS with NFPA 855, the International Fire Code (IFC), or any other applicable Codes and Standards. Instead, the focus of this analysis is narrowly defined, addressing the performance of the deflagration venting system and its adherence to the relevant provisions within NFPA 855 and NFPA 68. Specific tasks undertaken within this defined scope include:

1. An analysis of plausible battery gas release scenarios based on the results from UL 9540A testing at the Cell, Module, and Unit levels, as well as from an NFPA 69 CCR evaluation.
2. Utilizing these battery gas release scenarios, an evaluation was performed to assess the effectiveness of the manufacturer's designed deflagration venting system in meeting the requirements set forth by NFPA 855 and NFPA 68.

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2.0 System Description

2.1 System Overview

BESS can be categorized into three fundamental levels: the cell, the module, and the unit/rack. The cell represents the smallest component. Multiple cells are assembled in series and/or parallel to form a module, and several modules are then integrated to constitute a unit/rack. The unit/rack also incorporates a Battery Management System (BMS), which provides real-time monitoring of the system's operational status and overall health. The BMS tracks critical parameters, including state of charge, operating temperature, and the detection of any anomalous occurrences. Based on these monitored parameters, the BMS also executes safety functions to ensure safe and reliable operation.

The CATL C1P BESS unit is housed within a non-combustible enclosure with dimensions of 20 feet [6.058 m] (width) x 8 feet [2.478 m] (depth) x 9.5 feet [2.896 m] (height). This unit has a rated energy capacity of 3.8 MWh and operates at a rated voltage of 1331.2 V. The unit accommodates up to 80 battery modules configured as model M01285P10L01, each with a rated voltage of 166.4 Vdc. Each module is comprised of 52 lithium iron phosphate (LFP) battery cells (model: CBDC0) connected in series, with each cell having a nominal voltage of 3.2 V. A summary of these BESS specifications is provided in Table 2-1, while Figure 1 presents illustrative images of the BESS enclosure, a module, and individual cell.



Figure 1: C1P Battery Energy Storage System BESS; M01285P10L01 module; CBDC0 cell (Left to Right)

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Table 2-1: BESS Specifications		
BESS	Model	C1P Battery Energy Storage System
	Manufacturer	Contemporary Amperex Technology Co., Ltd.
	Configuration	52 cells per module, 8 modules per rack, 10 total racks.
	Ratings	1331.2 Vdc, 3.8 MWh
	Enclosure	Metal casing, filled with flame-retardant materials
	Dimensions	6058 mm (20 ft) (W) x 2478 mm (8.0 ft)(D) x 2896 mm (9.5 ft) (H)
	Tested To	UL 9540A unit level
Unit	Model	C04285P10L01-R
	Manufacturer	Contemporary Amperex Technology Co., Ltd.
	Configuration	1P8S
	Tested To	UL 9540A unit level
Module	Model	M01285P10L01
	Manufacturer	Contemporary Amperex Technology Co., Ltd.
	Configuration	52S1P
	Ratings	166.4V, 285 Ah
	Dimensions	1150 mm (W)*810 mm (D)*241.5 mm (H)
	Weight	325±10 kg
	Operating Range	Charge temperature range, °C:0~60 Discharge temperature range, °C:-20~60
	Tested To:	UL 9540A module level
Cell	Model	CBDC0
	Manufacturer	Contemporary Amperex Technology Co., Ltd.
	Format	Prismatic
	Ratings	3.2Vdc, 285Ah
	Chemistry	$LiFePO_4$
	Tested To:	UL 9540A cell level
	Dimensions	（W*L*H）71.55±0.8mm×174.3±0. 8mm×207.3±0.8mm
	Weight	5.46±0.3 kg

2.2 Design Features

The CATL C1P Battery Energy Storage System containerized BESS incorporates a suite of safety mechanisms to mitigate potential electrical and operational anomalies [9]. This section provides an overview of these mechanisms.

2.2.1 System Overview

The C1P BESS integrates the power electronic equipment, control systems and safety components for the DC side of the battery energy storage system. The layout of C1P

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Battery Energy Storage System and an overview of the key components are shown in Figure 2.

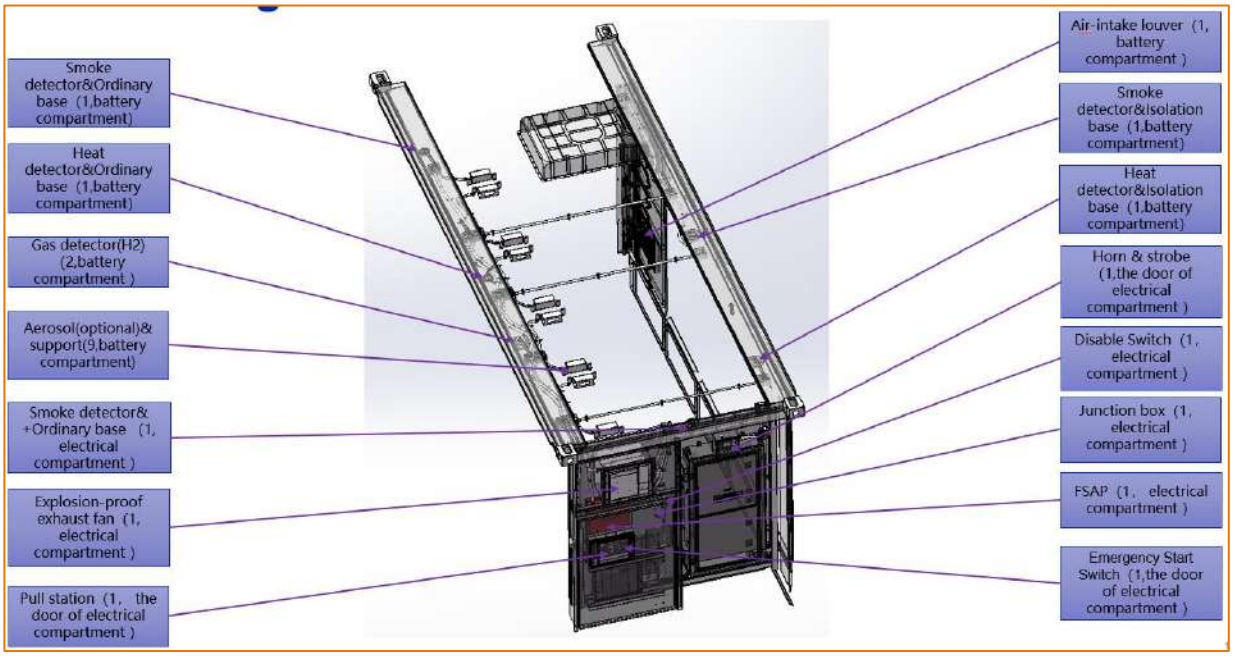

Figure 2: Key Components of C1P Battery Energy Storage System

2.2.2 Battery Management System

The battery management system is a real-time monitoring system composed of electronic circuit devices, which can effectively monitor battery voltage, battery current, battery cluster insulation status, battery State of Charge (SOC), manage system charging and discharging safety, alarm and emergency protection for possible faults, optimize control of the battery system, and ensure safe, reliable, and stable operation of the battery.

2.3 C1P Battery Energy Storage System Fire Protection Systems

2.3.1 Conceptual Design

The energy storage fire protection systems include an aerosol fire extinguishing system and a CCR system. When the battery undergoes thermal runaway and produces flammable gases, the CCR system is activated via gas detectors to reduce the concentration of combustible gases in the enclosure. When a fire occurs, the aerosol fire extinguishing system activates.

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2.3.2 Combustible Concentration Reduction System

The CCR system is comprised of two gas detectors (hydrogen), an exhaust fan, and a make-up air inlet. If the gas concentration reaches the trigger thresholds, the detector transmits a signal to the control interface, which then activates the ventilation system to reduce the concentration of gases within the container. The CCR system and its compliance with NFPA 69 is described in the NFPA 69 evaluation report by Atar Fire, LLC [5].

2.3.3 Aerosol Fire Extinguishing

The BESS is equipped with an optional aerosol fire extinguishing system. The system is triggered automatically via heat or smoke detection. When the heat and smoke detectors in the container are activated simultaneously, the aerosol fire extinguishing system is automatically activated. An evaluation of the adequacy of the aerosol system, and its compliance with applicable codes and standards, is not part of this evaluation. Refer to the NFPA 69 evaluation report [5] by Atar Fire, LLC, for a discussion on control logic and interaction between the aerosol system and the CCR system. This NFPA 68 analysis assumes full functionality of the NFPA 69 system in the absence of discharge of the aerosol agent.

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3.0 CFD Modeling Approach

3.1 CFD Simulation Tool

Leveraging performance-based design principles, CFD modeling presents the potential for enhanced analytical precision. This analysis utilized CFD modeling, specifically employing FLACS by Gexcon. FLACS is a three-dimensional CFD tool that is widely recognized in the process safety industry for modeling hazard scenarios involving flammable gas dispersion and explosions. For this study, FLACS version 24.1 was utilized. FLACS has been developed with gas explosions in mind. It solves Favre-averaged transport equations on a structured Cartesian grid using a finite volume method. Various chemistry models are invoked to simulate the combustion process. It is important to note that all CFD modeling has uncertainty. Numerous experiments have been utilized to validate the results of FLACS, improve sub-models, and derive guidelines on uncertainty. These validation experiments have not been performed specific to lithium-ion battery energy storage system geometries or gas mixtures. The validation results section of the FLACS user manual indicates that there is no perfect model, and that acceptable ranges for uncertainty are a factor of two from the observed value, 50% of the time.

The model geometry was established by importing a 3D CAD file provided to Chuweineng Testing Technology (Shanghai) Co., Ltd (CWN) directly from Contemporary Amperex Technology Co., Ltd. into FLACS.

3.2 Mesh generation and resolution criteria – Sensitivity Discussion

The battery gas and air mixture explosion event was modeled using the FLACS CFD solver. Significant user judgement is needed in assessing the adequacy of a grid within FLACS. Based on professional experience, engineering judgement, consultation with the FLACS CFD development team, and the FLACS user manual, gas clouds were discretized. As stipulated in the FLACS user manual [10], a well-represented gas cloud should have a cell size of between D/14 (maximum) to D/17 (minimum), where D is the smallest dimension of the gas cloud. For these simulations, a resolution of approximately 18 cells was utilized to discretize the gas cloud. This resulted in a grid size of 10 cm for Approach 1 (discussed later), and 5 cm for Approach 2 and 3 (discussed later). As such, the chosen mesh size resolves the gas cloud sufficiently. For approach 1, Atar Fire did consider using the smaller grid size (5 cm) to ensure a consistent grid size between approaches, but this method was not utilized as smaller grid sizes have not been validated in FLACS nor was the resulting grid discretization within the previously stated bounds of the FLACS user manual [10].

Best practice for FLACS is to reposition large objects so they are aligned with the grid. This modeling effort therefore attempted to represent the geometry in accordance with

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this guidance from FLACS. Additionally, as directed by the FLACS user guide, smaller obstacles are included, even if smaller than the grid, and treated by the sub-grid models.

Furthermore, FLACS recommends limiting the aspect ratio of the gas cloud to a maximum of 2:1, which was adhered to.

To evaluate fireball propagation within the BESS enclosure and to ascertain the vertical extent of the flame during high-temperature fireball events, the computational domain for CFD analysis was extended vertically. The computational domain range utilized in this study is illustrated in Figure 3 and is bounded by a zero-pressure gradient boundary condition.

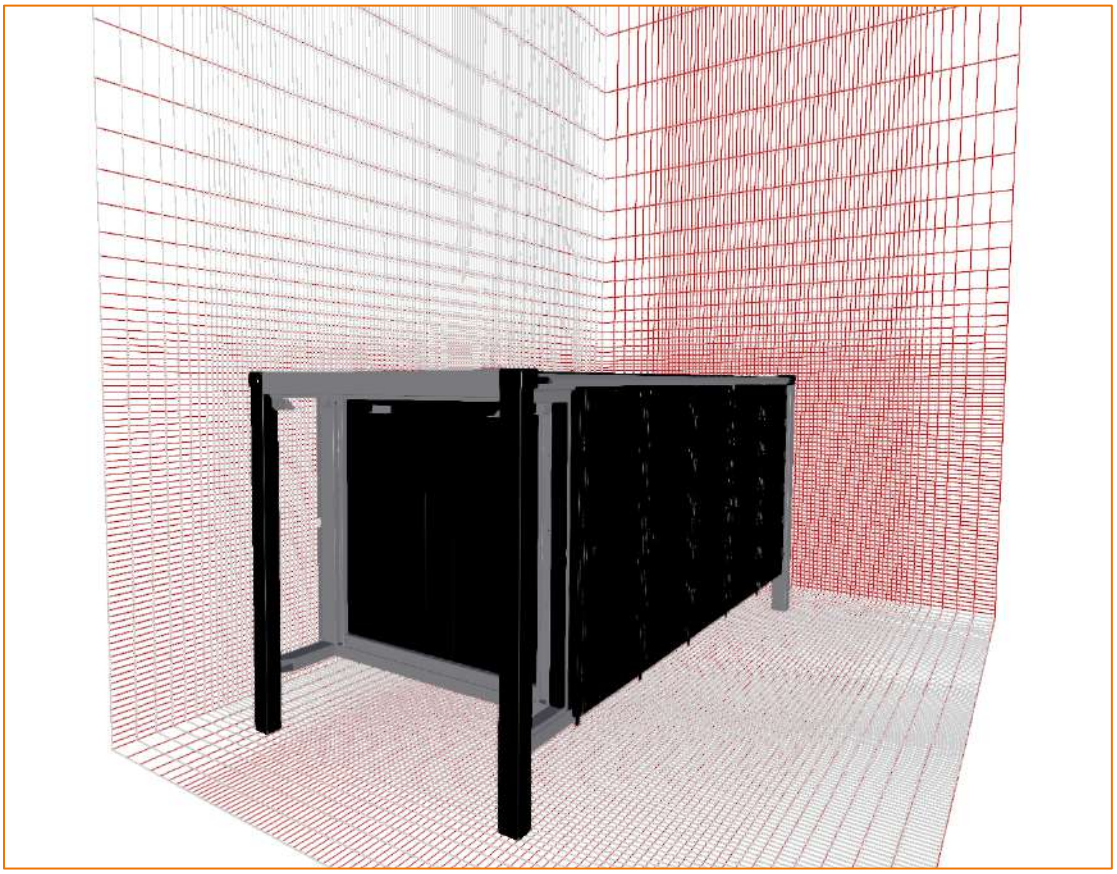

Figure 3: Model in the Computational Domain

3.3 High Level approach

While a physical model reflecting the product's geometric configuration was established, this analysis incorporates several assumptions that warrant consideration. UL 9540A data, gas composition, and estimations of cloud size and position, informed by engineering judgment and a corresponding NFPA 69 CFD model [5], were integrated into

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the model. Furthermore, multiple ignition points were strategically configured to assess variation in simulation results based on ignition location. The presented results are, therefore, contingent upon these assumptions and the inherent limitations of the employed modeling techniques.

This modeling approach utilizes a performance-based design option in accordance with NFPA 68, Chapter 5. CFD modeling specifically constitutes a performance- based design approach and is expressly permitted in accordance with Section 4.3.1 of the Standard: "*Deflagration venting meeting the goals and objectives of Sections 4.1 and 4.2 shall be provided in accordance with either of the following: 1) Performance-based provisions of 4.3.2; 2) Prescriptive-based provisions of 4.3.1.*" The performance-based design option is an alternative to the prescriptive-based approach, which follows the calculation methodologies outlined in Chapter 6 and 7 of the Standard.

Section 4.3.1(1) of NFPA 68 directs the reader to Section 4.3.2, which directs the reader to Chapter 5 for the design-basis requirements for performance-based designs.

The performance criteria specified by NFPA 68, Chapter 5 are as follows, and will be utilized to evaluate whether the design meets the requirements of NFPA 68.

Section	Table 3-1: Performance Criteria
5.2.2	*Deflagration vents shall limit the reduced pressure (Pred) within an enclosure and any attached vent ducts to meet the objectives in 4.2.1.1 and 4.2.1.2.*
5.2.3.1	*Combustible materials outside the enclosure shall not attain their ignition temperature from flame or hot gases discharged from a deflagration vent.*
5.2.3.2	*Blast load from deflagration vent discharge shall limit the risk of damage to exposed structures.*
5.2.3.3	*Access to spaces into which deflagration vents discharge shall be restricted so as to minimize, to a level acceptable to the authority having jurisdiction, the risk of injury from flame, hot gases, hot particles, or projectiles.*
4.2.1.1	*Deflagration venting for occupied enclosures shall prevent the structural failure of the enclosure and minimize injury to personnel in adjacent areas outside of the enclosure.*
4.2.1.2	*Deflagration venting for unoccupied enclosures shall prevent the rupture of the enclosure.*

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4.0 Model Input Parameters and Assumptions

4.1 CFD Geometry

The CAD geometric model of the CATL BESS enclosure, including the designed explosion vent panels engineered to rupture at a specified pressure, was imported into FLACS. The model geometry incorporates eight explosion vent panels arranged in a row on the long axis of the top surface of the enclosure. Each panel measures 0.6 m x 0.6 m, providing a total ventilation area of 2.88 square meters. Figure 4 illustrates the FLACS geometric model.

Based on the client-provided three-dimensional CAD model, the internal dimensions of the CATL BESS enclosure, exclusive of wall thickness, are 2.35 m in width, 4.9 m in length, and 2.15 m in height.

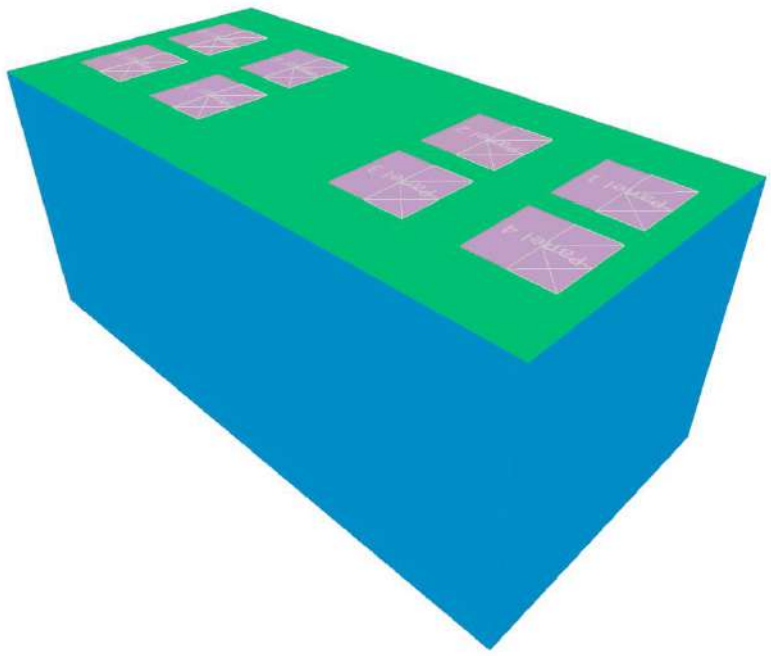

Figure 4: BESS Model Incorporating Upper Pressure Relief Panels

4.2 The Composition of Battery Gas

UL 9540A cell-level testing was conducted on a lithium-ion battery cell (Model CBDC0) manufactured by CATL. In this evaluation, a single cell was placed within a 100 L pressure vessel and induced into thermal runaway using flexible film heaters applied to both sides, with heating rates ranging from 4° C/ min to 7° C/ min. Venting commenced at a cell

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surface temperature of 161° C, with the cell subsequently transitioning into thermal runaway at 220° C. The total volume of gas vented during the event was 176.3 L.

Analysis of the vented thermal runaway gas composition revealed the presence of approximately 43.569% hydrogen, 10.610% carbon monoxide, 30.116% carbon dioxide, 6.625% Methane, 4.159% Ethylene, 1.245% Ethane, 1.056% Propylene, 0.188% Acetylene and 2.432% total hydrocarbons. Based on this composition, the LFL for the battery gas mixture, as calculated by the testing laboratory, was approximately 7.545% [2] by volume in air at vent temperature, and 8.05% at ambient temperature. Further refinement of this LFL was performed as part of the NFPA 69 analysis, in which an LFL value of 7.88 was derived for the dispersed vented gas within the enclosure. The chemical properties associated with the vented battery gas mixture are detailed in Table 4-1. For the purposes of this analysis, the total hydrocarbon component (C_xH_y) was assumed to be equivalent to propane (C_3H_8). Propane is utilized as the proportion of hydrocarbons is a small percentage of the overall battery gas mixture, and the various hydrocarbons have similar thermal properties to propane. Furthermore, data extracted from the UL 9540A cell report indicates a measured gas burn velocity of approximately 0.64 m/s and a maximum pressure (P_{max}) of 6.5 bar (94.29 psi).

Table 4-1: Gas Composition Derived from UL9540A Cell Test Data

Component	Volume Fraction (%vol)	Density (at NTP) (kg/m^3)
H_2	43.569	0.0838
C_3H_8	2.432	1.833
CO	10.610	1.165
CO_2	30.116	1.83
CH_4	6.625	0.668
C_2H_4	4.159	1.167
C_2H_6	1.245	1.25
C_3H_6	1.056	1.748
C_2H_2	0.188	1.079
Mixture	100	0.885

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4.3 The Cloud Dimensions of Battery Gas

Determination of the appropriate gas cloud size for modeling was assessed by considering three distinct approaches, each representing a different partial volume deflagration methodology. Within the performance-based framework, engineering judgement is necessary to inform the most appropriate modeling scenario. The approaches considered were:

1) Use of UL 9540A module level data to estimate the number of failed cells
2) 25% LFL calculation based on BESS product dimensions and UL 9540A cell level data
3) Utilizing the results of an FDS CFD model of the CCR system [5].

4.3.1 Approach 1 – UL 9540A Module Level Data

Assuming that the explosion event within the BESS container is triggered by the release of flammable gas due to thermal runaway of the battery cells, this approach considers explosion events resulting from a three-cell failure based on UL 9450A test data [2] [3] [4].

After calculations, it is determined that the gas released from the thermal runaway of these three battery cells is 0.53 m^3 by volume, or 0.47 kilograms by mass [3 cells × 176.3 (L/cell) × 0.001 (m^3/L) =0.53 m^3 × 0.885 (kg/m^3) = 0.47 kg]. The UL 9540A unit level test report did not indicate any potential for propagation between modules; therefore, this approach assumes there is no module-to-module propagation.

The BESS has an internal volume of approximately 24.757 m^3 (2.35 m×4.9 m×2.15 m = 24.757m^3). After accounting for internal obstructions, which occupy approximately 19.375 m^3 (as determined via the FLACS simulator), the resulting free volume is approximately 5.382 m^3. A gas volume of 0.53 m^3 within the 5.382 m^3 of free volume represents approximately 130% of the LFL of the entire volume [7.88*X*5.382 m^3)/100=0.53 m^3]. Solving for 'X' yields an LFL of 125%. Note that 7.88 represents the LFL of the gas mixture derived from the NFPA 69 analysis [5].

It should be noted that this gas volume does not consider the operation of the NFPA 69 CCR system, which is anticipated to reduce the gas volume and is discussed in Approach 3. The uniform stoichiometric gas volume considered in this analysis provides a conservative estimate for evaluating overpressures caused by combustion characteristics.

4.3.2 Approach 2 – 25% LFL of Volume and UL 9540A Gas Mixture LFL

Based on the experience of Atar Fire, it is understood that some deflagration vent panel manufacturers as well as other agencies utilize a simplified approach to the partial volume deflagration calculations, in which the gas volume is assumed to be 25% of the LFL of

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the entire volume. This approach is consistent with the worst-case expectations of performance of an NFPA 69 CCR system, as prescribed by both NFPA 855 and NFPA 69.

Given that the LFL of the gas mixture is 7.88% [5], 25% of the LFL corresponds to a concentration of 1.97%. This concentration, if dispersed throughout the available free volume, would equate to a gas volume of 0.106 m^3 (5.382 m^3 ×1.97%), or 0.094 kilograms by mass (0.10 m^3 × 0.885 kg/m^3). However, this volume is less than the total gas released by the three battery cells undergoing thermal runaway described in Approach 1. It should also be noted that this calculated gas cloud size does not consider the operation of the NFPA 69 CCR system based on CFD modeling results, which is anticipated to reduce the gas cloud size and is discussed next in Approach 3.

4.3.3 Approach 3 – NFPA 69 CCR System

The results from the FDS model for the CCR system performance indicate that both the maximum hydrogen concentration, and maximum overall flammable gas concentration, prior to fan activation and after fan stabilization, remain below 25% of the LFL. The FDS model of the NFPA 69 CCR system [5] resulted in a combustible gas mixture that reached a concentration of 1.86%. Utilizing a similar calculation method as Approach 2, the combustible gas volume is estimated as 5.382 m^3 ×1.86% = 0.10 m^3 or 0.089 kilograms by mass (0.10 m^3 × 0.885 kg/m^3). As such, Approach 2 and Approach 3 result in nearly identical combustible gas volume, when rounding to two significant figures. As such, Approach 2 and Approach 3 are both approximated as 0.10 m^3 gas volumes.

Table 4-2: Combustible Gas Volume

Approach	*Combustible Gas Volume*
1 – 9540A Module Level	*0.53 m^3*
2 – 25% LFL Approach	*0.10 m^3*
3 – NFPA 69 CCR System	*0.10 m^3*

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4.3.4 Final Scenario Determination

Considering the above three scenarios, the release involving thermal runaway of three battery cells represents the most conservative assessment by several measures (Approach 1). First, it exceeds the gas concentration developed in the NFPA 69 CFD analysis [5]. Second, at 0.53 m^3 , it exceeds 25% of the LFL of the anticipated gas volume developed in Approach 2 by 430% (0.53 m^3 /0.10 m^3). Approach 1 is a very conservative choice, while Approaches 2 and 3 are more in line with the actual situation as well as best practices and the intent of NFPA 855 [8]. Therefore, the results of Approach 2 and 3 (which result in very similar gas volumes in this case) are ultimately adopted in this report.

When the stoichiometric ratio equals one, combustible gas burns completely and the most rapidly. As an example, for a combustible gas volume of 0.53 m^3 (Approach 1), utilizing the ideal gas law (PV=nRT) a stoichiometric mixture is formed when 1.88 m^3 of air is added, resulting in an overall stoichiometric gas cloud size of 2.41 m^3. The stoichiometric gas cloud size is used in the FLACS simulations. Table 4-3 provides a complete summary of all Approaches.

Table 4-3: Method Summary

Approach	Combustible Gas Volume	Fuel quality	Percent of LFL	Stoichiometric Gas Cloud Size
1 – 9540A Module Level	0.53 m^3	0.47kg	130%	2.41 m^3
2 – 25% LFL Approach	0.10 m^3	0.09kg	25%	0.45 m^3
3 – NFPA 69 CCR System	0.10 m^3	0.09kg	25%	0.45 m^3

4.4 The Location of Battery Gas Cloud

FLACS simulates explosions by defining a gas cloud of known volume and concentration within a confined space and then initiating ignition to evaluate the resulting overpressures. In the scenario involving thermal runaway of three battery cells, the released battery gas will only partially fill the BESS container.

Given the presence of eight explosion ventilation panels strategically located on the roof of the BESS, and considering the thermal and buoyancy effects associated with the battery gas, the released gas is expected to accumulate as depicted in Figure 5. The spatial definition of the gas cloud within the simulation was informed by findings presented in the NFPA 69 report, which identifies this general area as exhibiting the highest concentration of flammable gas based on a worst-case gas release scenario.

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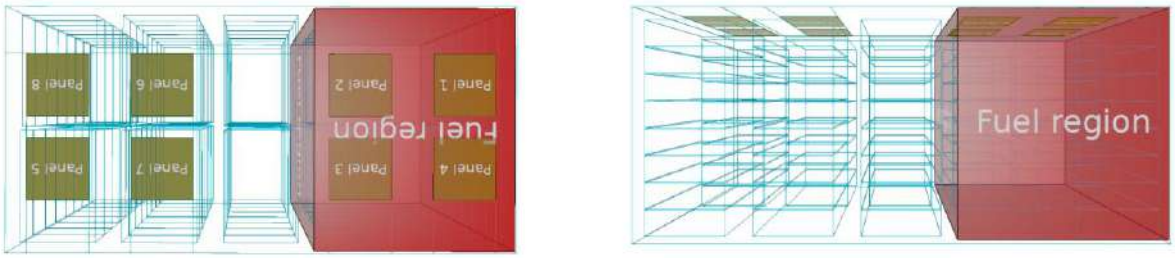

Top View **Front View**

Figure 5: Location of the Fuel-Air Gas Cloud in FLACS

4.5 Deflagration Vent Panels

Explosion pressure relief is achieved through the incorporation of explosion vents strategically positioned on the roof of the enclosure. Specifications for these vents are detailed in Table 4-4.

It is important to note that all pressure relief devices examined within the scope of this analysis possess uniform pressure relief characteristics.

Table 4-4: Explosion Relief Vent Characteristics

Panel Property	Value
Vent Area	0.6 m × 0.6 m
Static Activation Overpressure	0.1 bar-g
Surface Density	9.9 kg/m^2
Type	Popout Rigid

4.6 Ignition Point Locations

Multiple ignition locations were modeled. The ignition locations were strategically selected at single points near the corners of the gas cloud. Corner ignition maximizes the acceleration path, leading to more extensive flame and pressure wave propagation; therefore, the eight corner ignition locations were prioritized. The locations are shown below in Figure 6. Furthermore, the lower-left corner positions (IP1) correspond with proximity to the leak source, as documented in the NFPA 69 FDS analysis report. IP9 corresponds to a bottom ignition location between racks, and IP10 corresponds to a middle ignition location. Collectively, the simulated ignition locations are deemed sufficiently representative of the innumerable number of potential ignition locations.

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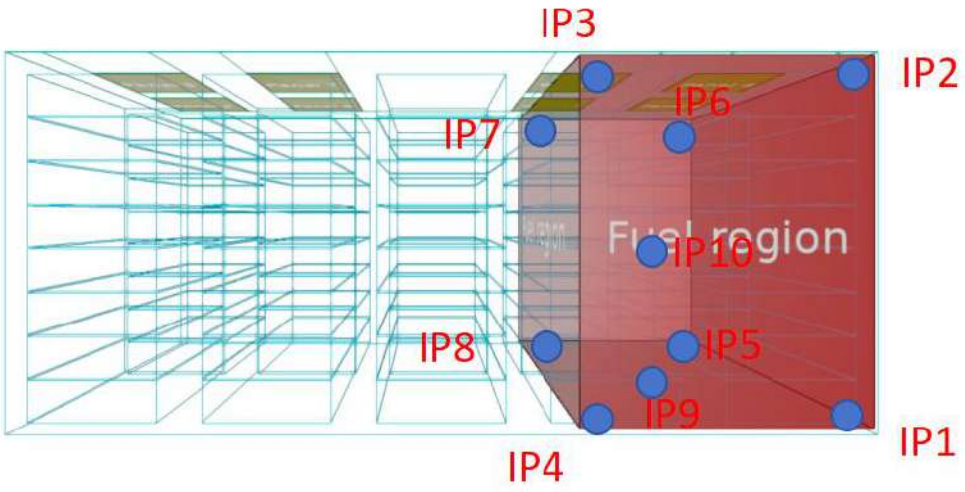

Figure 6: Ignition Positions

4.7 Initial Conditions

Given the objective of modeling gas explosions within a confined container, the obstructions in this simulation were configured as inert. The initial conditions for the model were defined by the following parameters: characteristic velocity, relative turbulence intensity, turbulence length scale, ambient temperature, ambient pressure, and ground roughness, as detailed in Table 4-5.

Table 4-5: The parameter for the initial condition

Parameter	Value
Characteristic Velocity	5 m/s
Relative Turbulence Intensity	0.3
Turbulence Length Scale	0.01 m
Temperature	20 ℃
Ambient Pressure	100000 Pa
Ground Roughness	0.0002 m

It should be noted that the FLACS user manual indicates that where there is congestion in the area near ignition origin, that initial turbulence conditions have a limited effect, as the turbulence will be quickly generated by the geometry in the explosion region. Therefore, these initial conditions were deemed reasonable and suitable.

4.8 Container Strength

According to the methodology outlined in NFPA 68, Chapter 6 "*Fundamentals of Venting of Deflagrations*," P_{red} can be determined using Formula 1.

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$$P_{red} = \frac{P_{es}}{DLF} \quad (1)$$

Equation (1) is derived from NFPA 68, Section 6.3.2 [7]. Here, P_{red} is the maximum pressure developed in a vented enclosure during a vented deflagration. P_{es} is the enclosure strength (units of bar-g). The dynamic load factor (DLF) is defined as the ratio of the maximum dynamic deflection to the static deflection of a structure [7], where static deflection refers to the displacement experienced by the system when subjected to peak load conditions applied statically. For this analysis, it is assumed that DLF equals 1.5, which represents a "worst-case scenario" and serves as the most conservative estimate (NFPA 68, Section 6.3.2.1). For this analysis, CATL has specified P_{es} as 0.64 bar-g (as specified by the CATL structural analysis [13]); consequently, P_{red} is determined to be 0.427 bar-g, when applying the DLF of 1.5.

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5.0 Results and Analysis

5.1 Deflagration Analysis

This section provides the results of the partial volume deflagration analysis, conducted based on the identified locations of flammable gas clouds as detailed in Section 4. Although not required by NFPA 855, a full volume deflagration analysis was performed on the BESS geometric configuration to ascertain the potential worst-case overpressure scenario in the event of NFPA 69 CCR system failure. The findings of this comprehensive full volume deflagration analysis are documented in Appendix A. The principal focus of this evaluation is the overpressure generated by a deflagration event within the BESS container, assessed against the client-specified maximum pressure limit discussed in Section 4.8.

5.2 Deflagration Overpressures – Approach 1

Table 5-1 summarizes the maximum pressure values recorded at different ignition locations. Given that IP9 demonstrates the most significant pressure output, this position was chosen for detailed analysis in the following sections.

Figure 7 illustrates the maximum deflagration overpressure distribution recorded within the BESS enclosure. These contour lines represent the peak overpressures measured at discrete locations during the deflagration event. Notably, the maximum overpressure observed within the enclosure remains below 0.427 bar-g.

Table 5-1: Maximum pressure at each ignition position

Ignition location	*Pressure max (bar-g)*
IP1	*0.21*
IP2	*0.18*
IP3	*0.13*
IP4	*0.13*
IP5	*0.41*
IP6	*0.14*
IP7	*0.13*
IP8	*0.30*
IP9	*0.41*
IP10	*0.19*

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Figure 7: Maximum Overpressures – Approach 1

Strategically positioned monitoring points (MPs) are located along the length of the BESS container to record overpressures. The location of these MPs, along with the ignition site, is illustrated in Figure 8.

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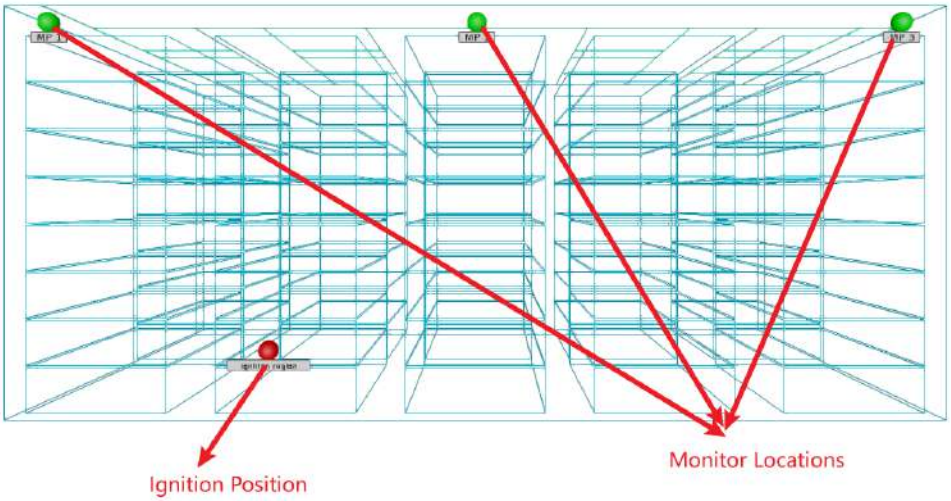

Figure 8: Location of Monitoring Points for Measuring Overpressures (Rear View)

Figure 9 illustrates the temporal evolution of overpressure at the MPs. MP #1, situated proximate to the ignition region; MP #2, located toward the center of the container; and MP #3, located at the end of the container remote from the ignition location. The maximum pressure observed at the monitoring points is approximately 0.22 bar-g.

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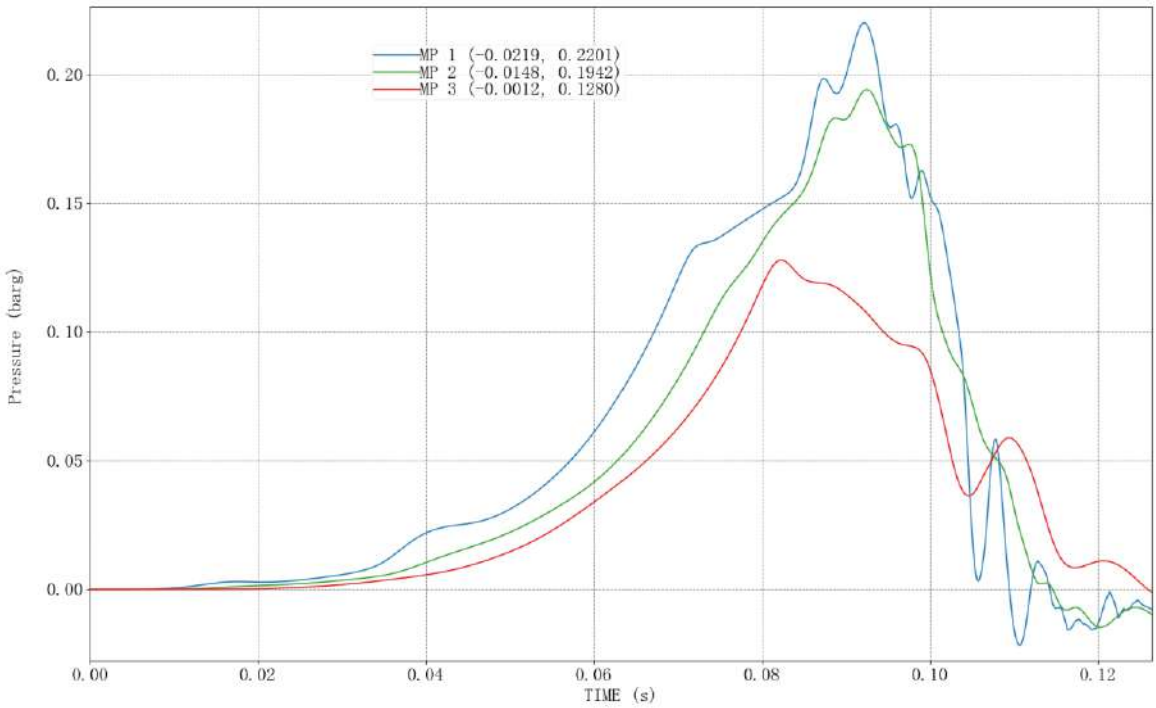

Figure 9: The Temporal Variation of Overpressure at Designated Monitoring Points.

5.3 Flame Propagation – Approach 1

Figure 10 presents two-dimensional cross-sections illustrating flame propagation within the BESS enclosure and through the deflagration vents at three discrete time points. These visualizations demonstrate the rapid dynamics of flame propagation, revealing that the combustion flame traverses the distance from the ignition point to up to three deflagration vents in under 0.10 seconds. This rapid diffusion is likely due to the flammable gas cloud, which extends approximately 48% of the BESS container's length.

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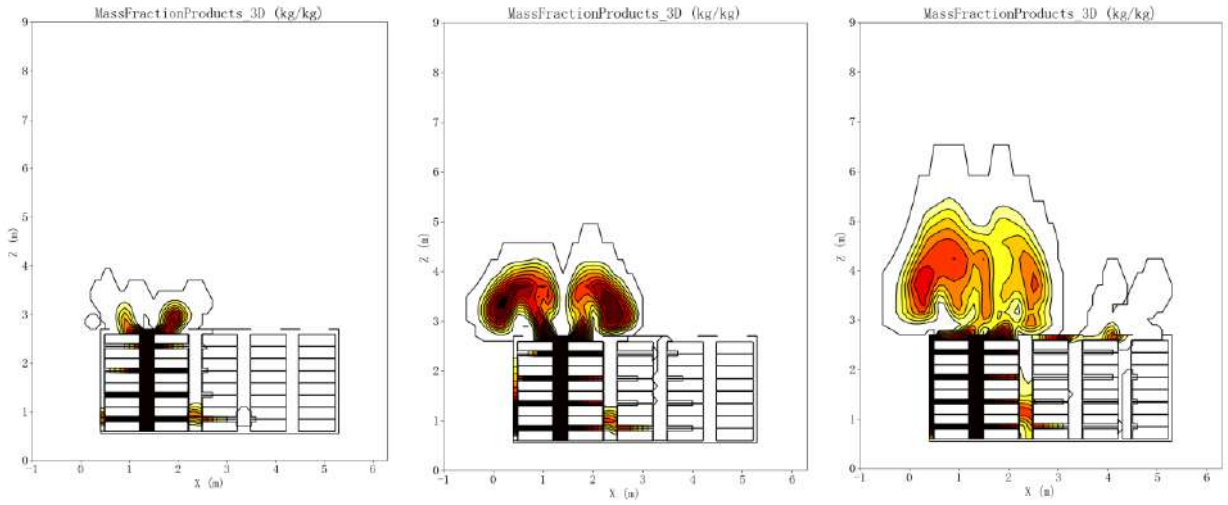

Figure 10: Two-dimensional Slices Illustrating the Propagation of Flames within the BESS Container at Various Time Intervals

5.4 Flame Extension Range – Approach 1

Figure 11 depicts the spatial extent of the flame, delineated by contour lines representing the maximum mass fraction of combustion products and the peak flame temperature recorded during the simulation. The resulting flame cloud ascends to a height of over 2 meters above the roof of the enclosure, reaching a maximum temperature exceeding 1000 ° C. This upward propagation of the flame is a significant factor in mitigating potential personnel risk and material damage beyond the immediate area of combustion.

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Flame Spread Extent **Temperature**

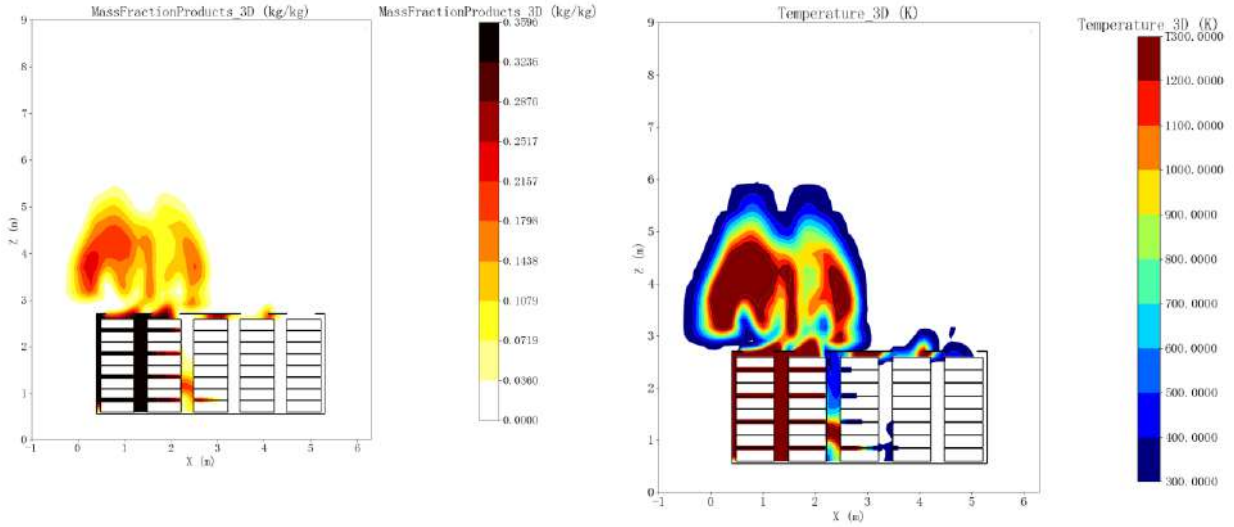

Figure 11 : The Maximum Spatial Extent and Temperature of the Fame Plume Emanating from the Container Roof

5.5 Approach 2 and Approach 3

The same method was then used to simulate Approach 2 and Approach 3. As previously discussed, Approach 2 and Approach 3 represent Atar Fire's understanding of best practice and are in line with the intent of NFPA 855 [8], taking into account the operation of an NFPA 69 CCR system. As expected, the overpressures were lower than Approach 1. Specifically, Approach 2 & 3 yielded peak overpressures of 0.14 bar-g. The spatial distribution of gas clouds and corresponding simulation results are illustrated in Figures 12 to 13. Note that the scales on Figures 7 and 13 differ, so any visual comparison between Figures should consider the varying scale.

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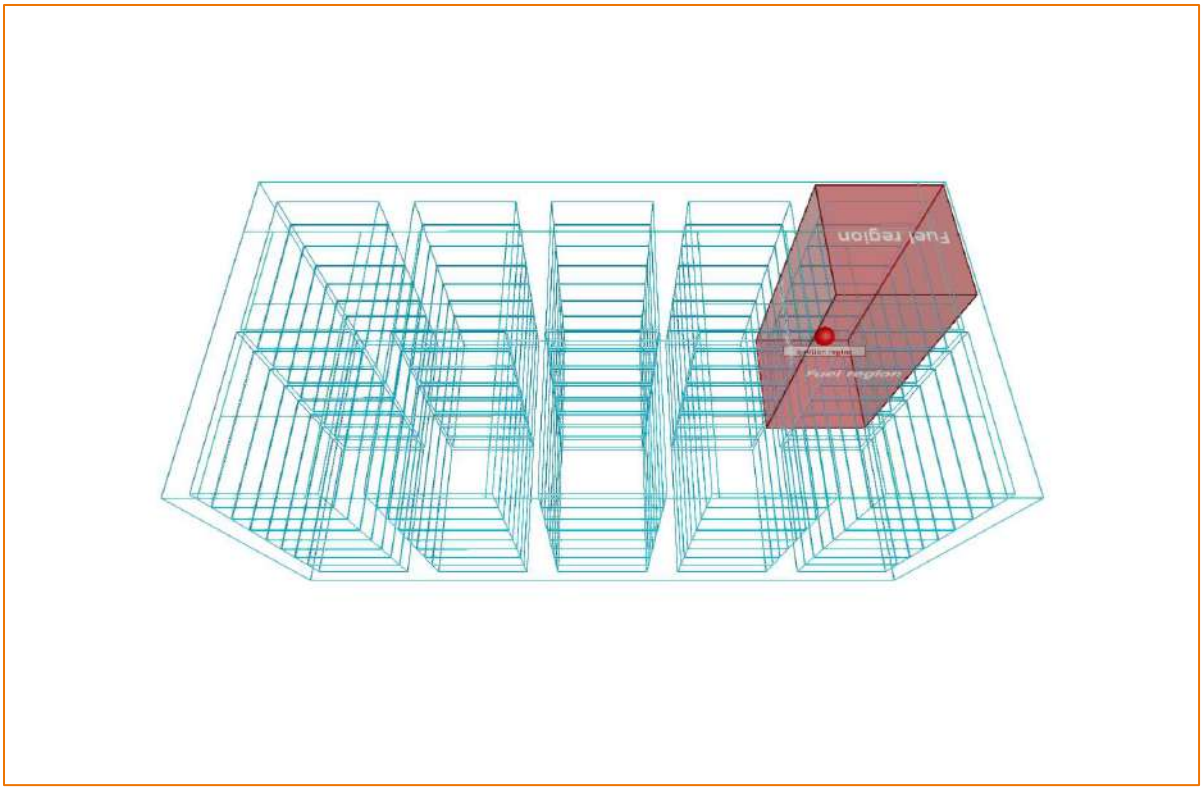

Figure 12 : Approach-2 & 3 gas cloud and Ignition Point

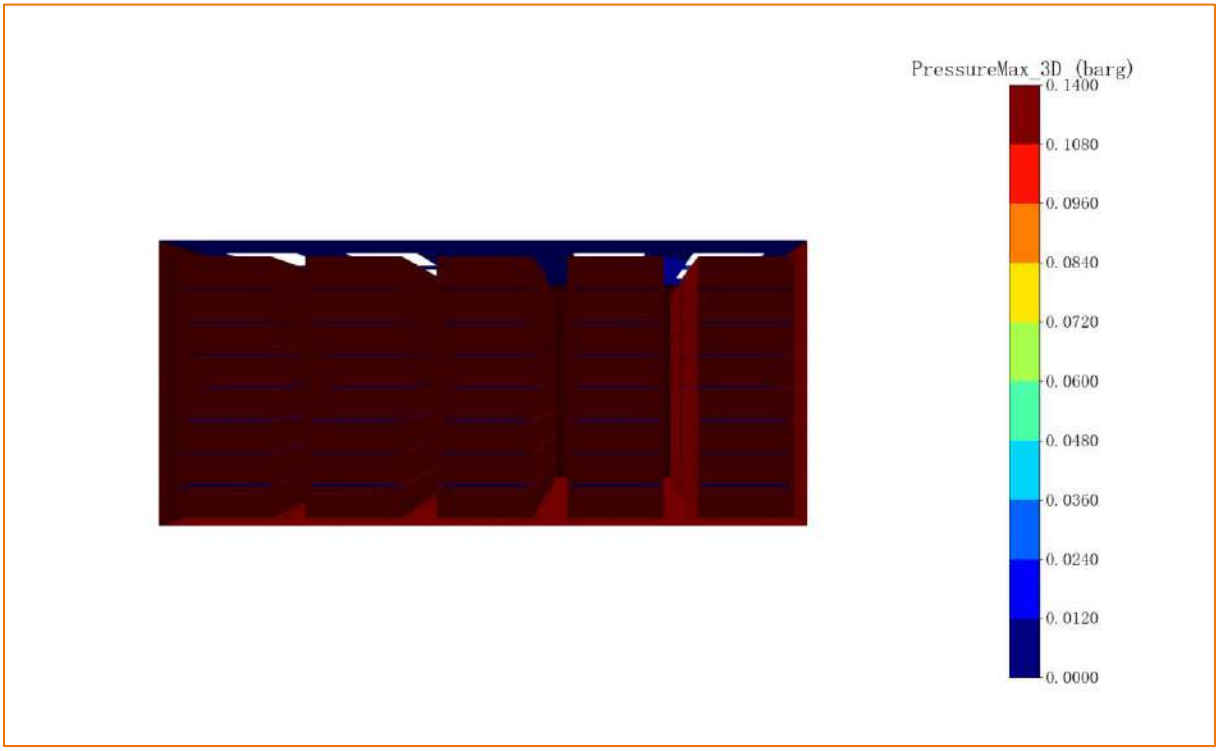

Figure 13 : Approach-2 & 3 Maximum Overpressures

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6.0 Assumptions and Limitations of the Study

6.1 Assumptions

The CFD analysis presented herein relies on several simplifying assumptions, which are considered conservative within the employed modeling framework and consistent with the scope of FLACS validation. These assumptions, detailed below, were implemented to streamline the computational process while maintaining reasonable accuracy:

a) The BESS enclosure is modeled as a rigid structure, neglecting potential deformation under pressure.

b) The flammable gas cloud is assumed to possess a spatially uniform stoichiometric mixture, disregarding potential variations in concentration.

c) Battery racks within the enclosure are represented as rigid obstacles, without accounting for their internal structure or potential for localized flow disturbances.

d) The heating, ventilation, and air conditioning (HVAC) system is assumed to be inactive throughout the simulation.

e) All active ventilation systems are non-operational during the simulated event (Approach 1 Only)

f) Deflagration vents are not hindered by snow or other obstructions preventing operation.

6.2 Limitations

This modeling approach is subject to certain limitations.

First, the gas explosion resulting from the thermal runaway of the three battery cells (Approach 1) assumes that the NFPA 69 CCR system has failed, but propagation is limited within the module in accordance with UL 9540A test data [3]. This simplification does not account for the potential propagation of thermal runaway to additional cells or the escalation of the event into a broader fire, thereby neglecting such scenarios. This partial volume analysis is permitted by NFPA 855 (2026 Edition) [8]. Overpressure due to fire is not part of the analysis.

Second, the determination of the combustible gas cloud location relies on information derived from a detailed analysis of the UL 9540A module level report, consideration of a simplified approach of modeling 25% LFL of the gas mixture throughout the enclosure, as well as the results of a conservative assessment of the NFPA 69 CCR system. These three approaches are highlighted in Section 4.0. Consequently, the analysis may not fully capture all of the potential explosion hazards present in other locations within the BESS enclosure that fall outside the scope of the scenarios considered.

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Third, the results are governed by constraints of the FLACS software. One constraint is the recommended cell size for discretizing gas clouds. The recommended range is between a maximum of D/14 to a minimum of D/17 [10]. As such, the gas clouds were generally discretized according to these bounding conditions. Gas clouds of varying sizes in this modeling report required different grid sizes to conform to the constraints of FLACS. The use of smaller grid sizes, for example the use of a 5 cm grid for Approach 1 to maintain consistency with the 5 cm grid utilized in Approach 2 and 3, did not conform to the FLACS guidelines, and was not used as it is assumed not to give credible results.

Last, the results of this simulation and conclusions drawn are limited in their comparison to the manufacturer provided enclosure strengths. The indicated enclosure strength by the manufacturer is 0.64 bar-g. This enclosure strength was developed based on a structural analysis performed by CATL [13] and was not independently verified by Atar Fire or a licensed structural engineer. The enclosure strength supplied by CATL was reduced in this analysis by a factor of 2/3, to 0.427 bar-g. The enclosure strength supplied is greater than generic enclosure strengths cited in FM 7-76 [11] of 0.2 to 0.3 bar-g, for vessel strengths below which deformation is not likely (but is still plausible). Furthermore, experiments involving ignition of hydrogen in standard 20-foot ISO containers [Reference 12 – known as the HySEA tests] showed under many configurations deformation of enclosures occurs, but no rupture (for example, Test 18, with eight deflagration vents, did not experience damage and resulted in a maximum pressure of 0.20 bar-g). For several cases in which no deflagration vents were present (Test 09, Test 014, in [12]), and the cases in which doors relieved pressure, high maximum pressures on the order of 1.0 bar were observed. It should be noted that hydrogen has a much higher burning velocity than battery gas mixtures (on the order of five times higher than the 64 cm/s in this project), and congestion in a BESS enclosure is much different, often less compared to experimental tests. The results of the HySEA experiments are comparable in the physical nature (20-foot ISO container) of the enclosure, but with likely more severe results than would be experienced in a BESS. Atar Fire anecdotal observations during real-world partial volume deflagration events, as seen during several large-scale fire tests of BESS, has shown that deformation of the container may occur, but rupture will not.

7.0 Conclusions

A CFD analysis was performed on the CATL BESS enclosure to evaluate overpressures resulting from a deflagration event and to assess the adequacy of the deflagration vent area provided on the roof. The design scenarios considered a thermal runaway of three battery cells, the release of gas reaching a concentration of 25% LFL in the enclosure, and the resulting concentration during the operation of the NFPA 69 CCR system. Given its lighter density and higher temperature relative to air, vented battery gas tends to

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accumulate near the ceiling of an enclosure. As the released battery gas mixes with the surrounding air, it forms a flammable cloud. Of the multiple ignition scenarios modeled, ignition of the flammable cloud at the lower right corner of the BESS enclosure represents the most severe overpressure conditions.

Deflagration scenarios were simulated using the FLACS CFD tool, incorporating the configured roof deflagration vents. The initial distribution of the fuel-air mixture in the ceiling area was informed by an NFPA 69 CFD analysis, predicated on the upward diffusion and accumulation of battery gas due to buoyancy effects. The FLACS CFD geometry included eight deflagration vents at the top of the BESS container, which are designed to release overpressure in the event of an explosion.

The simulation of three battery cells is utilized as a reference point in the event of CCR system failure. The simulation results indicate a maximum overpressure within the BESS enclosure of approximately 0.41 bar-g. This is less than the reduced pressure of 0.43 bar-g (0.64 bar-g manufacturer supplied enclosure strength reduced by a factor of 2/3). Furthermore, the flame emitted from the roof created a high-temperature zone, reaching approximately 1000 °C and extending more than 2 meters beyond the roof height.

According to the NFPA 69 report [5], based on a conservative gas release scenario, the gas volume in the compartment will reach approximately 25% LFL. A partial volume deflagration analysis approach, incorporating NFPA 69 system performance, is intended by NFPA 855 (2026). This scenario results in an overpressure of 0.14 bar-g.

In order to account for the uncertainty of FLACS results (refer to Section 3.1), the resulting overpressure of 0.14 bar-g has been doubled to 0.28 bar-g. Given that the maximum allowable pressure (P_{es}) specified by the client is 0.64 bar-g, the NFPA 68 methodology results in a maximum allowable pressure (P_{red}) 0.427 bar-g (refer to Section 4.8 for more details). The simulation results for the CATL BESS suggest that the roof-mounted deflagration venting panels provide sufficient pressure relief when compared to the maximum allowable pressure of 0.427 bar-g. The overpressure of 0.28 bar-g is also within the limits of FM Datasheet 7-76 [11], which cites an upper bound of 0.30 bar-g as the limit at which enclosure deformation is unlikely. As such, the requirements of NFPA 68 are met for a performance-based analysis. However, this analysis is subject to limitations described in Section 6.

This report concludes the design provided complies with the intent of the Next Edition of NFPA 855 (2026), which requires a partial volume deflagration analysis where an NFPA 69 CCR system is also used within the same enclosure. This report also concludes that the design provided complies with the requirements of NFPA 68, specifically, the performance-based methodology criteria.

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The criteria as noted in NFPA 68, and demonstration of the compliance for this system, are shown in Table 7-1:

Section	Table 7-1: Performance Criteria	Compliant?
5.2.2	*Deflagration vents shall limit the reduced pressure (P_{red}) within an enclosure and any attached vent ducts to meet the objectives in 4.2.1.1 and* 4.2.1.2	*Yes. The developed maximum pressure is 0.41 bar-g for Approach 1. For Approach 2 and Approach 3, the maximum pressure developed is 0.14 bar-g. These values are less than the customer supplied P_{es} of 0.64 bar-g, taking into account a reduction by a factor of 2/3 (stated otherwise, divided by 1.5) (0.427 bar-g). The manufacturer supplied enclosure strength is based upon structural modeling by CATL [13].*
5.2.3.1	*Combustible materials outside the enclosure shall not attain their ignition temperature from flame or hot gases discharged from a deflagration vent.*	*N/A. The site-specific installation shall preclude the installation of any combustible materials above the deflagration vents.*
5.2.3.2	*Blast load from deflagration vent discharge shall limit the risk of damage to exposed structures.*	*N/A. The site-specific installation shall ensure that no exposed structures are located above the deflagration vents.*
5.2.3.3	*Access to spaces into which deflagration vents discharge shall be restricted so as to minimize, to a level acceptable to the authority having jurisdiction, the risk of injury from flame, hot gases, hot particles, or projectiles.*	*N/A. The site-specific installation shall restrict access. However, the design directs all energy and flaming upwards, away from personnel.*
4.2.1.1	*Deflagration venting for occupied enclosures shall prevent the structural failure of the enclosure and minimize injury to personnel in adjacent areas outside of the enclosure.*	*N/A. This enclosure is not occupied.*

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4.2.1.2	*Deflagration venting for unoccupied enclosures shall prevent the rupture of the enclosure*	*Yes. See 5.5. The developed maximum pressures are less than the reported container strength.*

This report is based solely on and is limited by and to the information provided in the documents submitted to Atar Fire for review. This report does not verify or guarantee compliance with any local regulations, nor does it address specific installation configurations.

The simulation results presented herein are applicable only to the explosion hazard scenarios modeled. Other potential explosion hazards warrant separate analysis. Furthermore, this analysis does not account for site-specific hazards such as spacing or separation distances between ESS enclosures in an installed configuration.

A comprehensive Hazard Mitigation Analysis, coupled with the development of appropriate mitigation strategies may be necessary to ensure the BESS does not pose a threat to adjacent personnel or property and that the BESS complies with all applicable local regulations.

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8.0 References

[1] ANSI/CAN/UL 9540A:2019. Standard for Safety. Test Method for Evaluating Thermal Runaway Fire Protection Association, 2023.
[2] CELL TEST REPORT UL 9540A – UL Solutions. Report Issued: 2024-07-23 Project Number: 4791281615
[3] MODULE TEST REPORT UL 9540A –UL Solutions. Report Issued: 2024-07-30 Project Number: 4791324742
[4] UNIT TEST REPORT UL 9540A – UL Solutions. Report Issued: 2024-09-24 Project Number: 4791320298
[5] CFD Modeling Report For Battery Energy Storage System. Analysis of Explosion Prevention in Accordance with NFPA 69. Prepared by Atar Fire, LLC. Report 20251004.
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[10]FLACS-CFD V24.2 User's Manual. January 15, 2025.
[11]FM 7-76, *Combustible Dusts*
[12] *Vented Hydrogen Deflagrations in Containers: Effect of Congestion for Homogeneous Mixtures*. GEXCON.
[13] Structural Analysis for BESS Cabinet. CATL. Dated: 2025/10/23

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Appendix A. Full Volume Deflagration Analysis

USER NOTE: A full volume deflagration analysis is not required. The NFPA 69 compliant explosion control system meets the requirements of NFPA 855 (2023 Edition), and the 2024 Edition of the IFC, for BESS. In addition, the previously presented partial volume deflagration analysis is intended to meet the requirement of NFPA 855 (2026), which requires that a partial volume deflagration analysis be performed in conjunction with any NFPA 69 compliant system. This full-volume analysis assumes the NFPA 69 system fails and does not consider UL 9540A failure results (such as the previously mentioned 3-cell failure) though such an analysis is not required. This Appendix is provided for completeness and information only.

A.1 CFD Geometry and Simulation Configuration

A full-volume deflagration analysis was conducted on the CATL BESS geometric structure to evaluate the worst-case explosion overpressure within the BESS container. This analysis assumed that the entire BESS container was filled with a stoichometric flammable mixture of battery gas and air, which was then ignited to determine the resulting overpressures. The ignition location was strategically chosen to coincide with the previously determined ignition point for the partial-volume deflagration scenario. Critically, this analysis assumes a rigid BESS container, precluding any structural deformation during the deflagration event. With the exception of the gas cloud volume, all other input parameters were held consistent with those used in the partial-volume analysis. The gas cloud configuration and ignition location used in this full-volume deflagration analysis are shown in Figure 14.

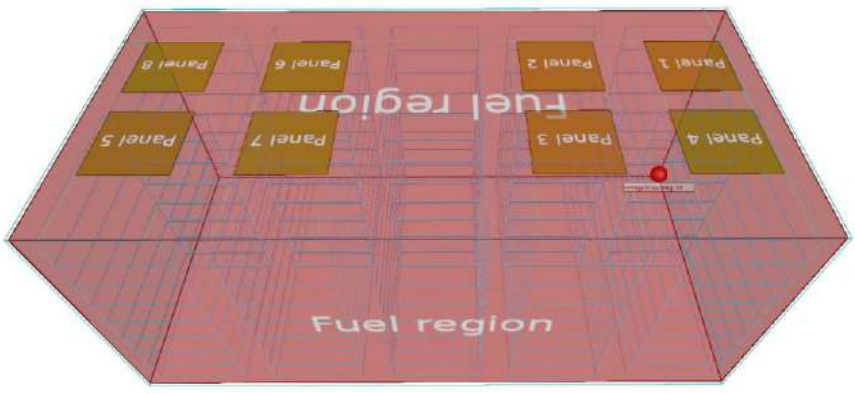

Figure 14 : Full Volume Deflagration Gas Cloud

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A.2 Deflagration Overpressures

Figure 15 illustrates the maximum overpressure profile attained within the BESS container as a consequence of the full volume deflagration event. Elevated overpressures are evident in the corner of the BESS container distal to the ignition point. Given that the flammable gas cloud encompasses the entire length of the BESS, obstructions along the flame propagation path contributed to an increase in overpressures, culminating in a peak overpressure of approximately 1.51 bar-g at one end of the container. It is crucial to note that the calculated maximum pressure (P_{red}) of the BESS container is considered 0.427 bar-g (Reduction of 1.5 from the manufacturer-specified 0.64 bar-g strength); therefore, a full volume deflagration event of this magnitude is expected to compromise the structural integrity of the BESS container.

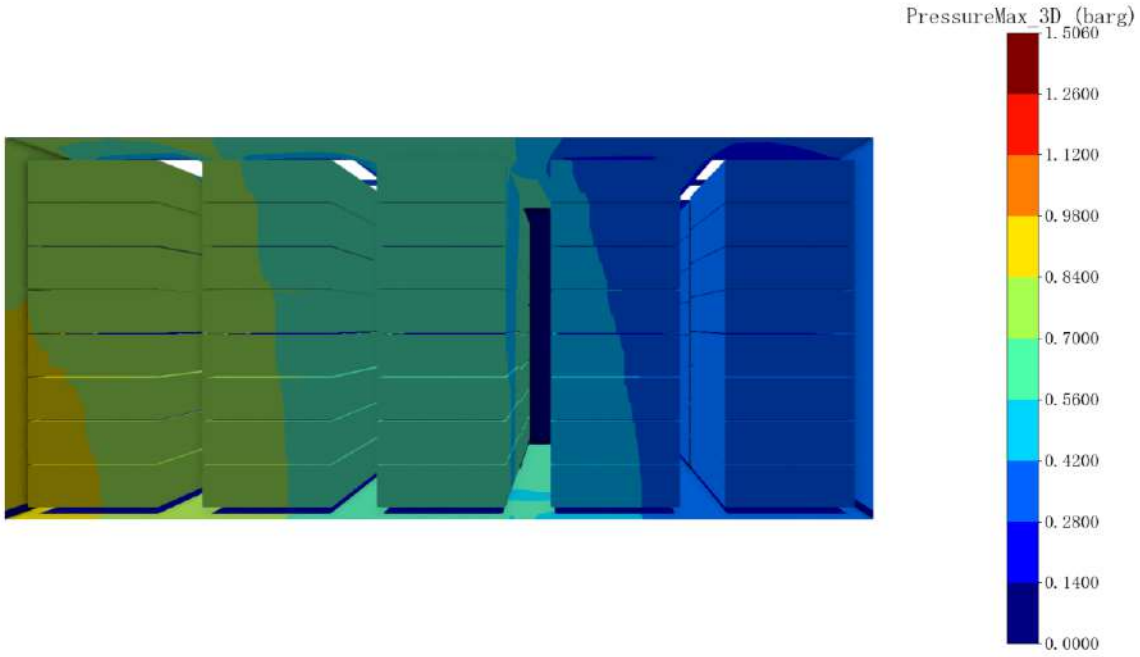

Figure 15 : Maximum Internal Overpressure within the BESS Container

A.3 Summary

The full volume deflagration analysis reveals that the ventilation area afforded by eight 0.6m × 0.6m vent panels is insufficient to mitigate the overpressures generated within the BESS container. Specifically, the peak overpressure significantly exceeds the structural strength of the BESS container, indicating a high probability of severe damage. This inadequacy is attributed to the elevated congestion levels inside the container, which exacerbate overpressure development, rendering the existing ventilation area insufficient for effective pressure relief.

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Appendix B. NFPA 68 Calculation Methodology

B.1 Physical Features

The internal dimensions of the BESS enclosure are 4.9 meters in length, 2.35 meters in width, and 2.15 meters in height. These dimensions yield a total volume of 24.757 cubic meters and a total surface area of 54.21 square meters. The top surface of the BESS enclosure incorporates eight vent panels, each measuring 600 mm by 600 mm, providing a cumulative ventilation area of 2.88 square meters.

The calculation of free volume accounts for the obstruction volume, which includes battery modules, control boxes, and other equipment, totaling 19.375 cubic meters. Consequently, the free volume, derived by subtracting the obstruction volume from the total volume of 24.757 cubic meters, is 5.382 cubic meters.

In accordance with Chapters 6 and 7 of the NFPA 68 standard, estimating the total surface area of obstructions within the container is crucial. Our estimation concludes that the surface area of obstructions (A_{obs}) is less than 0.2 times the total surface area (A_s).

The static opening pressure of the vents (P_{stat}) is configured to 0.1 bar-g. The structural strength (P_{es}), as specified by the client, is 0.64 bar-g, and a Design Load Factor (DLF) of 1.5 is applied. Therefore, the maximum permissible pressure inside the BESS container should not exceed a reduced pressure (P_{red}) of 0.427 bar-g. A comprehensive summary of all values used in the NFPA 68 calculations is presented in Table B-1.

Table B-1: Volume and Surface Area of Container and Obstructions

	Total volume(m^3)	A_s(m^2)	V_{obs} (m^3)	A_{obs} (m^2)	V_{eff}(m^3)
BESS	24.757	54.21	19.375	$<0.2A_s$	5.382

B.2 Flammable Gas

Table 4-1 presents the gas composition of vented thermal runaway gases as determined by UL 9540A testing.

For complete combustion, the stoichiometric volume fraction of battery gas, *$X_{g,s}$*, was calculated to be 22%. Combustion properties, including burning velocity (S_u), peak pressure (P_{max}), and LFL, were determined according to the UL 9540A cell-level test report and are summarized in Table B-2.

Furthermore, properties of the unburned gas mixture (G_u, ρ_u, and μ_u, representing the sonic flow mass flux, density, and dynamic viscosity of the unburned gas-air mixture, respectively) and the specific heat ratio (γ_b) of the final gas mixture were assigned default values as specified by NFPA 68 and are detailed in Table B-3.

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This recognizes that some properties, such as density and specific heat ratio, will be different from the default values when calculated at off gas temperatures. However, use of these parameters at the off-gas temperature has the net effect of decreasing the required vent area, not increasing required vent area. As such, the default values are more conservative.

Table B-2: The Characteristics of Combustible Mixtures		
	Parameter	***Value***
Cell	S_u	***0.64 m/s***
	P_{max}	***6.5 bar-g***
	LFL	***7.545% (7.88 based on [5])***

Table B-3: Calculated gas properties		
	Parameter	***Value***
Cell	G_u	***230.1 kg/m2-s***
	ρ_u	***1.2 kg/m3***
	μ_u	***1.8 × 10-5 kg/m-s***
	γ_b	***1.15***

Prior to the release of battery gas, the volume of air occupying the enclosed space corresponds to its effective internal volume (V_{eff}). Given the assumption of substantial air leakage during the gas release process, maintaining ambient pressure within the enclosure, the partial filling fraction, X_r, can be calculated according to Formula 1.

$$X_r = \frac{V_{gas}/V_{eff}}{X_{g,s}} \quad (1)$$

Table B-4 presents a scenario-based analysis quantifying the combustible gas released into the enclosure following thermal runaway events affecting varying numbers of battery cells. It is important to acknowledge that the number of cells undergoing thermal runaway is contingent upon the specific testing conditions employed. Consequently, recognizing this potential variability, the outcomes associated with each scenario were meticulously analyzed and comparatively assessed to provide a comprehensive understanding of the potential range of gas release.

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Table B-4: Flammable gas from varying battery cell counts in thermal runaway, leading to different partial volume fill fractions

Cell(s) in Thermal Runaway	Flammable Gas Volume (m^3)	X_r(%)
1	0.176	14.9
3	0.528	44.6
Full volume (>7)	1.184	100

B.3 Refinement of Deflagration Vent Size Calculations

As detailed in Section 4.8, the client-specified pressure (P_{es}) is 0.64 bar-g. Applying a Design Load Factor (DLF) of 1.5 yields a calculated reduced explosion pressure (P_{red}) of 0.427 bar-g.

Chapter 7 of NFPA 68 provides a comprehensive methodology for designing gas mixture explosion venting systems based on defined criteria, a methodology applicable to contemporary BESS. The primary goal is to determine the minimum required explosion vent area (A_v) according to the standard's prescribed procedures. The aggregate area of all explosion vents implemented during installation must equal or exceed A_v. When inertia is less than 40 kg/m^2 and P_{red} does not exceed 0.5 bar-g, the minimum required vent area can be calculated using equations 2 and 3 (corresponding to equations 7.2.1a and 7.2.1b in NFPA 68). For detailed information and clarification of terminology, consult the NFPA 68 Standard directly.

$$A_{v0} = \frac{A_s C}{\sqrt{P_{red}}} \qquad (2)$$

$$C = \frac{S_u \rho_u \lambda}{2 G_u C_d}\left[\left(\frac{P_{max}+1}{P_0+1}\right)^{\frac{1}{\gamma_b}} - 1\right](P_0+1)^{\frac{1}{2}} \qquad (3)$$

where:

A_{v0} = the vent area calculated from formula (2) (m^2)

A_s = the enclosure internal surface area determined according to B. 1 (m^2)

P_{red} = the maximum pressure developed in a vented enclosure during a vented deflagration (bar-g)

S_u = fundamental burning velocity of gas-air mixture (m/s)

ρ_u = mass density of unburned gas-air mixture (kg/m^3)

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λ = ratio of gas-air mixture burning velocity accounting for turbulence and flame instabilities in vented deflagration to the fundamental (laminar) burning velocity

G_u = unburned gas-air mixture sonic flow mass flux (kg/m^2-s)

C_d = vent flow discharge coefficient, 0.7

P_{max} = the maximum pressure developed in a contained deflagration by ignition of the same gas-air mixture (bar-g)

P_0 = the enclosure pressure prior to ignition (bar-g)

γ_b = ratio of specific heats for the burned gas-air mixture

NFPA 68, Section 7.2.6 specifies the determination of λ. The baseline value λ_0 of λ is calculated based on equations 7.2.6.1a to 7.2.6.1f in section 7.2.6.1, where

D_{he} = the enclosure hydraulic equivalent diameter (m)

μ_u = the unburned gas-air mixture dynamic velocity (kg/m-s)

β_1 = 1.23

β_2 = 2.37 x 10^{-3} m/s

D_v = the vent diameter as determined through iterative calculation (m)

u_v = maximum velocity through vent (m/s)

a_u = the unburned gas-air mixture sound speed (m/s)

θ = 0.39

Based on NFPA 68, Section 7.2.3, conservative estimations for the dynamic viscosity (μ_u) and the speed of sound (a_u) are 1.8 × 10^{-5} kg/m-s and 343 m/s, respectively. Furthermore, employing NFPA 68, Chapter 6 and Section 7.2.6, equation 7.2.6.1e, the derived values for D_{he}, D_v, and u_v are 0.488 m/s, 0.61 m/s, and 266.8 m/s, respectively. Consequently, utilizing formula 7.2.6.1f, the initial dimensionless deflagration parameter (λ_0) is calculated to be 1.98.

Following NFPA 68 Section 7.2.6.4, and given that A_{obs} < 0.2 A_s, the modified dimensionless deflagration parameter (λ_1) is assigned the value of λ_0. Additionally, due to the enclosure's length-to-diameter ratio (L/D) being 2.5 to 5, NFPA 68 Section 7.2.6.7 dictates that the final dimensionless deflagration parameter (λ) is calculated by λ_1, hence 2.59.

$$\lambda = \lambda_1[1 + (\frac{L/D}{2.5} - 1)^2] \quad (4)$$

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The enclosure pressure prior to ignition (P_0) was assumed to be equivalent to P_{stat}, representing the maximum pressure under which a flammable gas mixture could exist at the moment of ignition, as stipulated in NFPA 68 Section 7.2.4.2. The partial volume deflagration vent area requirement was subsequently calculated incorporating the reduction factor provided in NFPA 68.

$$A_{v1} = A_{v0} X_r^{-1/3} \sqrt{\frac{X_r - \Pi}{1 - \Pi}} \quad (5)$$

To account for the potential influence of partial volume fill fraction (X_r) and normalized pressure ($\Pi = P_{red}/P_{max}$) on vent performance, an assessment was conducted to determine if the vent panel area required augmentation. Specifically, the panel mass per unit area was calculated and subsequently compared against a predefined threshold mass, as dictated by Equation 6 to evaluate the potential impact of panel inertia on vent effectiveness.

$$M_T = \left[\frac{P_{red}^{0.2} n^{0.3} V}{(S_u \lambda)^{0.5}}\right]^{1.67} \quad (6)$$

B.4 Results of Vent Area Calculation

Table B-5 presents the calculated required ventilation areas for both partial and full volume scenarios. As indicated in the table below for all scenarios, the provided vent area exceeds the required vent area. As such, the provided vent area meets the prescriptive requirements of NFPA 68.

Table B-5: Required Ventilation Area for the BESS

Scenario	Flammable Gas Volume (m^3)	Required Vent Area (m^2)
1 cell	0.176	1.30
3 cells	0.528	1.94
Full volume (>7)	1.184	2.32
Provided vent area	2.88m^2	

Given that the mass of the vent panel per unit area (9.9 kg/m^2) falls below the established threshold of 25.2 kg/m^2, adjustments to the ventilation area are deemed unnecessary. Consequently, the ventilation area remains unchanged ($Av_2 = Av_1$).

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B.5 Overview and Suggestions

This analysis investigated the feasibility of deflagration venting for the CATL Battery Energy Storage System (BESS) through a partial volume assessment, considering scenarios involving thermal runaway in one and three battery cells. The calculated venting areas required for these scenarios were 1.30 and 1.94 m^2, respectively. For the both scenarios, the provided designs can comply with NFPA 68, as the required venting area of 1.30 m^2 and 1.94 m^2 are less than the available venting area of 2.88 m^2.

Similarly, a worst-case scenario involving full volume deflagration, where the entire enclosure is filled with a stoichiometric gas-air mixture, necessitates a venting area of 2.32 m^2. This requirement does not exceed the available venting area of 2.88 m^2 and, consequently, comply with NFPA 68 for adequate explosion venting.

The prescriptive-based calculations presented in this Appendix are derived from Chapters 6 through 11 of NFPA 68. Given that guidance within NFPA 68 is based on conservative assumptions and is derived from testing date not specifically derived from full scale BESS tests, the findings presented herein should be considered supplementary and specific to the scenarios examined. The calculations are also dependent upon the manufacturer supplied enclosure strength of 0.64 bar-g.

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Appendix H

ENCLOSURE LEVEL HMA

HAZARD MITIGATION ANALYSIS OF THE CATL EnerC 1P BATTERY ENERGY STORAGE SYSTEM IN ACCORDANCE WITH NFPA 855 STANDARD FOR THE INSTALLATION OF STATIONARY ENERGY STORAGE SYSTEMS (2023 EDITION) AND THE 2024 INTERNATIONAL FIRE CODE

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2025-12-29	1	Revised to ensure aerosol system is described as optional.
2026-03-14	2	Replaced Figure 8
2026-05-08	3	Updated 9540 Certificate; Misc. Edits Based on Minor Product Changes. Change Figure 1 to reflect relocated e-stop button per CATL request

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2.0 Authors' Note

Authors' Note on NFPA 855 and the International Fire Code: In Jurisdictions where the 2023 Edition of NFPA 855 is enforced either through adoption or reference, this Hazard Mitigation Analysis provides a direct path to evaluating the CATL EnerC 1P for fire and life safety compliance.

Where the International Fire Code (IFC) is enforced, compliance with NFPA 855 is compulsory beginning with publication of the 2024 Edition of the IFC as noted in Section 1201.1. Editions of the IFC that are earlier than 2024 do not reference NFPA 855; however, the requirements in IFC Section 1207 (2021 Edition) directly mirror those of NFPA 855. Where even earlier Editions of the IFC are enforced in a local Jurisdiction (e.g., 2018 Edition or earlier), IFC Section 102.8 allows for the implementation of NFPA 855 or IFC Section 1207 as "Subjects Not Regulated By This Code," due to the emergence of lithium-ion battery technologies not being thoroughly codified in those Editions of the IFC. The 2024 Edition of the IFC adopts the 2020 Edition of NFPA 855 via reference; however, for consistency, this HMA uses the 2023 Edition of NFPA 855.

When compared across the totality of 2023 NFPA 855 and 2024 IFC Section 1207, compliance with NFPA 855 generally ensures compliance with the IFC, though small variations do exist. The specific language of 2024 IFC Section 1207 is not provided in this Hazard Mitigation Analysis in an effort to reduce redundancy and to ensure a streamlined evaluation. The exception to this methodology is the two additional Conditions of Approval that are provided in 2024 IFC Section 1207.1.4.2. Those two additional Conditions are discussed on the following page, below in Table 1.

Several sections of NFPA 855 and the IFC address customer or site-specific requirements which are not reviewed herein other than where a distinction is required. In these instances, site specific requirements are typically the responsibility of the end user, customer, system installer, or operator.

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3.0 HMA Background & Summary

The 2023 Edition of NFPA 855 *Standard for the Installation of Stationary Energy Storage Systems* requires a Hazard Mitigation Analysis (HMA) in accordance with Section 4.4.1 when any of the following conditions exist:

1. Technologies not specifically addressed in Table 1.3 of NFPA 855 are provided.
2. More than one Energy Storage System (ESS) technology is provided in a single fire area where adverse interaction between the technologies is possible.
3. Where approved by the Authority Having Jurisdiction (AHJ), as a basis for increasing maximum stored energy beyond maximum stored energy requirements of NFPA 855 based on ESS type. This allowance is for installations in non-dedicated use buildings, outdoor ESS installation, ESS installations in open parking garages and on rooftops of buildings, and mobile ESS.
4. Where required by the AHJ to address a potential hazard with an ESS that is not addressed by existing requirements.
5. Where required for existing lithium-ion ESS systems that are not UL 9540 listed.
6. For outdoor ESS installation, ESS installations in open parking garages and on rooftops of buildings, and for mobile ESS equipment, where lithium-ion ESS capacity exceeds 600 kWh.

This HMA is intended to satisfy and to address the fire protection conditions in which an HMA is required. This HMA applies specifically and solely to design features integral to the CATL EnerC 1P.

This HMA was performed with the documentation provided and our experience and training in Fire Protection Engineering. The assessment and conclusions were developed with a reasonable level of engineering and scientific confidence, with generally accepted engineering principles and judgement concluding that for the failure modes prescribed by NFPA 855, the CATL EnerC 1P meets the required HMA approval conditions, as described below. Final approval of any project shall involve additional site-specific review. All Findings referred to at the end of this report apply.

NFPA 855 prescribes three conditions under which an HMA can be approved in §4.4.3 as shown in Table 1 below. The 2024 IFC mirrors these approval conditions, with the exception that it is limited to only the first two items in Table 1.

Table 1 - HMA Approval Conditions and Summary

HMA Approval Conditions Summary		
Approval Condition	**Code Section**	**Results**
Fires will be contained within unoccupied ESS rooms for the minimum duration of the fire	NFPA 855 §4.4.3 (1) IFC §1207.1.6.2 (1)	The CATL EnerC 1P is intended for outdoor installations.

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resistance rating specified in Section 9.6.4.		
Fires and products of combustion will not prevent occupants from evacuating to a safe location.	NFPA 855 §4.4.3 (2) IFC §1207.1.6.2 (1)	The CATL EnerC 1P is not intended for indoor installations and is for outdoor installations only. Occupants in the vicinity of the outdoor installation will be capable of evacuating the area to a safe location
Deflagration hazards will be addressed by an explosion control or other system.	NFPA 855 §4.4.3 (3)	NFPA 68 & 69 explosion control systems have been provided to address deflagration hazards.

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4.0 Product Description

The CATL EnerC 1P lithium-ion ESS is a 20-foot self-contained energy storage system product. The formal model number for the overall ESS is C04285P10L01.

The CATL EnerC 1P has enclosure dimensions of 6058 mm x 2462 mm x 2896 mm [approximately 20’ x 8’0” x 9’6”] (L x W x H). It is comprised of 285 Ah, 3.2 V cells utilizing prismatic lithium-iron phosphate (LFP) chemistry, which are manufactured by CATL. The cell model is CBDC0. Each module is comprised of 52 cells arranged in a 52 Series 1 Parallel (52S1P) configuration. Each rack (also referred to as a ‘unit’ in this case) is comprised of eight modules, arranged in an 8 Series 1 Parallel (8S1P) configuration. A fully populated enclosure contains 10 racks. The full ESS product has a rated capacity of 3.79 MWh. Representative product images are shown as follows:



Figure 1 – Enclosure End View

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Figure 2 – Enclosure Exterior Isometric View – Chiller Shown



Figure 3 – Front View – Interior – Modules/Racks Shown

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Figure 4 - Enclosure End View - Controls & Systems



Figure 5 – Module

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An overview of some of the most salient specifications of the CATL EnerC 1P is as follows:

Table 2 - Relevant Product Parameters

Parameter	Value/Description
ESS Operating Temperature	-25 to 55° C
ESS Storage Temperature	-30 to 60° C
Enclosure Ingress Protection	IP 55 [27]
Module Ingress Protection	IP 67 [28]
Maximum Altitude	<4000 m
Battery Chemistry	LiFePO4 (Lithium Iron Phosphate)
Cells Manufacturer & Model	CATL CBDC0
Cell Voltage	3.2 V
Cell Capacity	285 Ah
Cell Format	Prismatic
Module Manufacturer & Model	CATL M01285P10L01
Module Configuration	52S1P
Module Capacity	285 Ah
Module Voltage	166.4 V
Unit Manufacturer & Model	CATL C04285P10L01-R
Unit Configuration	8S1P
ESS Manufacturer & Model	CATL C04285P10L01 (referred to as EnerC 1P)
ESS Number of Units/Racks	10
ESS Nominal DC Voltage	1331.2 V
ESS Cooling	Liquid (50% Ethylene Glycol – aqueous solution)
UL 1973	Yes [32]
UL 9540	Yes [7]

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The overall ESS enclosure includes a separate compartment, accessed via an exterior door, used to house ancillary control equipment and systems. This includes the master control box, fire detection and suppression system control equipment, uninterruptible power supplies for backup power for various systems, and an auxiliary/electrical distribution box. The auxiliary/electrical distribution box provides auxiliary power for the control system and liquid cooling system.

Some of these features are shown in the following figures.

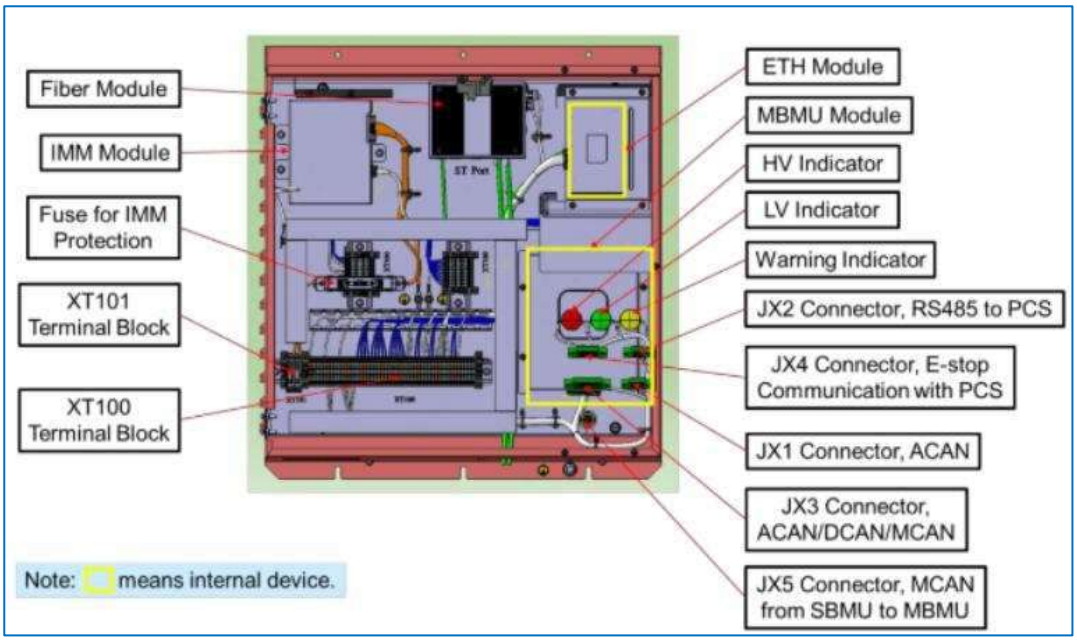

Figure 6 - Master Control Box

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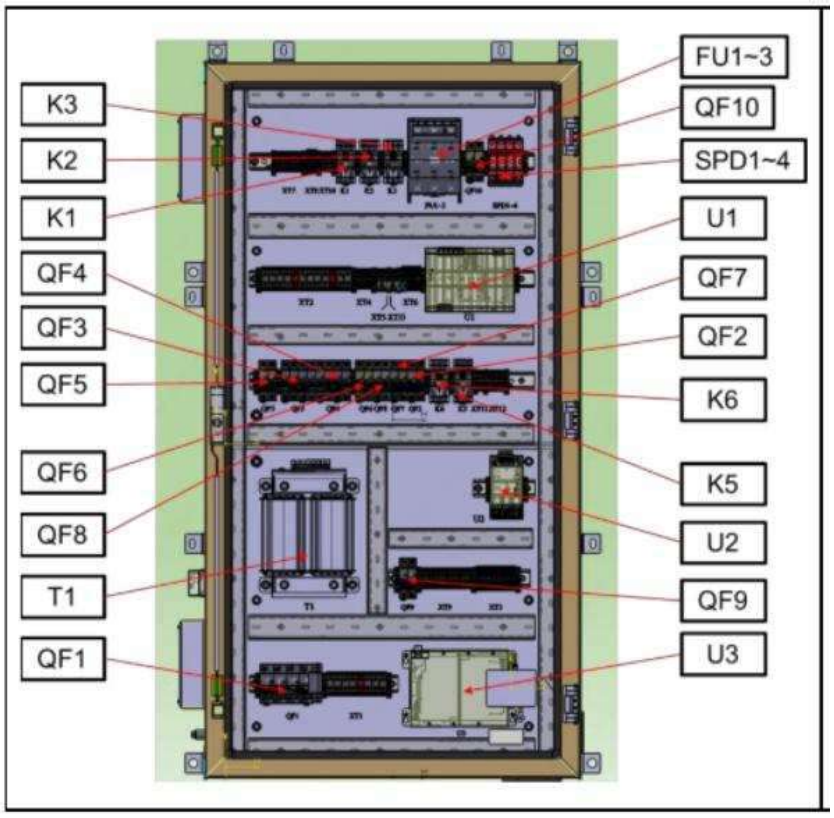

Figure 7 – Electrical/Auxiliary Distribution Box

The battery modules utilize a liquid cooling system for thermal control. The liquid coolant is an ethylene glycol and water mixture. The liquid coolant mixture is cooled via R134a refrigerant. The liquid cooling system also includes a network of coolant delivery pipes to the modules, utilizes two chillers, a condenser, a compressor, a liquid storage tank, and fans. A separate dehumidifier assists in controlling humidity levels. The thermal management system components are located on one end of the ESS.

The EnerC 1P is provided with an NFPA 69 combustible concentration reduction system. On-board gas detection in the form of two hydrogen gas sensors is designed to provide detection of battery off-gas components in the event of thermal runaway. The gas detection system is interlocked with the provided ventilation system, which turns on an exhaust fan, and opens a make-up air inlet, to reduce the concentration of combustible gases within the enclosure. This system is described in more detail later in this HMA.

The EnerC 1P is also provided with an NFPA 68 deflagration venting system. Eight passive deflagration vent panels are roof mounted. In the event of a deflagration, the vents are designed to safely relieve pressure. This system is described in more detail later in this HMA.

An optional aerosol fire extinguishing system is also provided for the enclosure. Where included, nine individual aerosol units are provided within the enclosure. The fire extinguishing system includes a disable switch and a manual pull station. The extinguishing system is initiated by detection of fire via activation of either a smoke and heat detector or two heat detectors.

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A fire alarm control panel is included and is located in a separate compartment at one end of the ESS. Two smoke detectors and two heat detectors are included in the battery compartment, and an additional smoke detector is included in the electrical distribution box. A single exterior horn/strobe is included. Dedicated battery backup is provided for safety systems in accordance with applicable codes and standards.

A graphic of the various safety systems and components are shown in the following image.

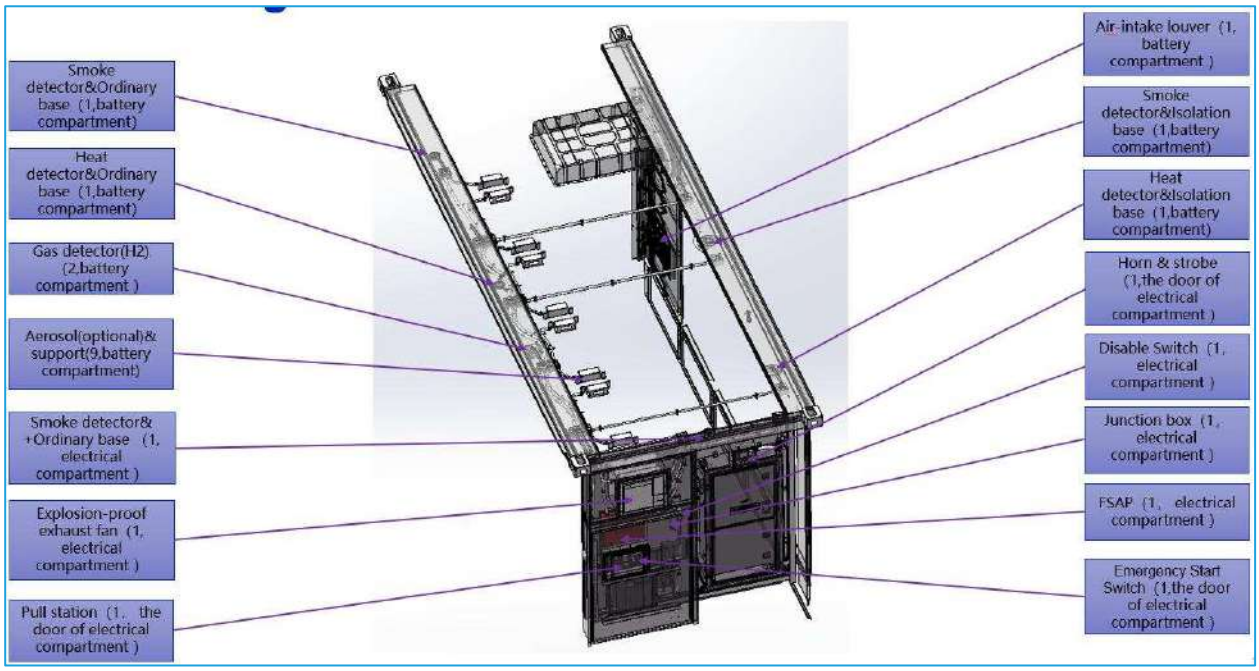

Figure 8 - Safety System Components

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5.0 Discussion of Lithium-Ion Technology Hazards

Lithium-ion batteries are subject to a phenomenon known as thermal runaway. Thermal runaway is self-heating of an electrochemical system in an uncontrollable fashion as defined in NFPA 855 §3.3.26 [1]. During a thermal runaway event, the electrolyte within the battery cells converts into flammable gases that are released in an energetic manner. Based on thermal runaway testing on sample cells in accordance with UL9540A [9], these vented gases include hydrogen, carbon monoxide, and various hydrocarbons. The total volume of gases created by the overheating of the electrolyte, and the gas composition, are dependent on the specific cell chemistry cell design.

The primary hazards associated with thermal runaway include the risk of fire and explosion, though there are other hazards, such as chemical, electrical, stranded energy, and physical. NFPA 855 is the primary consensus standard that seeks to mitigate the hazards associated with ESS.

ESS safety is achieved through a layered approach. There is no single factor that can deem an ESS installation safe. The layers of safety include but are not limited to explosion control, size and separation of ESS units, fire department response, battery management systems, thermal management systems, fire detection systems, commissioning, maintenance and operations, battery management systems, cell chemistry, product certifications, and physical siting. Some of these factors are graphically shown below.

Through the application of NFPA 855, the aggregation of the aforementioned items and others, when adhered to properly, provide for what is deemed a safe installation. These items are discussed in this HMA and evaluated for overall fire protection safety.



Figure 9 - ESS Safety Layers

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6.0 Hazard Mitigation Analysis Background

One of the key safety basis documents of NFPA 855 is the HMA. The purpose of the HMA is to consider potential failure modes within an ESS system and the associated consequences. NFPA 855 provides prescriptive requirements for what failure modes must be considered, and what the acceptance criteria are. The AHJ has the final authority on approval of an HMA. The overall concept is that there must be a sufficient level of mitigating measures in place to address incidents and their potential.

Mitigating measures can either prevent an incident from occurring, or should an incident occur, they can serve to reduce the potential impact of the incident. The approach utilized in this HMA generally follows concepts outlined in NFPA 550, *Guide to the Fire Safety Concepts Tree* [2]. This method of fire risk assessment (FRA) is referenced as a qualitative method in NFPA 551, *Guide for the Evaluation of Fire Risk Assessments* [3]. Within NFPA 855, Annex G.3, the terms HMA and FRA are used interchangeably. Additionally, NFPA 855 Annex G.3 references NFPA 550/551, and more specifically, the fire safety concepts tree, as an acceptable approach to the HMA. In NFPA 550, the terminology used for mitigating measures are 'Prevent Fire Ignition' and 'Manage Fire Impact'. These terms will be used throughout this report accordingly.

The failure modes that shall be analyzed are as follows [1]:

1) A thermal runaway or mechanical failure condition in a single ESS unit.
2) Failure of an energy storage management system or protection system that is not covered by the product listing failure modes and effects analysis (FMEA).
3) Failure of a required protection system, including but not limited to, ventilation (HVAC), exhaust ventilation, smoke detection, fire detection, suppression, or gas detection.

Only single failure modes are considered. The approval conditions by the AHJ are as follows [1]:

1) Fire will be contained within the unoccupied ESS rooms for the minimum duration of the fire resistance rating specified in NFPA 855 Section 9.6.4.
2) Fires and products of combustion will not prevent occupants from evacuating to a safe location.
3) Deflagration hazards will be addressed by an explosion control or other system.

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7.0 Hazard Mitigation Analysis per NFPA 855 Section 4.4

The following analysis directly addresses the requirements of an HMA as required by NFPA 855. Where direct text from NFPA 855 is referenced, it is provided in italics to provide clarity.

Failure Mode 1

Thermal Runaway in a Single ESS Unit

A thermal runaway is the worst-case scenario in an ESS and may result from many factors. Typically, a short circuit occurs due to mechanical, electrical, or physical abuse. Unmitigated thermal runaway in a single cell may lead to cell-to-cell propagation and may also lead to fire or explosion.

Barriers to Thermal Runaway

Mitigating measures to prevent thermal runaway ('Prevent Fire Ignition' per NFPA 550) for the CATL EnerC 1P are as follows:

1) UL 9540 [5]: UL 9540 is a fundamental certification standard for ESS's. UL 9540 certification involves a wide range of mechanical, electrical, and environmental tests. In addition, there are 19 construction related requirements. Amongst the variety of testing required, a robust safety analysis, typically a Failure Modes and Effects Analysis (FMEA), is required to obtain certification from the testing laboratory. The tests within UL 9540 work systematically to reduce the overall hazard and risk profile of the ESS, which includes limiting the propensity for thermal runaway.

   The CATL EnerC 1P is certified to UL 9540 (3rd Edition) by TUV Rheinland [7]. TUV Rheinland is considered an Occupational Safety and Health (OSHA) Nationally Recognized Testing Laboratory (NRTL) and is specifically recognized by the OSHA NRTL program to certify energy storage systems to UL 9540. This provides additional confidence in the listing mark by the testing laboratory.

2) UL 1973 [8] Listing: UL 1973 is the fundamental certification standard for the battery modules. UL 1973 includes mechanical, electrical, and environmental tests, in addition to construction requirements, and factory production audits. UL 1973 is an abuse testing standard. Batteries are subjected to a wide array of testing (for example drop testing, overcharging, short circuits, salt fog, and more). After testing, the rigorous pass criteria include that the module shall not exhibit signs of explosion, fire, combustible vapor, toxic vapor, electric shock hazard, leakage, rupture, or loss of protective control. UL 1973 certification is required in order to obtain a UL 9540 certification. UL 1973 certification provides significant confidence that the product can withstand abuse conditions and certification of modules to this standard is considered a critical mitigating measure. The CATL EnerC 1P has achieved UL 1973 certification [32].

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3) Battery Management System (BMS): A BMS is a system that monitors, controls, and optimizes performance of an individual or multiple battery modules [1]. It serves as a critical initial mitigating measure in the event of off-normal conditions.

   For the CATL EnerC 1P, the BMS monitors battery voltage, current, and temperatures. It also performs functions such as controlling thermal management, monitoring the enclosure temperature, monitoring faults and taking actions, and provides for external communication. The BMS is comprised of a master control box and sub control box. The master control box includes IMM, MBMU, ETH, fiber conversion module. The sub control box includes SBMU, fuses, isolation switches, and more. The MBMU communicates with 10 local battery management units, located inside the battery enclosure at each rack.

   A risk assessment of safety controls as well as an evaluation of the software was independently evaluated as part of the UL 9540 certification process [19]. The evaluation was performed by TUV Rheinland in accordance with IEC 60730-1 Annex H and IEC 61508 [19] [31]. Both standards are a referenced standard within UL 9540 [5], specifically as it pertains to electronic controls and software. A battery management system that has been evaluated as part of the UL 9540 listing is an approved method of thermal runaway protection per NFPA 855, §9.6.5.5.2.

4) IP Ratings: The CATL EnerC 1P utilizes an IP55 (Ingress Protection) rated enclosure. An IP55 enclosure is weather resistant and rated for outdoor use for protection against dust and water. This rating is critical as ESS thermal runaway incidents have resulted from dust or water ingress. The enclosure water ingress rating is only suitable for low-pressure water jets. In the event of an incident in which an enclosure must be cooled by the Fire Department, it is recommended a fog nozzle or similar be utilized to prevent water ingress into the enclosure. The IP55 rating of the enclosure must be maintained for the unit to maintain its stated water protection level. Independent attestation of the IP55 rating via testing to IEC 60529:2013 (*Degrees of Protection Provided by Enclosures (IP Code)*) was provided by Suzhou Electrical Apparatus Science Research Institute Co., Ltd. [24]. In the event of water intrusion to the enclosure, metal floor drains (one-way valves) are included on the enclosure floor.

   Additionally, the module casings are provided with an IP67 rating. This rating provides protection against dust as well as temporary immersion in water. Should water enter the enclosure, the module level IP rating provides a secondary layer of protection against dust and water. CATL Testing and Validation Center performed testing [25] to validate the IP67 rating in accordance with Chinese Standard GB4208-2017, *Degrees of Protection Provided by Enclosure (IP Code)*.

   Additional IP ratings are provided for the sub control boxes (IP66), electrical/auxiliary distribution box (IP55), and cooling unit (IP56).

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5) Thermal Management Systems (TMS): Excess humidity and high or low temperatures within an ESS can increase the probability of failures. As such, methods of managing temperature and humidity may safeguard against this.

   Temperature control is provided for the CATL EnerC 1P via a liquid cooling system to maintain the batteries within operating parameters. The liquid cooling uses a 50% ethylene glycol-water solution. Liquid coolant is delivered to the modules through a piping network. Ancillary components of the liquid cooling system include two chillers, fans, a compressor, condenser, liquid storage tank, and R134a refrigerant. The TMS is also capable of heating coolant when battery temperatures are too low.

   Two dehumidifiers control the humidity within the battery compartment. The suitability of the heating and cooling systems has been evaluated as part of the UL 9540 certification [33] (ref. Section 19 of UL 9540, 3rd Edition [5]).

   The liquid cooling system must be installed in accordance with the applicable installation standards (such as the International Mechanical Code), as required by NFPA 855 §5.3, to be credited as a mitigating measure. In addition, compliance with applicable mechanical design standards, and maintenance of the system, is essential for the performance of the system and to minimize the chance of leaks or malfunctions. Maintenance requirements and intervals are provided in the CATL O&M Manual [20] and must be adhered to.

6) Passive Fuse Protection: The CATL EnerC 1P is equipped with several layers of fuse protection. These fuses provide a one-time use to interrupt current flow during an off-normal electrical event. Levels of fuse protection are provided as follows:

   450 Amp Fuse Protection: Rack Level
   500 Amp Fuse Protection: Module Level Fuse
   100 Amp Fuse Protection: Upstream fuse protection for the surge protective device
   15 Amp Fuse Protection: Fuse in DC bus insulation measurement circuit
   15 Amp Fuse Protection: Fuse for sampling wiring harness protection

   FINDING 1: There is no overcurrent protection on the DC side. This needs to be added externally. The AC input to the control loop requires an external manual switch as a maintenance switch. These items are required by the UL 9540 certification report [33].

7) Insulation Monitoring: Insulation monitoring is typically performed by power conversion systems on the DC side. While this provides an added layer of safety to complement all other preventative mechanisms, it is not an inherent feature of the EnerC 1P. Therefore, it is not credited as a safety measure in this HMA.

Consequence Reduction Measures

In the event thermal runaway occurs, the following mitigating measures serve to reduce potential consequences ('Manage Fire Impact' per NFPA 550):

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1) UL 9540A Testing: UL 9540A cell, module, and unit level testing was performed by UL Solutions [9][12][13]. The UL 9540A cell level report [9] indicates that a single cell produces 176.3 liters of gas. Of this, approximately 30.116% is CO_2, 10.610% is CO, 43.569% is H_2, and the remaining balance is hydrocarbons. The lower flammability limit of the gas mixture was determined to be 8.05% at ambient temperature, and 7.545% at cell vent temperature. The vent temperature is approximately 321.8 °F (161 °C), and the thermal runaway temperature is 428 °F (220 °C). The cell level test resulted in vented flammable gas, but there were no observations of flaming, as is typical with LFP chemistry. Due to the presence of flammable gas, a module level test was conducted.

   The UL 9540A module level test [12] placed a single cell into thermal runaway utilizing the standard UL 9540A test methodology. During this test, thermal runaway spread to two adjacent cells, and no flying debris, explosive discharge of gases, sparks, arcs, electrical events, or flaming was observed. Due to the presence of flammable gas that was generated during thermal runaway, a unit level test was conducted.

   The UL 9540A unit level test [13] placed a single cell into thermal runaway utilizing the standard UL 9540A test methodology. During this test, four full units were placed in an arrangement determined by the manufacture to assess the potential for unit-unit propagation. The test also captures increases in temperature and heat flux on target units. Test results indicated that thermal runaway spread to two adjacent cells, and no flying debris, explosive discharge of gases, sparks, arcs, electrical events, or flaming was observed. This testing indicates that in the absence of additional ignition sources, when thermal runaway is initiated in a single cell via overheating, propagation may be limited in nature. The maximum observed temperature on target units was 111 °F (44 °C). The maximum heat flux on a target module was 0.54 kW/m^2.

   This HMA recognizes that this testing and the use of LFP chemistry does not eliminate fire or explosion hazards, nor does it represent all potential failure conditions that could occur. LFP chemistry is more resilient to failure in overheating events (generally it enters thermal runaway at higher temperatures than other battery chemistries) and may reduce the potential of flaming and cell to cell propagation under failure conditions like the UL 9540A test. Lithium iron phosphate (LFP) cells often display non flaming behavior during UL 9540A, with limited cell to cell propagation. The ultimate propensity for fire and cell to cell propagation will depend on the nature of the failure. Failure conditions in an as-installed incident may differ from laboratory testing (multi cell external short circuit due to coolant leak, for example). Both fire and explosion consequence reduction measures are discussed in detail in this HMA. Due to the fact that non-UL 9540A failures are possible, the design of the NFPA 69 combustible concentration reduction (CCR) system, NFPA 68 deflagration venting system, and the large-scale fire test, take this into account and are discussed in this HMA.

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2) Explosion Control – NFPA 69 CCR System

The CATL EnerC 1P includes an NFPA 69 CCR system. The CCR system consists of an exhaust fan and a make-up air inlet, interlocked with gas detection. The ATEX certified explosion proof exhaust fan is model TPF03, manufactured by Electro Man. Gas detection is provided in the form of two hydrogen detectors. The manufacturer is Honeywell and the model is Sensepoint XCL. This gas detector is UL 2075 certified by Intertek (refer to Intertek Control Number 4006991). Each detector will activate a set of dry contacts upon reaching ten percent of the lower flammability limit (LFL) for hydrogen. When the CCR system activates, it works to reduce the volume of flammable gases within the enclosure and limit the deflagration potential. The exhaust fan and air inlet are located as shown in Figure 10. According to CATL, activation of the fire extinguishing system will not shut down the CCR system. Once the CCR system is activated, it requires a manual reset, thereby preventing the system from being overridden.

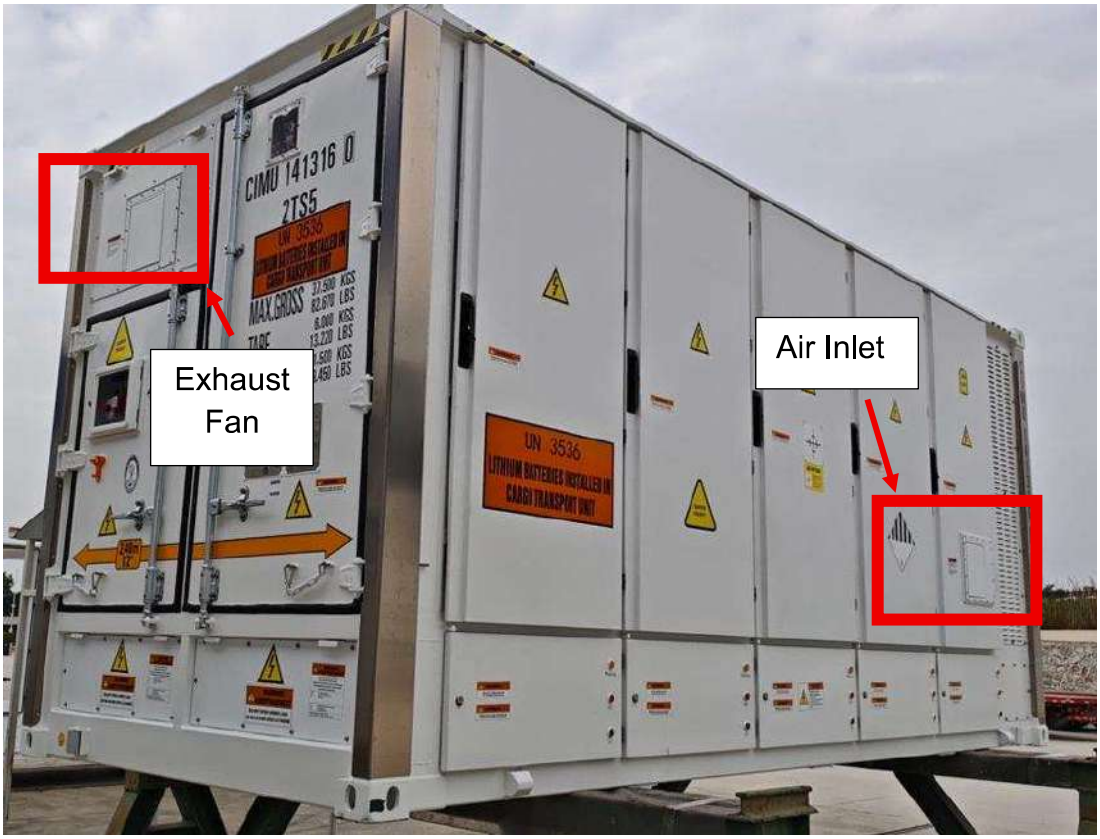

Figure 10 - CCR System Components

An NFPA 69 analysis report [14], performed by Atar Fire, LLC utilized a computational fluid dynamics (CFD) model. In the NFPA 69 report, a conservative gas release rate was derived from UL 9540A testing, coupled with conservative assumptions regarding static fan pressure loss, gas detection times, and fan start up delays and fan ramp up times. This conservative and layered approach allow for uncertainty in potential failure modes as well as modeling uncertainty. The NFPA 69 report concluded that the system effectively

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reduces the concentration of flammable gases below 25% of the LFL of the gas mixture. However, a partial deflagration hazard exists. As such, an NFPA 68 deflagration venting analysis was performed and is discussed later. An image of the model is shown as follows, demonstrating that gas released during thermal runaway travels from the worst-case release location to the exhaust fan location. In the following figure, the colored region indicates areas where gas concentration is greater than 25% LFL. This phenomenon is anticipated and expected, as gas concentrations will reduce from the point of release to the exhaust location.

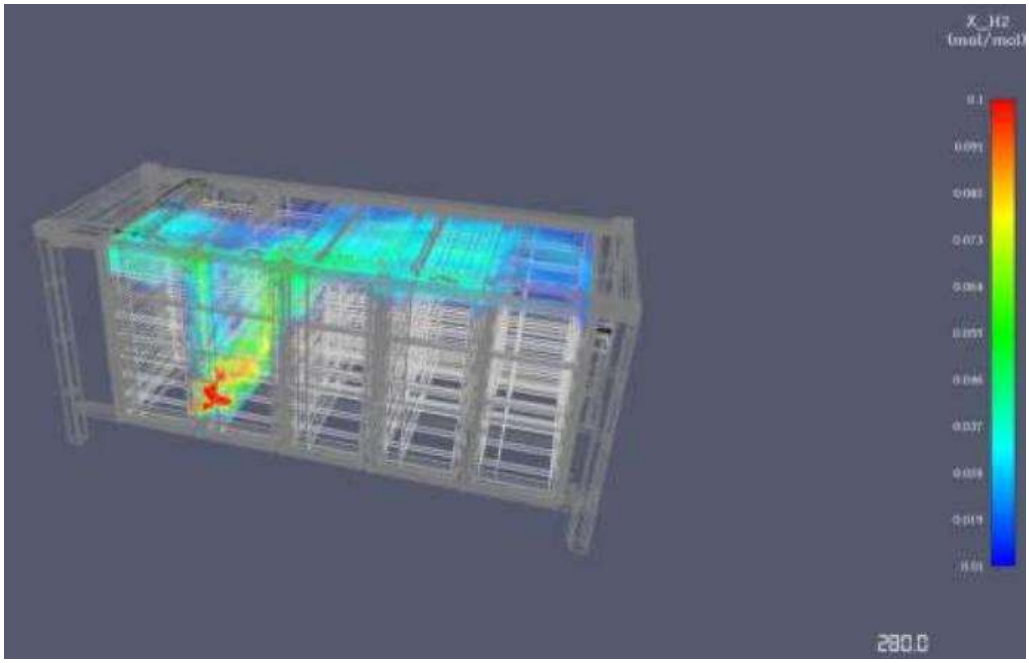

Figure 11 – System Model

The CCR system is provided with battery backup to meet the requirements of NFPA 855. A dedicated battery for the exhaust fan is provided for this purpose. Battery backup for the gas detector and associated equipment is provided by the fire alarm system battery backup. Calculations demonstrating that the included battery backup has a capacity that exceeds the power draw of the fan over the required duration were provided for review as part of this HMA. This review concluded that the provided backup battery exceeds the requirements of NFPA 855, §9.6.5.6.7, which requires 24 hours of standby power and 2 hours in alarm. The location of the backup power supply for the exhaust fan is as follows.

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Figure 12 - Battery Backup

According to CATL, the CCR system cannot be overridden and is designed to latch and requires manual reset once activated. This design ensures compliance with NFPA 855 (2026 Edition), §9.7.6.7.4.1 (A) and (B) which requires that suppression systems do not impede the operation of the CCR system. The gas detection system is configured to trigger the exterior horn/strobe. Signage should be provided to indicate the horn/strobe performs both fire alarm and gas detection functions.

FINDING 2: When installed in a specific site, the gas detection system should be configured to annunciate a trouble signal upon failure of the gas detection signal, as well as an alarm signal where hydrogen gas concentrations exceed 10 percent of the LFL. The signals should annunciate at an approved central, proprietary, or remote station in accordance with NFPA 72, or at an approved constantly attended location.

FINDING 3: The exterior horn/strobe should be provided with signage to indicate the dual purpose (such as 'FIRE ALARM AND GAS DETECTION') in line with the intention of IFC §916.9, where required by the local AHJ.

3) Explosion Control – NFPA 68 Deflagration Venting

The CATL EnerC 1P is provided with eight roof mounted deflagration vents. Each vent has dimensions of 0.6 m x 0.6 m [23.6 in. x 23.6 in]. The vent activation pressure is 0.1 bar-g.

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The deflagration vent design was assessed by Atar Fire [22] utilizing a partial volume deflagration approach. This approach is in line with the expectations of the 2026 NFPA 855 [26] §9.7.6.7.3, which states that a partial volume deflagration evaluation must be conducted where an NFPA 69 CCR system is present.

A computation fluid dynamics model using the software Flame Acceleration Simulator (FLACS) was utilized to assess the overpressures resulting from a partial volume deflagration, and the adequacy of the designed deflagration vents. The results of the NFPA 69 CCR system CFD model were used as input to the NFPA 68 CFD model to inform the partial volume approach. The NFPA 68 CFD model results indicate a potential overpressure of 0.14 bar-g during a partial volume deflagration. To take into account uncertainties, this value was doubled to 0.28 bar-g. When compared to the manufacturer provided enclosure strength of 0.64 bar-g (informed by a finite element analysis developed by CATL – this value was then reduced by a factor of 2/3 to 0.43 bar-g), the results demonstrated that the design complies with the intent of NFPA 68 and NFPA 855. In order for the NFPA 68 CFD model results to be valid, both the NFPA 68 and NFPA 69 systems must be properly maintained.

FINDING 4: The NFPA 68 deflagration vents must be always maintained free of snow or any other obstructions and inspected, tested, and maintained in accordance with NFPA 68.

FINDING 5: The NFPA 69 CCR system must be commissioned, inspected, tested, and maintained in accordance with NFPA 69.

4) Large Scale Fire Testing - Whereas the UL9540A cell, module, and unit reports [9][12] [13] indicate that thermal runaway of a single cell via overheating will not lead to fire, and the unit level test [13] indicated that maximum target unit temperature was 44 °C (far below the cell thermal runaway temperature of 161 °C), it is plausible that a fire could occur. A fire could result from other more severe methods of cell failure (internal short, unmitigated fire originating in other equipment, etc.), or from an external ignition source present in the final installation that may not have been present in the UL 9540A unit level test.

To assess the potential for fire propagation in the event of a fully developed fire in one enclosure, the CATL EnerC 1P underwent large scale fire testing. The large-scale fire testing was performed in Yichang, China. The test plan was developed and executed by UL Solutions to meet the draft large-scale fire testing requirements of UL 9540A [27] as well as the published version of CSA/ANSI C800:25 [28]. A review of the test plan, on site 3rd party test verification and witnessing, as well as reporting [23], was provided by Atar Fire, LLC.

In the large-scale fire test, three EnerC 1P enclosures were placed at the distances shown in the following figure. Within the initiating enclosure, enclosure A, thermal runaway was initiated, and the gases were ignited to create a fully developed fire. The test was

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performed to simulate a post deflagration event, in which the deflagration vent panels operated. A photo of enclosure A prior to the test, with the deflagration vents open, is also shown as follows.

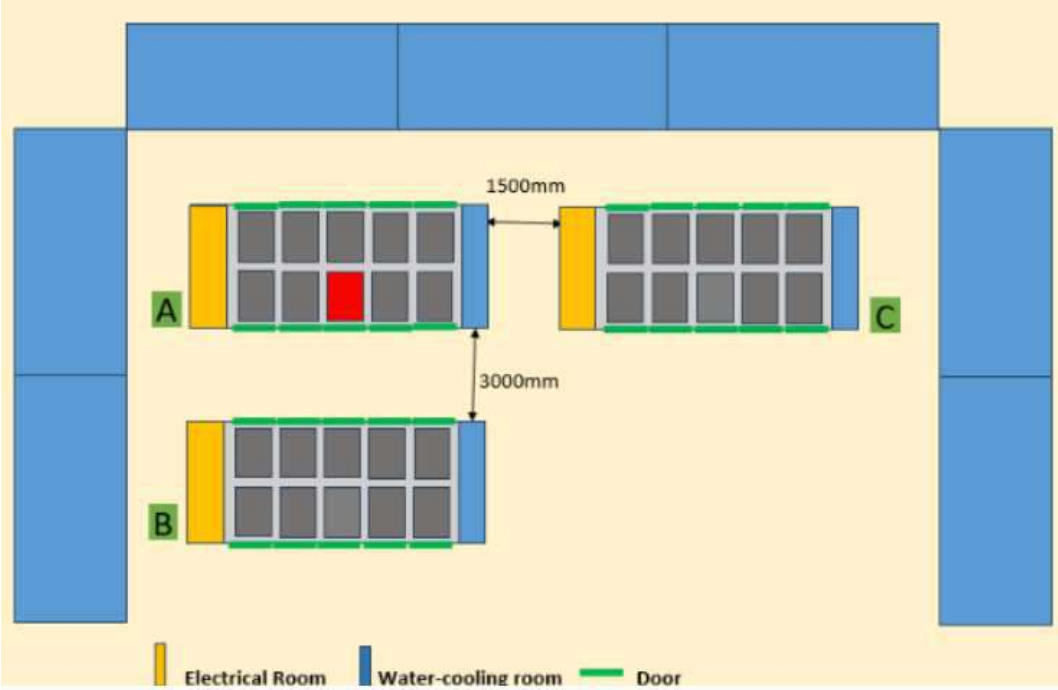

Figure 13 - Large Scale Fire Test Setup



Figure 14 - Enclosure A - Large Scale Fire Test

On-site witnessing by Atar Fire showed that a fully developed fire resulted in enclosure A and completely consumed all contents of the enclosure. The observed peak heat release rate was approximately 8 MW. No enclosure-to-enclosure fire propagation was observed.

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Atar Fire did observe a partial volume deflagration during the test, highlighting the need for appropriate emergency response preparedness.

When the EnerC 1P is installed in a specific site, the spacing between enclosures should be equal to or greater than the spacing in the large-scale fire test. It is recognized that the large-scale fire test cannot account for every situation that may arise in a real-world installation, including varied environmental conditions (wind, humidity, temperature).

FINDING 6: Ensure the emergency response plan highlights the potential for partial volume deflagrations and flying debris, as observed during large-scale fire testing.

FINDING 7: For site-specific installations, install EnerC 1P at distances equal to or greater than the large-scale fire test spacing. Incorporate any site-specific considerations for spacing into the final site design.

5) Thermal Insulation - The CATL Ener EnerC 1P is insulated with mineral wool. The thickness of the mineral wool is 1.57 inches (40 mm) The density is 7.49 pounds per cubic foot (120 kg/m^3). The mineral wool serves to reduce the temperature rise on the opposing side of the enclosure wall, minimizing radiant heat transfer to exposed enclosures. While large scale fire test data validates the as-installed performance of the enclosure wall construction, this section provides a review of the mineral wool insulation as it pertains to anticipated fire resistance.

Prescriptive fire resistance recommendations generally attribute approximately fifteen minutes for the presence of mineral wool. For example, 2021 IBC Table 722.6.2 (5) [15], and the SFPE Handbook [16] provides for a 15-minute allowance, where placed between wood studs, with a mineral wool density of 2 pounds per cubic foot (36 kg/m^3). The density of the mineral wool in the CATL EnerC 1P is more than three times higher, at 7.49 pounds per cubic foot (120 kg/m^3). Fire resistance ratings are typically achieved in a furnace according to test methods such as UL 263 [17] by measuring the unexposed back side temperature of the wall under furnace thermal exposure, such that the unexposed temperature is no greater than 250 °F (120.1 °C). This is less than the vent temperature of the cells in the CATL EnerC 1P of 322 °F (161 °C). It is recognized that a battery fire will not follow the same time temperature curve as a UL 263 fire test; however, this standard methodology has been utilized for decades in in building and fire codes as a means of describing passive fire resistance.

To further explore the fire resistance of the enclosure walls past theoretical calculations, CATL had the wall tested by a testing laboratory [21] in accordance with GB/T 9978.1-2008. This Chinese test standard is based on the same time-temperature curve used in UL 263. The test included a 0.157 inch (4mm) thick metal plate in addition to 1.57 inches (40 mm) of insulation. The test concluded that the after a 60-minute exposure in accordance with the prescribed time temperature curve, the average temperature rise on the unexposed side of the wall was 259.9 °F (126.6 °C), while the maximum observed

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temperature rise on the unexposed side was 302.7 °F (150.4 °C). The report indicates a 60-minute fire resistance rating is achieved.

While this analysis and testing provide confidence that the walls of the enclosure can achieve a one-hour fire resistance rating, and this time duration is well within the typical response time of most fire departments, the large-scale fire testing should be relied on. The large-scale fire test represents an as-installed condition and potential real-world fire conditions. In addition, the burn duration for the large-scale fire test exceeds the one-hour furnace test. This analysis of the thermal insulation is provided to ensure the HMA is thorough, complete, and fully assesses all mitigating measures.

6) Fire Detection: The CATL EnerC 1P is provided with two smoke detectors within the main battery enclosure and one smoke detector for protection of the electrical distribution cabinet. The main battery enclosure is also protected by two heat detectors. The supplied smoke detectors are built by Potter Electric Signal Co LLC, Model PAD-300-PD. The smoke detectors are listed to UL 268. The supplied heat detectors are built by Potter Electric Signal Co LLC, Model PAD-300-HD. The heat detectors are listed to UL 521. The exterior horn strobe is a Potter HS-24WR-WP. This is a weatherproof model and is listed to UL 464.

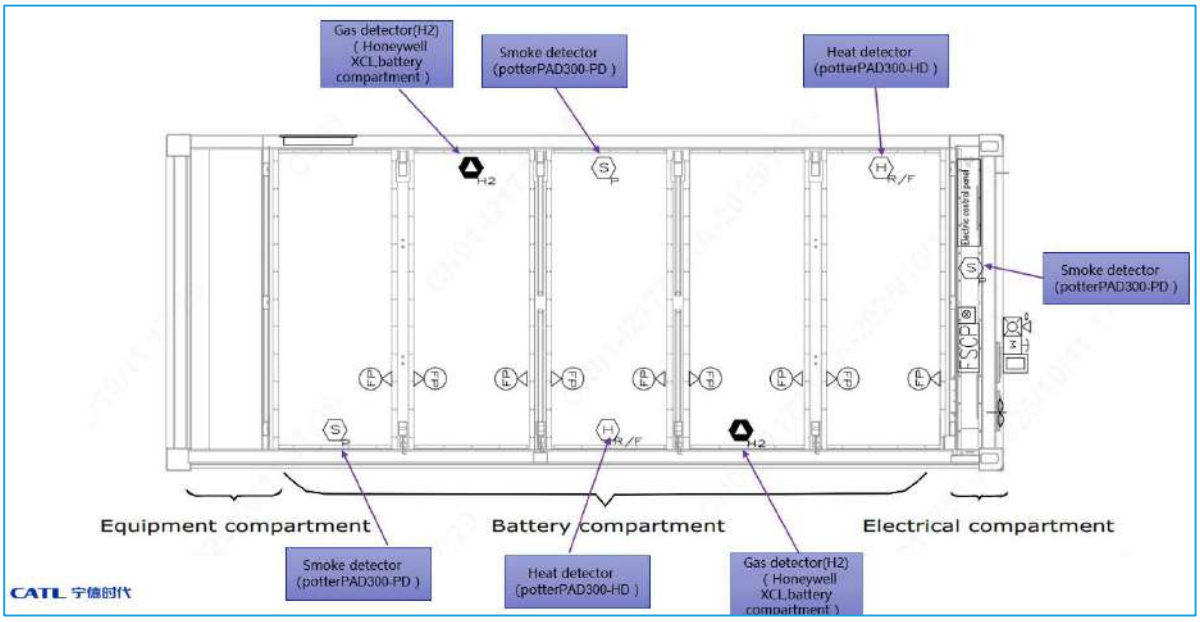

Figure 15 - Fire Alarm and Gas Detection Device Locations

In the event of a fire, the detection system will sense smoke/heat, send a signal to the included fire alarm control panel, and notify the responding fire department. The fire alarm control panel is a Potter ARC-100. As part of this HMA, this product was confirmed to be UL 864 listed. For a multi-enclosure installation, panels should be aggregated at a central master panel on a project specific basis, in accordance with NFPA 855 §4.8.2. The activation of any detection device will initiate an exterior horn/strobe.

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The fire detection system, aerosol generators (optional – where included), and gas detectors, and all ancillary components (horn/strobe, modules, relays, etc.) are provided with battery backup in excess of NFPA 855 requirements of 24 hours in standby and 2 hours in alarm. Two 20 Ah dedicated batteries are provided to meet the calculated required capacity of approximately 14.6 Ah. Battery backup calculations were verified as part of this HMA. The battery backup is co-located with the fire alarm control panel.

7) Water Supply: Where provided on a project specific basis, water supply can be utilized by the responding Fire Department protect adjacent exposures in the event of fire.

8) Facility Staff Planning, Training and Emergency Response: Facility staff for each specific installation should be familiar with the ESS, the overall installation, and understand roles, responsibilities, and emergency procedures. Furthermore, emergency responders must be trained in a site-specific manner for installations. Through the development of site-specific response plans and training for facility staff and first responders, appropriate actions can be taken during an incident, and risk to personnel and responders can be mitigated. All facility staff and responders should be trained in the potential explosion and fire hazards of ESSs, including specific training of the equipment onsite. All responders must be trained to never open cabinet doors in an emergency unless it is confirmed there is no flammable gas present.

   Current best practices for responders suggest that simply letting the fire burn itself out while cooling exposures is the safest response. This approach is codified in the 2024 Emergency Response Guidebook, Guide 147 – Lithium-Ion Batteries [11].

   FINDING 8: Develop an Emergency Operations Plan for facility staff for each site. Develop an Emergency Response Plan for first responders for each site. Provide training for all potential first responders (this could include Fire Department, Emergency Management, Law Enforcement, or other entities), and facility staff. Plans and training should adhere to NFPA 855 and the IFC.

9) Fire Suppression and Control: Within the context of NFPA 855, fire suppression and control encompass both fire sprinkler systems as well as fire extinguishing systems.

   NFPA 855 does not require fire suppression and control for outdoor, non-occupied ESS enclosures (see NFPA 855 §4.9). Fire suppression and control is typically required for buildings and occupied spaces. The CATL EnerC 1P is not occupied and is not a building (see 2024 IBC §3114 regarding intermodal shipping containers).

   The CATL EnerC 1P is provided with an optional fire extinguishing system, which includes nine aerosol units. The optional aerosol system is triggered by the activation of both a heat detector and a smoke detector (two inputs required).

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It is widely recognized that fire extinguishing agents will not stop thermal runaway [20]. This is because extinguishing agents, while they are expected to extinguish a flaming fire, may not stop thermal runaway or cell to cell propagation. Should cell to cell propagation continue in the absence of fire, flammable gases may accumulate in the enclosure, and lead to an explosion risk. The extinguishing system is anticipated to extinguish non battery fires originating in electrical equipment. To address the potential explosion hazard, the optional aerosol system is designed such that it will not override any function of the NFPA 69 CCR system. If the CCR system is activated, it will continue to run until manually reset, even if the extinguishing system also activates. Should the optional aerosol system override the CCR system, the conclusions of this HMA are no longer valid, as this could create an explosion hazard.

The cumulative mitigating measures discussed above that serve to both 'prevent fire ignition' and 'manage fire impact' of a thermal runaway event are visually demonstrated on an NFPA 550 fire safety concepts tree as follows on the next page.

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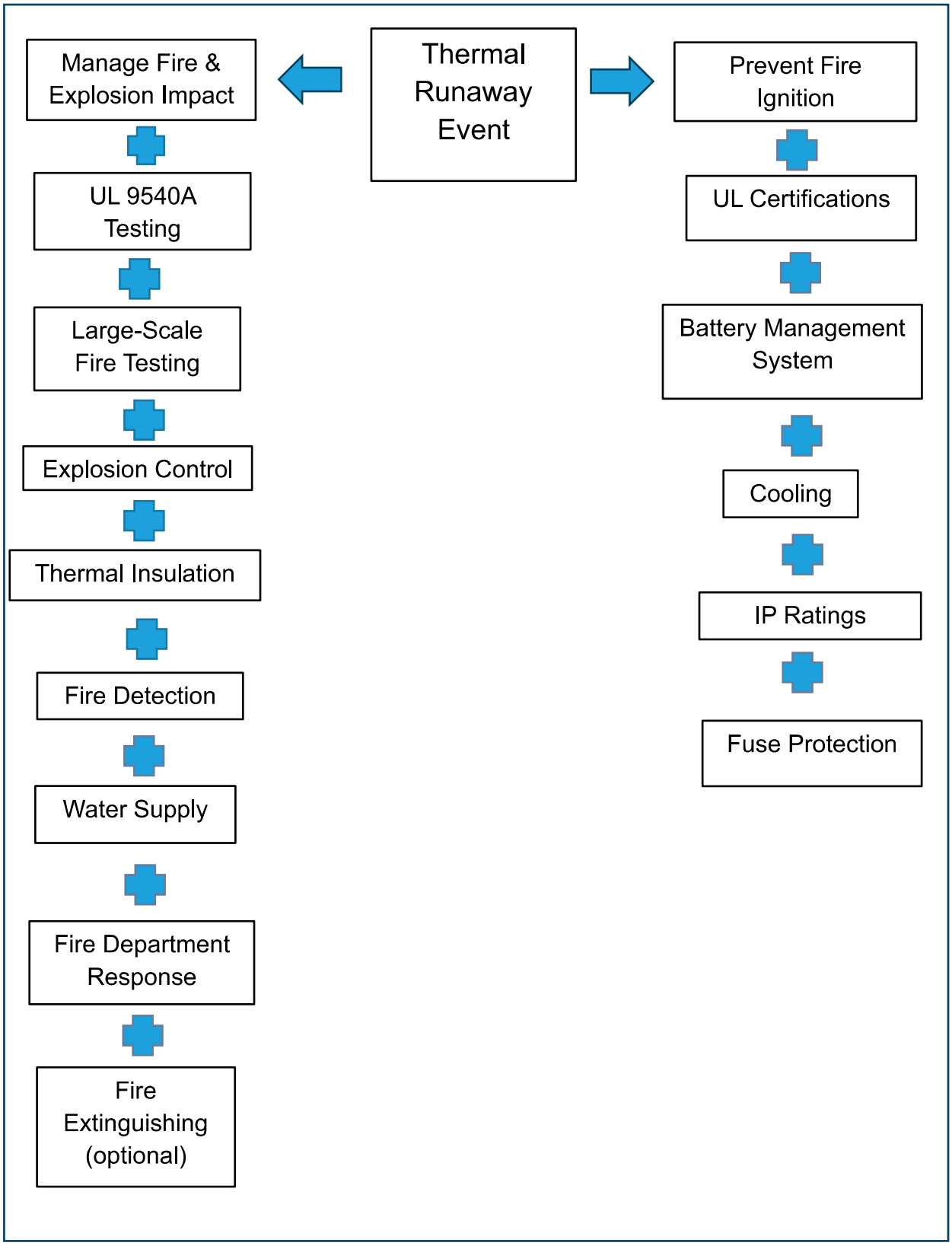
Figure 16 - NFPA 550 Fire Safety Concepts Tree - Thermal Runaway Event



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Fault Condition 2

Failure of an energy storage management system or protection system that is not covered by the product listing failure modes and effects analysis (FMEA).

Discussion: The battery management system (BMS) is designed to monitor temperature, voltage, and current of the batteries, and to shut down the system as appropriate if any of these variables are outside the acceptable range. The BMS is designed to prevent thermal runaway from occurring. It is not intended to control the response to thermal runaway. If the BMS fails to detect a variation in any of these metrics or fails to shut down the system appropriately, the battery may enter thermal runaway. The BMS has been evaluated as part of the UL 9540 certification, functional safety analysis, and associated FMEA [19] [31].

Should the BMS fail, the additional mechanisms described in the fire safety concept tree for preventing fire ignition would take precedent. In the event that these protective mechanisms also fail, thermal runaway could occur. Should thermal runaway occur, the mitigating measures shown in the fire safety concepts tree for managing fire and explosion impact would prevail. All passive engineered mechanisms for limiting incident hazard, such as the deflagration venting system, thermal insulation, and installation spacings validated by large scale fire testing, will function as designed during BMS failure. In addition, active systems including the CCR system and the optional aerosol extinguishing system are independent of the BMS. They will continue to function in the event of a BMS failure.

Fault Condition 3

Failure of a required protection system including but not limited to ventilation (HVAC), exhaust ventilation, smoke detection, fire detection, fire suppression, or gas detection.

Discussion: In the unlikely scenario that the liquid cooling system fails, this condition would be detected by the battery management system. The BMS includes multiple types of checks of the thermal management system, including communication faults, communication warnings, and two fault levels. When the battery management system detects an off-normal condition in the liquid cooling system, it places the EnerC 1P in a power off state. Should cells ultimately be subject to extreme temperatures to the point that thermal runaway does occur, the mitigating measures shown in the fire safety concepts tree for managing fire and explosion impact would prevail. All passive engineered mechanisms of limiting incident hazard, such as the deflagration venting system, thermal insulation, and installation spacings validated by large scale fire testing, will function as designed during failure of any of the cooling systems.

In the scenario in which active fire protection equipment fails, which could include the NFPA 69 CCR, fire detection, as well as the optional aerosol fire extinguishing system (only single failure modes are considered by NFPA 855), the BMS and liquid cooling system would continue to function and preclude thermal runaway incidents. Additionally, other mitigating measures such as passive deflagration vents, thermal insulation, and installation spacing validated by large scale fire testing would remain in service. According to CATL, the BMS is independent of the NFPA 69 CCR system, fire detection system, and optional aerosol fire

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extinguishing system. If components of the fire protection systems fail (e.g., smoke detector or suppressant system failure), the fire alarm system will still register the system failure and report a trouble signal to the supervising station. Should the CCR system components fail, other active mitigating measures, such as the BMS and liquid cooling would remain in effect. On the whole, multiple independent safety mechanisms are in place.

Summary of Fault Conditions

Table 3 - Fault Condition Summary

Fault Condition	Comments
Thermal runaway or mechanical failure condition in a single ESS unit	A variety of active and passive measures are built into the CATL EnerC 1P to reduce the potential of thermal runaway. These include UL 9540 and UL 1973 product certifications, BMS control, liquid cooling, enclosure humidity control, enclosure and module IP rating, and electrical fuse protection. Should thermal runaway occur, mitigating measures are provided to reduce the impact of an incident. These mitigating measures are described in this HMA. See 'Manage Fire and Explosion Impact' in the NFPA 550 Fire Safety Concepts Tree.
Failure of an energy storage management system or protection system that is not covered by the product listing failure modes and effects analysis (FMEA).	In the vent of failure of the BMS, additional mitigating measures remain in place as shown in 'Prevent Fire Ignition' in the NFPA 550 Fire Safety Concepts Tree. Should thermal runaway occur, mitigating measures are provided to reduce the impact of an incident. These mitigating measures are described in this HMA. See 'Manage Fire and Explosion Impact' in the NFPA 550 Fire Safety Concepts Tree.
Failure of a required protection system including, but not limited to, ventilation (HVAC), exhaust ventilation, smoke detection, fire detection, fire suppression, or gas detection.	The CATL EnerC 1P is provided with an NFPA 69 CCR system (including gas detection and exhaust ventilation) and a fire detection system. Should either system fail, trouble notifications are required by code so that the situation can be corrected. The EnerC 1P does not rely on fire extinguishing systems, and fire propagation potential has been validated by large scale fire testing. Should one of these systems be in a failed state while an incident occurs, multiple additional mitigating measures are provided to reduce the impact of an incident. These mitigating measures are described in this HMA. See 'Manage Fire and Explosion Impact' in the NFPA 550 Fire Safety Concepts Tree.

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8.0 Layers of Protection Analysis

In order to provide for a simplified risk assessment using semi-quantitative data, Atar Fire performed a Layers of Protection Analysis (LOPA). LOPA is a methodology that was originally published by the Chemical for Center Process Safety (CCPS) in 2001. LOPA can be utilized to assess if the safeguards and barriers provided lead to an acceptable level of risk, by treating each layer as an independent layer of protection. For this analysis, initiating event frequencies for failure mechanisms and probability of failure on demand (PFD) for each safeguard were derived from CCPS's *Layer of Protection Analysis: Simplified Process Risk Assessment* [29].

PFDs describe the probability that a safeguard will not activate when needed. The following table includes published PFD data for safeguards identified for the CATL EnerC 1P. Each of these is analyzed as an independent layer of protection.

Table 4 - Probability of Failure Upon Demand

Safeguard Type	Safeguards	PFD (per year) [29]
Mechanical Failure	Passive Fuse Protection	0.1
Safety System	Deflagration Vent	0.01
Safety Systems	Thermal Management System Battery Management System Gas Detection/Ventilation	0.1

Initiating event frequencies (IEFs) estimate the likelihood of an event occurring. Published initiating event frequencies that could lead to a fire or explosion are as follows:

Table 5 – Initiating Event Frequencies

Failure Type	Description	Frequency per year [29]
Mechanical Failure	Damage due to impact during maintenance or transport	0.01
Electrical Failure	Undercharge or overcharge	0.01 [30]
Mechanical Failure	Manufacturing Defect	0.01
Thermal Failure	Overheating	0.1
Human Error	Issues during commissioning, maintenance, etc.	0.01

CCPS recommends the likelihood of exposure to a worker and the public be estimated using IEFs, PFDs, probability of an exposure, and presence factors. The likelihood of an exposure was first calculated without any safeguards present. Two calculations are presented. One for a facility

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worker (utilizing a presence factor of 10%), and one for the public (utilizing a presence factor of 100%).

A presence factor of 10% was used in reference to a worker being present at the ESS. A presence factor of 100% was used for the public (i.e., on- and off-site communities surrounding an installation). The likelihood of an exposure without safeguards was calculated for the worker and the public using the following equations and initiating event frequency values:

Likelihood of exposure without safeguards = IEF x Presence Factor x Probability of Exposure

Likelihood of facility worker exposure without safeguards = (0.1 to 0.01) x 0.1 x 1 = 10^{-2} to 10^{-3}

Likelihood of public exposure without safeguards = (0.1 to 0.01) x 1 x 1 = 10^{-1} to 10^{-2}

The likelihood of failure leading to an exposure of a facility worker or the public accounts for initiating event frequencies, PFDs, presence factors, and probability of an exposure. The final likelihood of exposure is calculated by multiplying the likelihood without safeguards with the PFDs as shown below.

Likelihood of worker exposure without safeguards = Likelihood of worker exposure without safeguards x PFD1 x PFD2 x PFDn = (10^{-2} to 10^{-3}) x (10^{-6}) = 10^{-8} to 10^{-9}

Likelihood of public exposure without safeguards = Likelihood of public exposure without safeguards x PFD1 x PFD2 x PFDn = (10^{-1} to 10^{-2}) x (10^{-6}) = 10^{-7} to 10^{-8}

The local jurisdiction can be consulted on typical risk acceptance thresholds. Because a full evaluation of risk includes both likelihood of failure (calculated here) and consequences (not considered here), the consequences should be evaluated based on local needs. The LOPA analysis provided here demonstrates that with the safeguards implemented for the EnerC 1P, the likelihood of exposure is greatly reduced.

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9.0 Engineering Analysis, Judgment, and Conclusion

A hazard mitigation analysis has been developed for the CATL EnerC 1P in compliance with the 2023 Edition of NFPA 855. Based on a review of the overall product design, and when installed in accordance with NFPA 855, locally adopted requirements, and the Findings of this HMA, the CATL EnerC 1P can be safely installed within an outdoor environment. The following table summarizes the required approval conditions and results of the evaluation:

Table 6 - HMA Approval Conditions

HMA Approval Conditions Summary		
Approval Condition	**Code Section**	**Results**
Fires will be contained within unoccupied ESS rooms for the minimum duration of the fire resistance rating specified in Section 9.6.4.	NFPA 855 §4.4.3 (1) IFC §1207.1.6.2 (1)	The CATL EnerC 1P is intended for outdoor installations.
Fires and products of combustion will not prevent occupants from evacuating to a safe location.	NFPA 855 §4.4.3 (2) IFC §1207.1.6.2 (1)	The CATL EnerC 1P is not intended for indoor installations and is for outdoor installations only. Occupants in the vicinity of the outdoor installation will be capable of evacuating the area to a safe location.
Deflagration hazards will be addressed by an explosion control or other system.	NFPA 855 §4.4.3 (3)	NFPA 68 & 69 explosion control systems have been provided to address deflagration hazards.

A number of findings have been generated as a result of this HMA:

FINDING 1: There is no overcurrent protection on the DC side. This needs to be added externally. The AC input to the control loop requires an external manual switch as a maintenance switch. These items are required by the UL 9540 certification report [33].

FINDING 2: When installed in a specific site, the gas detection system should be configured to annunciate a trouble signal upon failure of the gas detection signal, as well as an alarm signal where hydrogen gas concentrations exceed 10 percent of the LFL. The signals should annunciate at an approved central, proprietary, or remote station in accordance with NFPA 72, or at an approved constantly attended location.

FINDING 3: The exterior horn/strobe should be provided with signage to indicate the dual purpose (such as 'FIRE ALARM AND GAS DETECTION') in line with the intention of IFC §916.9, where required by the local AHJ.

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FINDING 4: The NFPA 68 deflagration vents must be maintained free of snow at all times and inspected, tested, and maintained in accordance with NFPA 68.

FINDING 5: The NFPA 69 CCR system must be commissioned, inspected, tested, and maintained in accordance with NFPA 69.

FINDING 6: Ensure the emergency response plan highlights the potential for partial volume deflagrations and flying debris, as observed during large-scale fire testing.

FINDING 7: For site-specific installations, install EnerC 1P at distances equal to or greater than the large-scale fire test spacing. Incorporate any site-specific considerations for spacing into the final site design.

FINDING 8: Develop an Emergency Operations Plan for facility staff for each site. Develop an Emergency Response Plan for first responders for each site. Provide training for all potential first responders (this could include Fire Department, Emergency Management, Law Enforcement, or other entities), and facility staff. Plans and training should adhere to NFPA 855 and the IFC.

Any installation of these systems must be reviewed in accordance with the locally adopted Codes and Standards, including local amendments thereto, with appropriate construction and operational permits obtained from the local jurisdiction.

It is strongly recommended that any installation of any ESS equipment be closely collaborated with the local jurisdiction, with preliminary discussions preceding site development consideration. As the Codes and Standards regulating ESS installations evolve, local requirements and interpretations of the IFC, CFC, NFPA 855 and other documents may place additional requirements or burdens upon the installation team that have not been considered herein.

Whereas no general review of an ESS can address all possibly risks or hazards, it is our professional engineering opinion that the CATL EnerC 1P system can be installed and perform safely, and in a code-compliant manner where all applicable Codes, Standards, Amendments, and other legal requirements are employed, and where properly commissioned and maintained.

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Appendix I

SHORT CIRCUIT STUDY

This Appendix is protected under a confidentiality agreement and has been redacted from this version of the report.