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UL9540A Unit Level Test Report

Final Report
Fireaway Inc.

ESS & Stat-X FSS

Report No.: R5097D-1

Date: 30 August 2021



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Project No.:	5097

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Revision	Date	Reason for Issue	Prepared by	Verified by	Approved by
1	30 August 2021	Initial Draft	Beryl Weinshenker	John Watts	John Watts

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1 Test setup

1.1. Introduction

The following is a test report on the UL9540A (Edition 4, dated November 12, 2019) Unit Level testing performed on 14 May 2021. The test was performed at 9300 OH-66, Piqua, Ohio 45356 on a mock-up of a Battery Energy Storage Solution (BESS) fitted with the Fireaway Stat-X fire suppression system (FSS). An excerpt of the NRTL Report is included in Section 2.2 of this Report. The NRTL Report indicates the test was in accordance with UL9540A Section 9.3, as well as the additional measurements detailed in Section 1.5.1.

This Report defines: the BESS and FSS tested, the construction of the mock-up BESS enclosure, gas measurement equipment, electrical measurement equipment, and test procedures. The actual energy storage solution is a standalone BESS packaged in a “20ft Hi-Cube” shipping container (exterior dimensions: 20’x8’x9.5’). An image of the representative BESS solution is shown in Figure 1 below as reference.



Figure 1 Battery Energy Storage Solution

Please note that in an effort to improve accuracy, the mock-up BESS test enclosure was approximately half the 20ft Hi-Cube length.

As indicated in Section 2 of this Report, the Stat-X FSS provided fire suppression from 2,726 seconds (FSS discharge) to 3,015 seconds (enclosure ventilation). During this time, the FSS seemed to inhibit any flaming combustion, and no temperature spikes were observed.

This Report includes the NRTL Report’s compliance tables in Section 2.2, with maximum gas concentrations listed towards the end of Section 2.2.

PVEL notes that at 3,015 seconds the enclosure was ventilated “when a potential of explosion [was] observed within the testing enclosure with high concentration[s] of vented gases”.

Figure 2 details the battery modules in the BESS rack assemblies. Figure 3 details the battery modules in the mock-up test enclosure.

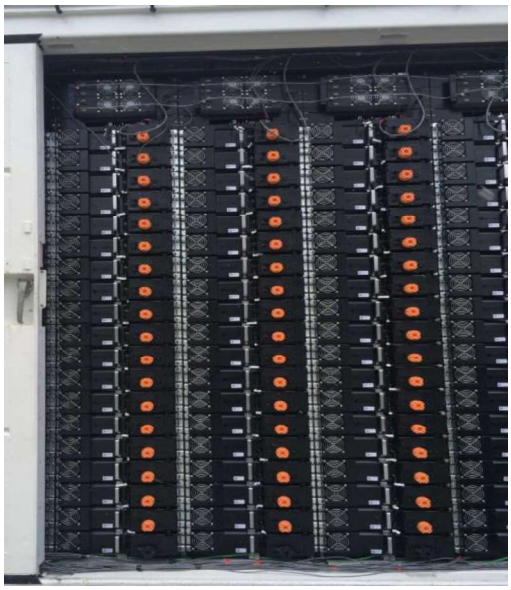


Figure 2 BESS rack/module assembly (19 modules and 2 BPU converters per rack)

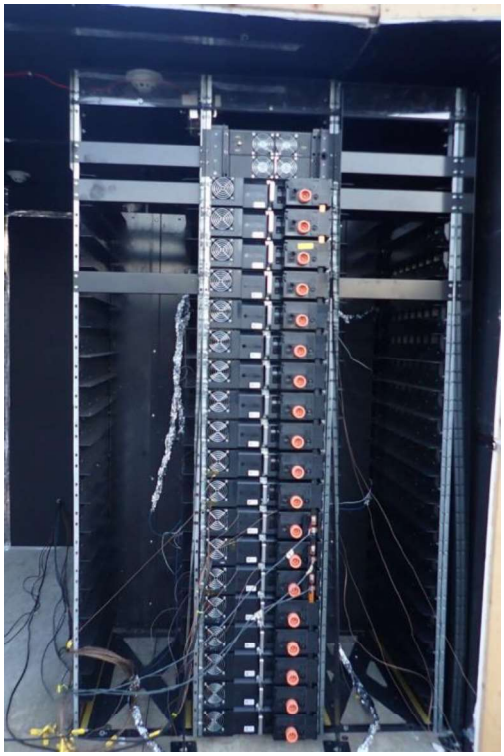


Figure 3 Test enclosure's rack/module assembly (initiating rack and adjacent target racks)

1.2. Product Specifications

The following lists the technical specifications of the components evaluated by the UL9540A test.

1.2.1. Cells [redacted] Pouch Lithium Li-ion chemistry (NMC)

The cells tested have the following technical specifications:

- Voltage = 3.67 V (nominal)
- Capacity = 72.5 Ah
- Mass = 1170 g (2.6 lbs)
- Dimensions = 100 mm x 353 mm x 16 mm

Figure 4 shows the film heater attached to the [redacted] cell.



Figure 4 [redacted] Cell with Installed Flexible Film Heater

1.2.2. Modules

The modules tested include (42) [redacted] cells and have the following technical specifications:

- Voltage = 51.8 V
- Capacity = 290 Ah
- Mass = 88.6 kg (195 lbs)
- Dimensions = 445 mm (without mounting bracket) x 979 mm (with MSD plug) x 110 mm.

Figure 5 shows a rendered image of the [redacted] module.

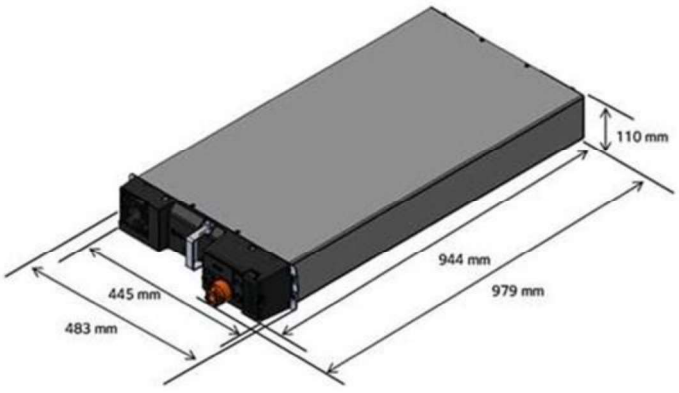


Figure 5 [redacted] Module

1.3. Racks

Each rack contains 19 [redacted] modules. In order to account for the various racking layouts in a deployed BESS, the racks in the test enclosure were configured as 3-linked rack configuration abutting and centered behind a single rack. The center rack of the 3-linked rack is the initiating rack, and the other racks are the target racks. Figure 6 shows this rack configuration.

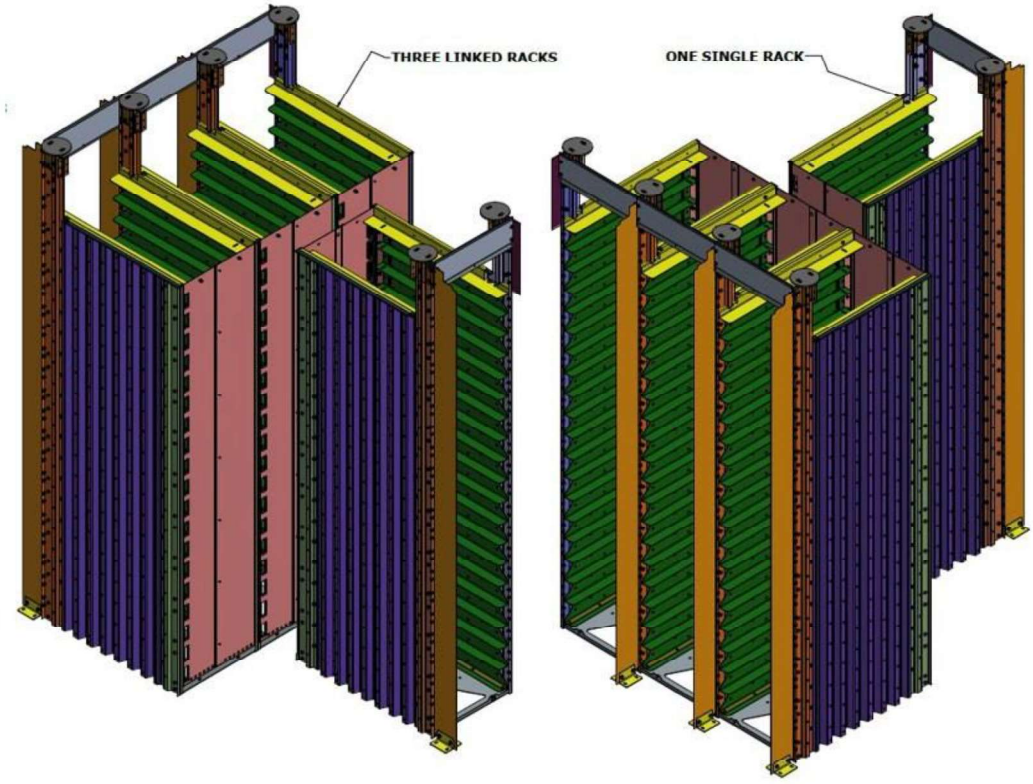


Figure 6 Rack layout from front side (right) and back side (left)

The dimensions of the racks are as follows:

- Width = 1568 mm (61 ¾”) (for the 3-linked)
- Height = 2614 mm (102 15/16”)
- Depth = 911 mm (35 7/8”)

1.3.1. Fire Suppression System

- Stat-X® Aerosol Fire Suppression System
  - Potter Electric PFC-4410RC fire alarm control panel
  - Potter manual release pull station
  - Stat-X model = 500E
  - Number of Stat-X model 500E devices = 4
  - Locations of Stat-X model 500E devices = See Figure 7 below

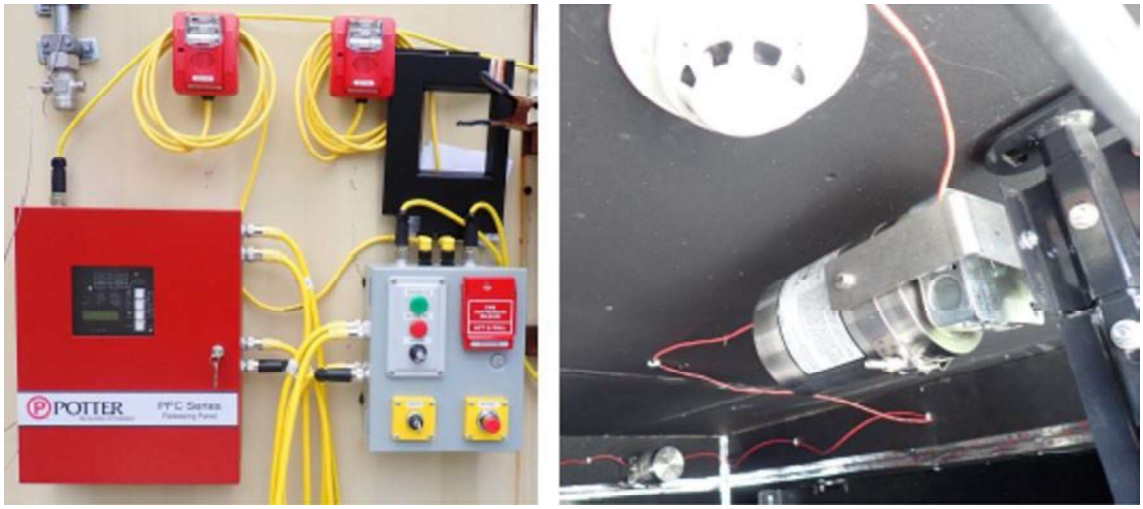


Figure 7 Integrated Stat-X fire suppression system. Stat-X monitoring and activation system (left). Stat-X generator and smoke detector (right).

  - Aerosol Mass = 500g
  - Weight = 3.4 kg ±5%
  - Total Length = 205 mm (including the ¾" threaded coupling)
  - Diameter = 127 mm
  - Approximate Discharge Time = 23.0 seconds
  - Initiation current = 0.5 amps in parallel; 1.0 amps in series
  - Releasing circuit pulse = 50 milliseconds
  - Maximum Supervisory Current = 0.005 amps (on release circuit)

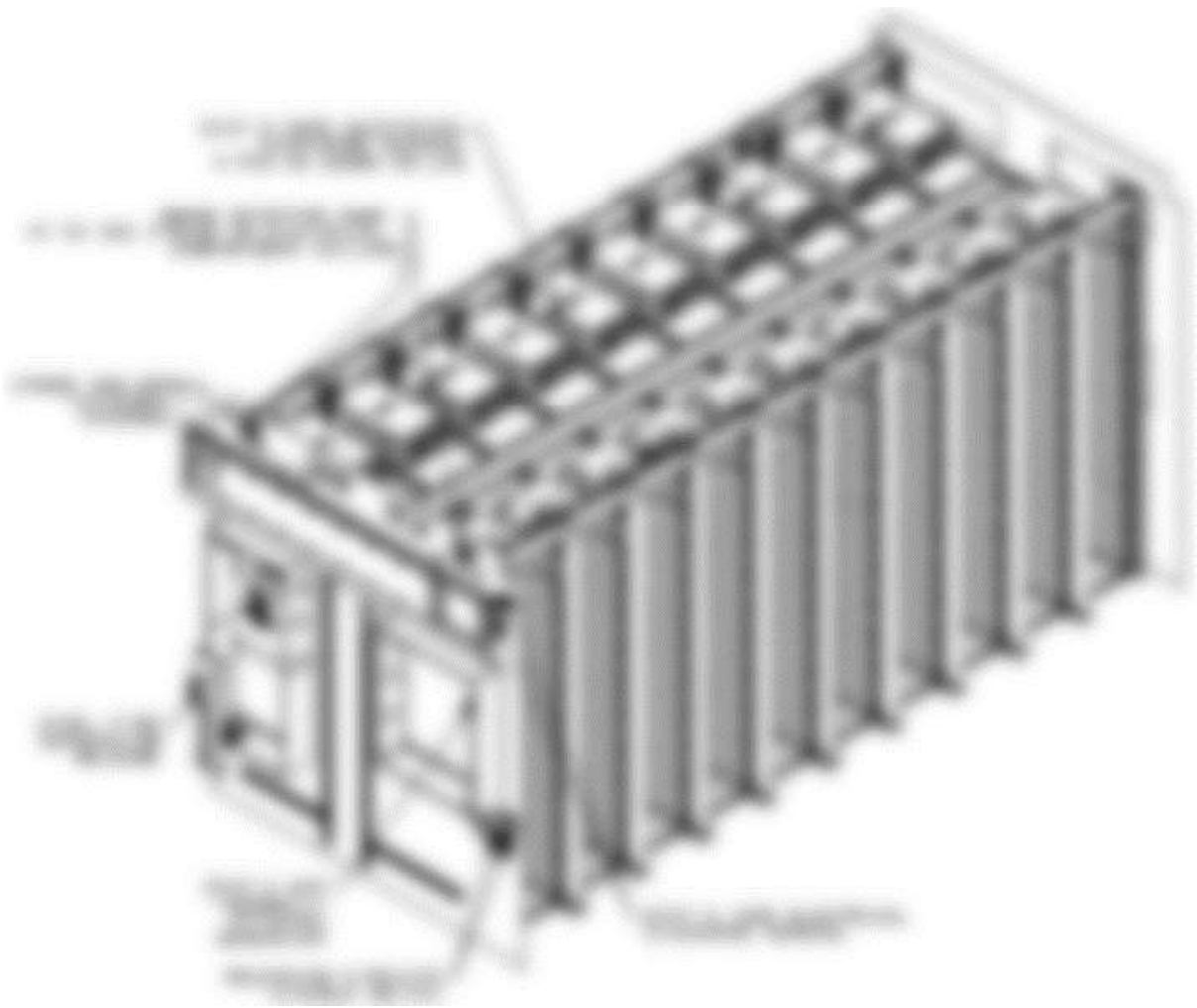


Figure 8 Stat-X Aerosol Fire Suppression Layout in an actual BESS application (test enclosure was half the length)

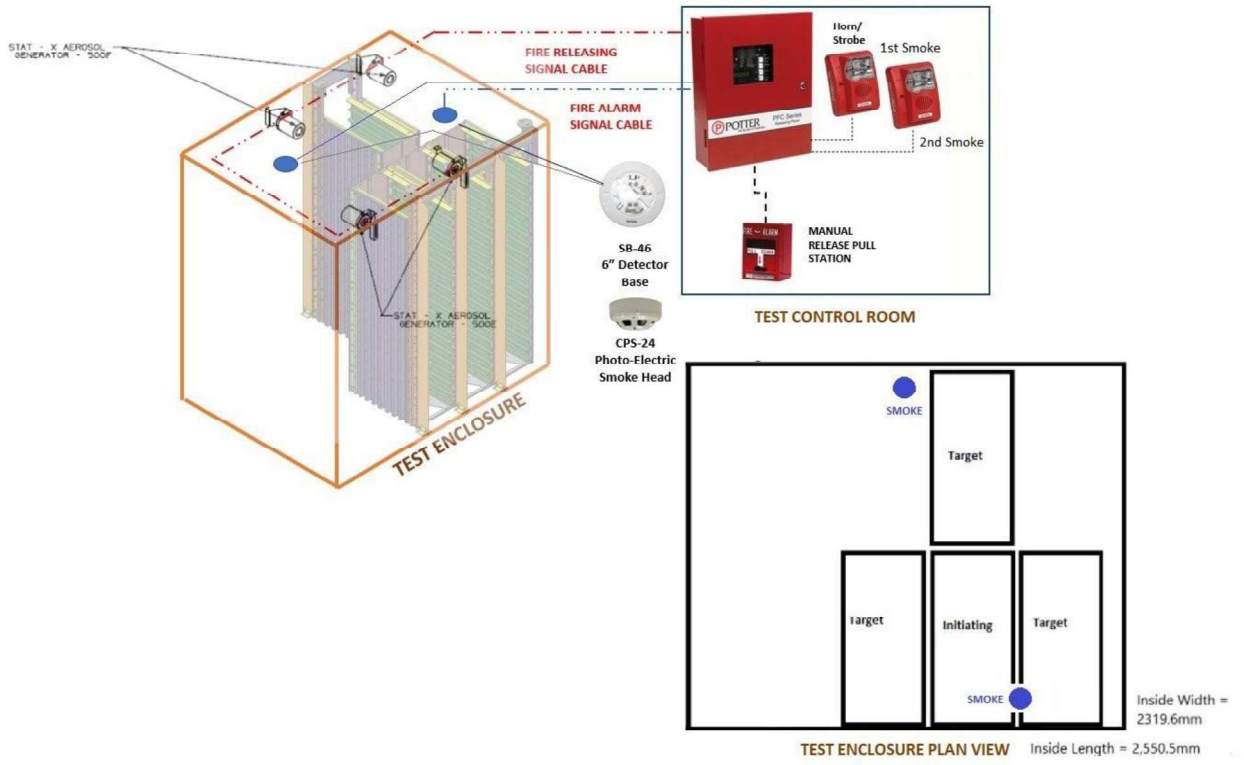


Figure 9 Stat-X Aerosol Fire Suppression Layout within the mock-up test enclosure

1.4. Definition of Unit and Test Philosophy

The BESS racks are capable of interlocking side to side as well as back-to-back. For this unit level test, the testing team installed 19 modules with 2 BPU converters in the center rack (initiating rack), and adjacent unpopulated target racks on each side. In addition, an unpopulated single rack was intertied to the initiating rack in a back-to-back fashion. The unpopulated target racks used sheet metal instead of modules.

All modules in the initiating rack were topped off at MOSOC within 8 hours of the testing start time. The initiation method was film heaters on the initiating cell inside the module. The initiating rack contained 19 modules. Monitoring equipment was installed as per UL9540A in all target units.

1.5. Unit Level Test Configuration

The unit level testing required construction of one mockup test enclosure intended to simulate a real-world application, and in which an internal fire condition was initiated. The mock-up enclosure also included target racks that were representative of adjacent racks in a BESS installation. The mock-up test enclosure was built as per the detailed container dimensions provided by [redacted] provided.

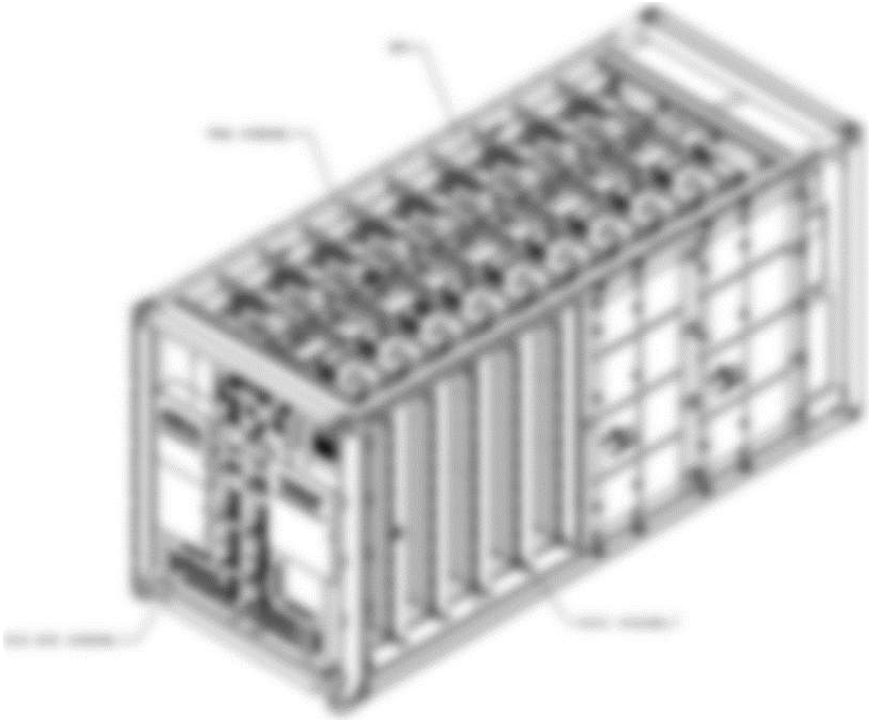


Figure 10 BESS container – isometric view (actual container shown; test enclosure will be half the length)

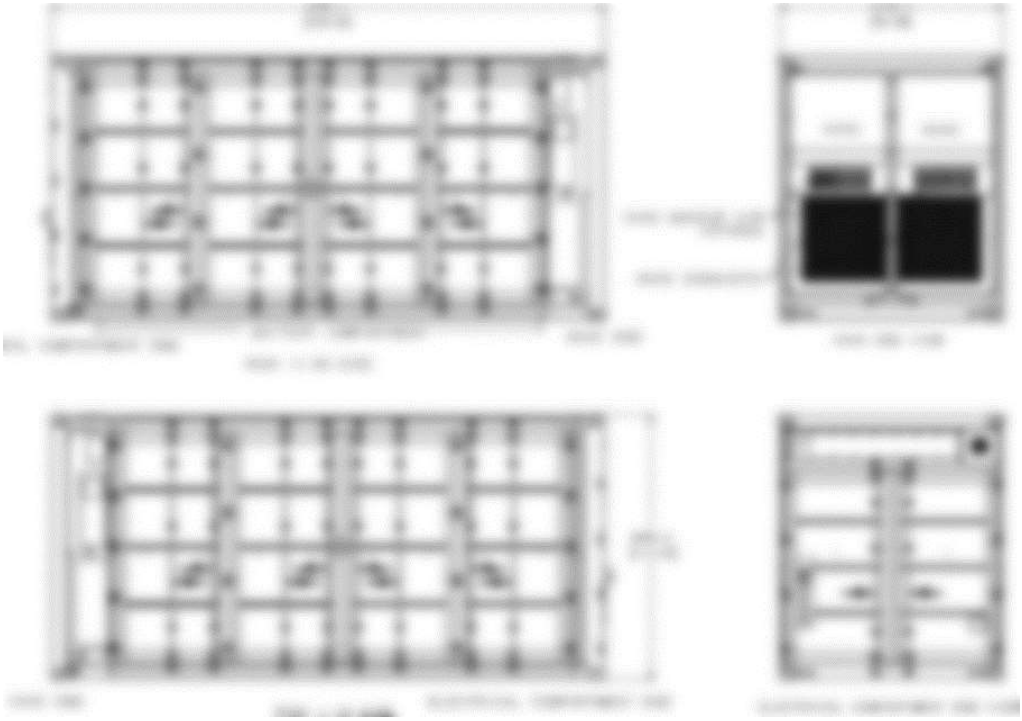


Figure 11 Actual BESS Container Exterior Dimensions (actual container shown; test enclosure will be half the length)

To accomplish the BESS Unit Level Testing, the configuration shown in Figure 12 was utilized.

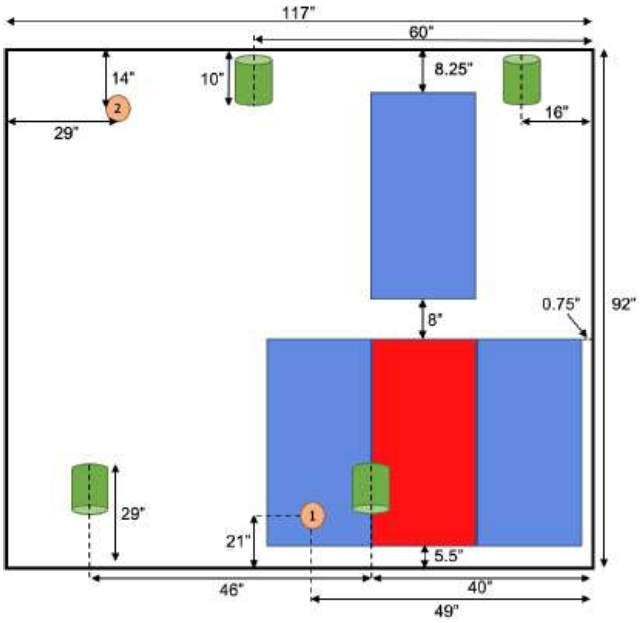


Figure 12 Test enclosure plan view. Initiating unit (red), target units (blue), Stat-X aerosol generators(green), and smoke detectors (orange).

BESS Container Dimensions (inside L x W x H): 2,550.5mm ±5mm x 2319.6mm ±3mm x 2640.7mm ±5mm



Figure 13 Mock-up test enclosure with the front wall in place (right) and without the front wall in place (left)

The distances (rack to rack, and racks to walls) materially aligned with the BESS solution. The testing team installed the instrument in the front and side walls as required by UL9540A edition 4.

For test purposes, a total of 4 [redacted] racks will be utilized. The locations of the racks, in terms of distance from the drywall on the front side, aligned with the intended installation. All distances between racks aligned with the intended installation. Heat flux gauges were utilized to understand the thermal properties of the initiation module and rack on neighboring target modules and rack.

PVEL notes that the illustrations provided in Figure 9.1 of UL9540A are examples, and are not intended to exclude other realistic representations, such as the one proposed in this Report.

Further considerations for testing:

1. The initiating rack set contained all components representative of a BESS unit in a complete installation. (This includes all materials, components, cabling, etc.)
2. The target back rack contained all components representative of a BESS unit in a complete installation, with the exception of being unpopulated with respect to modules (i.e. sheet metal was used instead of modules).
3. The target side racks contained all components representative of a BESS unit in a complete installation, with the exception of being unpopulated with respect to modules (i.e. sheet metal was used instead of modules).
4. Heat flux gauges were placed throughout the setup in line with UL9540A requirements.
5. The initiating modules was at maximum operating state of charge (MOSOC), in accordance with the manufacturer's specifications, for conducting the tests in this recommended practice.
6. After charging, the test was initiated within eight hours.
7. All components (enclosure, cabling, electronics, coolants, etc.) that were part of the complete BESS installation were positioned and connected as part of the test setup. The initiating BESS unit was in an operational state prior to testing. However, modification of the initiating module to allow for insertion of the film heaters took place as required and resulted in altered bus bars.
8. The instrumented wall section consisted of 24ga (or smaller), bare end, "K" Type thermocouples placed every 6" colinear with the heat flux gauges. The instrumented wall section was painted black and was 12" in width running the full vertical height of the wall. The non-fire exposed side of the wall had thermocouples placed as appropriate to demonstrate fire resistance through the wall.

The custom fabrication of the mock-up test enclosure mimicked the BESS solution, while allowing for alternate rack configurations. The test team assured that there were no material "air leaks" in the construction, which could adversely impact the deployment of the Stat-X FSS. The enclosure included a rapidly removable roof in case of explosion or explosion risk. The walls of the enclosure were comprised of non-flammable masonry framed on 16" centered studded walls. As the fire rating of the walls was not the subject of testing, the walls were constructed of a single layer of gypsum board taped and plastered. Construction of the mock-up enclosure was a of single layer of (one hour rated) 5/8" Type-X drywall on 16" centered studs to simulate the masonry construction of a standard room layout. The instrumentation section of the walls was painted matte black in alignment with the UL 9540A requirements.

1.5.1. Measurements Plan

Table 1 Gas measurement and sampling plan

Measurement [1] [2]	Method	Measurement range	Sensor location	Measurement duration [3]
H_2 hydrogen	Palladium-nickel thin film solid state sensor	0.4 to 5.0 % vol.	• 1" below the test enclosure ceiling. • Above the initiating rack, center rack of the triple linked rack	Full duration of test
H_2 hydrogen	Catalytic hydrogensensor	0 to 4 % vol.	• 1" below the test enclosure ceiling. • Above the initiating rack, center rack of the triple linked rack	Full duration of test
CH_4 Total hydrocarbons	Flame ionization detection (FID)	0 to 30,000 ppm	• 1" below the test enclosure ceiling. • Above the initiating rack, center rack of the triple linked rack	Full duration of test
Container pressure	Multi-range differential pressure transducer array	0 to 10 inches of water	• Center of enclosure volume	From Thermal Runaway to Fire Suppression System Activation
Container average gas temperature	"TC tree" type-K thermocouples of size 24 AWG or larger)	0 to 1000C	• 3 to 5 measurement locations across the elevation of the center of the enclosure	From Thermal Runaway to Fire Suppression System Activation
O2 oxygen	Paramagnetic oxygen analyzer	0-100%vol	• 1" below the test enclosure ceiling. • Above the initiating rack, center rack of the triple linked rack	From Thermal Runaway to Fire Suppression System Activation
CO carbon monoxide	Nondispersive infrared carbon monoxide analyzer	0-3000ppm	• 1" below the test enclosure ceiling. • Above the initiating rack, center rack of the triple linked rack	From Thermal Runaway to Fire Suppression System Activation
CO2 carbon dioxide	Nondispersive infrared carbon dioxide analyzer	0-2000ppm	• 1" below the test enclosure ceiling. • Above the initiating rack, center rack of the triple linked rack	From Thermal Runaway to Fire Suppression System Activation
CO2 carbon dioxide	Nondispersive infrared carbon dioxide analyzer	0-5%vol	• 1" below the test enclosure ceiling. • Above the initiating rack, center rack of the triple linked rack	From Thermal Runaway to Fire Suppression System Activation

1. Additional safety factors should be considered when the volumetric gas measurements are intended for life/safety applications. Determination of such safety factors is beyond the scope of this Test Plan or Final Report.
2. Please note: Accuracy of the volumetric gas measurements may be approximately ±50%. Factors that may affect this accuracy include: test enclosure integrity, gas leakage calibration, gas production rate and volume from failing BESS prior to FSS activation, and FSS activation time.
3. Activation of the Stat-X suppression system may impact the data collected. Further, based on the proposed placement of the suppression system, initiating device (2nd smoke detector), and anticipated early activation of the Stat-X system, the gas monitoring will likely be unableto detect the gas released from the cells if the number of thermal runaway / venting events is limited.

Table 2 Thermocouple and heat flux gage count per location

Section	Number of TCs
Front Instrumented Wall Section (IWS)	17 TCs
Lateral Instrumented Wall Section (IWS)	17 TCs
Left Lateral Unit	4 TCs outside, 2 TCs inside
Right Lateral Unit	4 TCs outside, 2 TCs inside
Rear Lateral Unit	4 TCs outside, 2 TCs inside
Ceiling Matrix	9 TCs
Internal	10 Heat Flux Gauges

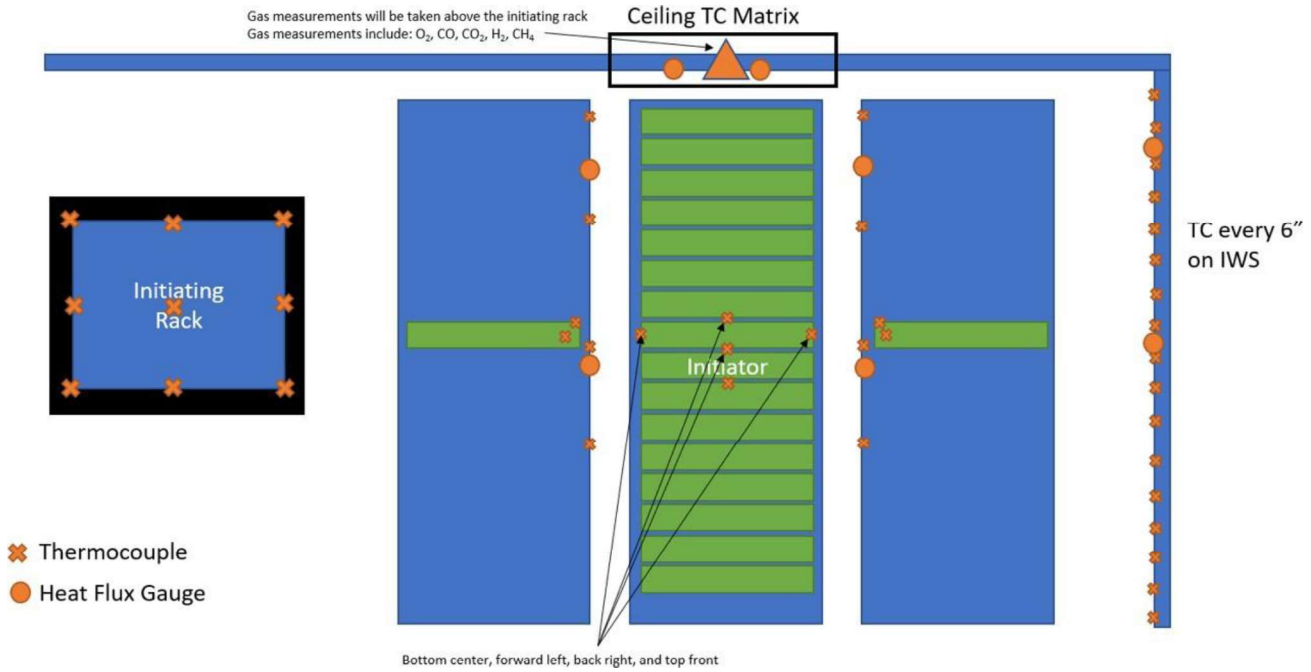


Figure 14 Orthographic (Multiview) Drawing of initiating rack and target racks. Location of instrumentation shown

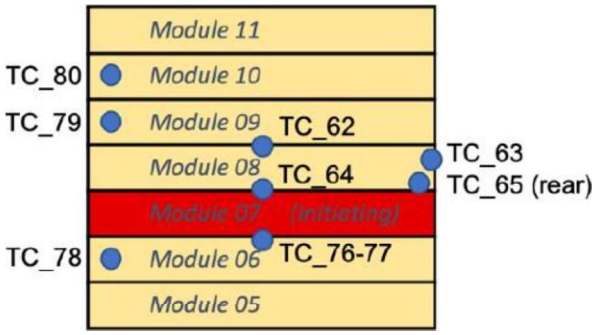


Figure 15 Instrumentation on the test unit

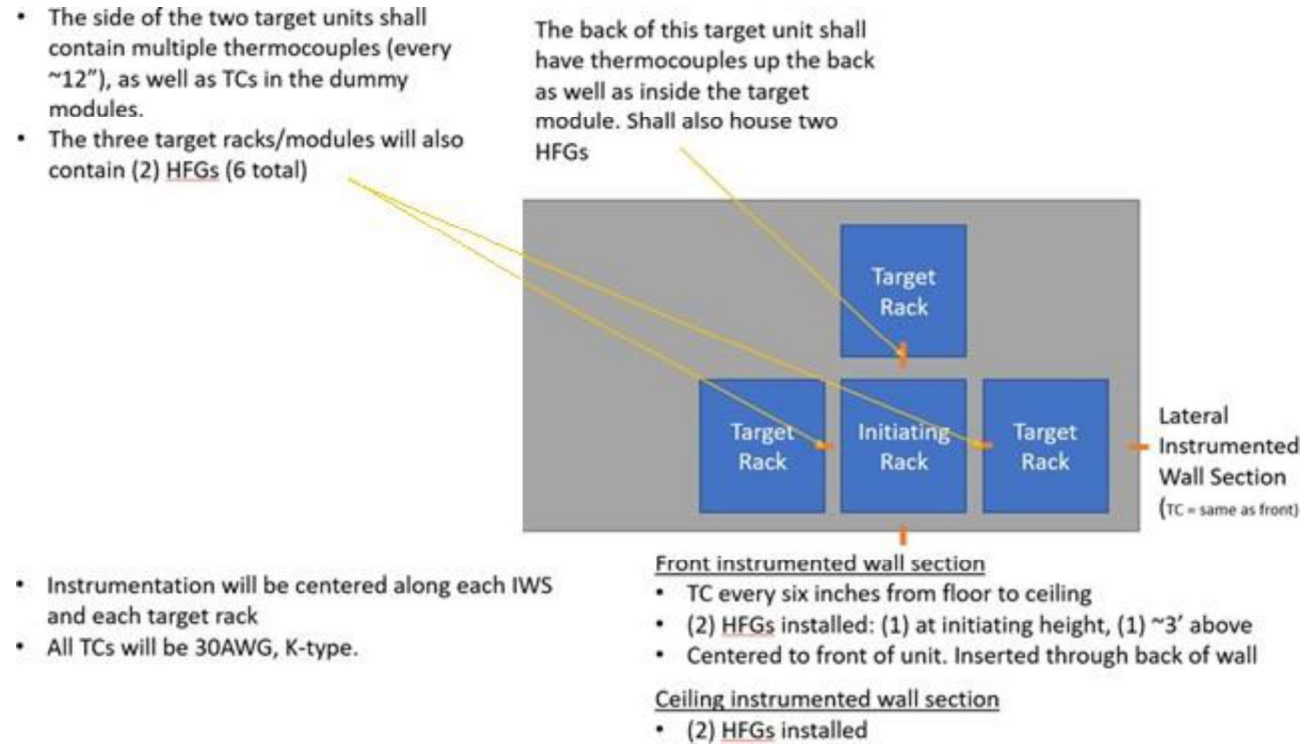


Figure 16 Thermocouple and heat flux plan for areas surrounding initiating rack

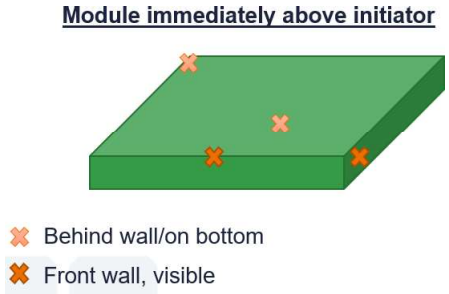


Figure 17 Location of thermocouples on module above the initiating module.

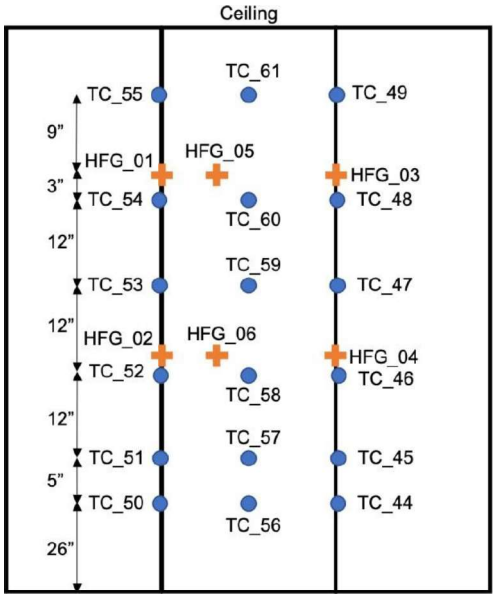


Figure 18 Instrumentation on the target racks viewed from the front

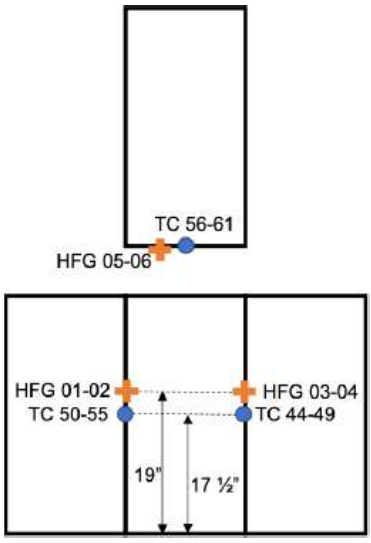


Figure 19 Instrumentation on the target racks from plan view.

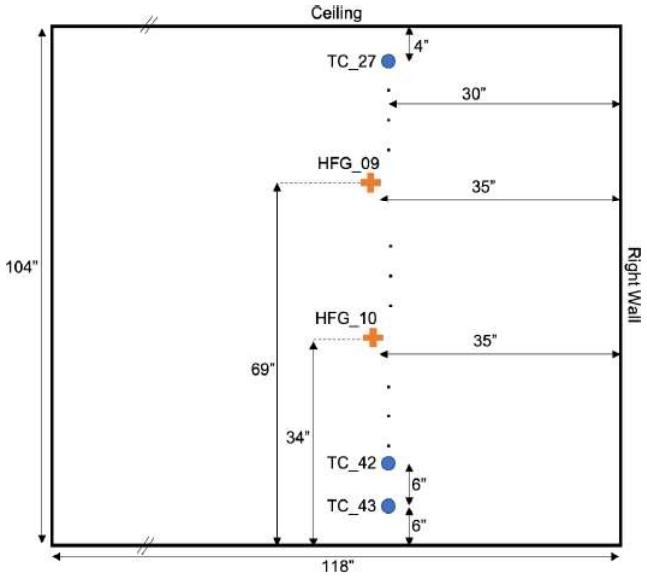


Figure 20 Instrumentation on the front wall viewed from the front of the structure.

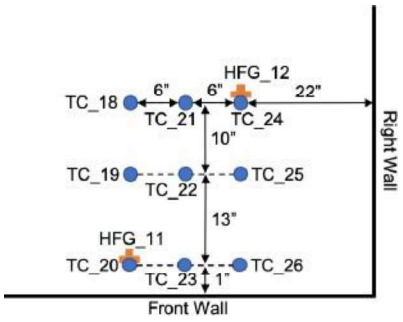


Figure 21 Instrumentation on the ceiling from plan view.

Additionally, a module mass measurement was performed (to the best of the testing team's abilities). Mass measurements for unit or installation level testing under the 4th edition of UL9540A are not required, but are recommended for test scenarios where module to module propagation is not anticipated. A calibrated scale was used for mass measurements of the initiating module. Mass measurements were taken before and after testing (the best of the testing team's abilities) to determine the mass loss of the selected initiating module to further demonstrate thermal runaway propagation or control.

1.5.2. Gas Production Rate

Additional measurements to approximate the gas volume produced by the thermal runaway event were included within the testing enclosure. This measurement approach sought to apply a qualitative methodology to determine the volume of each gas constituent (O2, CO, CO2, H2, and UHC) within the enclosure, from the time of thermal runaway until the activation of the fire suppression system. The measurements included the use of a multi-range differential pressure transducer array to measure the pressure of the enclosure over the identified period of time. Additionally, a thermocouple tree consisting of three to five measurement locations across the elevation of the enclosure was applied at the center of the enclosure volume to determine an average temperature of the gas within the enclosure, type-K thermocouples of size 24 AWG or larger were used. To determine the gas production, the approach applies the gross enclosure volume to perform calculations based on ideal gas law approximations.

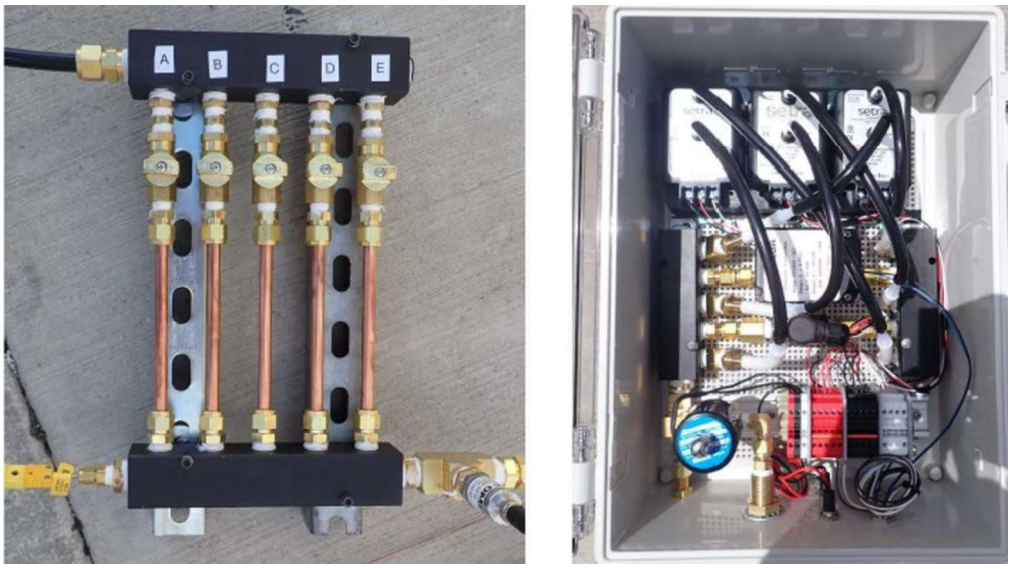


Figure 22 Pressure measurement apparatus: Flow control manifolds (left), and differential pressure transducer array (right)

The proposed measurement approach additionally applied a calibration to the enclosure using a mass flow controller to supply compressed air to the test volume at a flow rate of up to 100 SLPM, in order to determine a relationship between enclosure pressure and leakage rate. These calibrations were applied to the enclosure after completed instrumentation, and prior to testing. While concentration of the sampled gas can be determined in the period of interest by extracting a sample from the enclosure and evaluating the concentration of the identified gases, the calculation of the volume production is dependent upon a number of variables that may result in measurement uncertainties equal in magnitude to the measured quantities. Thus, the applicability of said measurement cannot be guaranteed, specifically for life safety applications. The factors affecting the accuracy of the proposed measurements include:

- Enclosure integrity
- Ability to characterize the gas leakage rate from the enclosure
- Gas production rate prior to fire suppression system activation
- Fire suppression system activation time

While every effort will be made to ensure measurements are collected in a scientifically rigorous manner, neither the level of accuracy, nor the applicably of said measurements, can be guaranteed.

1.6. Testing Method

PVEL and its partners performed the Unit Level testing in accordance with the UL 9540A recommended test practice as outlined in Section 9.3 of UL9540A, plus the additional measurements detailed in herein.

a. This includes all setup requirements, standoff distances, and measurement criteria
b. The system was configured based on its final proposed configuration and test plan
c. Initiation took place via film heaters on cells in the initiating module.

1.6.1. Test Initiation

The initiating module was located in the seventh position in the rack, counting upwards. Prior to testing, the team brought all modules, including the initiating module, to full charge. Following the top-off charge, PVEL and the testing team instrumented the initiating module with film heaters in a similar fashion as described in the UL9540A module level testing report. It has been determined by both the Cell Level Report (UL LLC, 21 March 2019) and Module Level Report (UL LLC, 12 December 2018) that the [redacted] cell can be reliably sent into thermal runaway using a single heater on one side of the [redacted] cell. The (42) [redacted] cells are configured in a 14S-3P configuration inside each module. A graphic showing the approximate film heater location is included in Figure 23. Note that the film heater replaced the cooling plate in the module layout. Also note that full charge prior to instrumenting the module was assured, since the cell electrodes were cut free from the bus bars in order to gain access to the cells for heater installation and thermocouple placement.

Front of Module
Compression Plate (material: EPP)
CMA #1
Compression Plate (material: EPP)
CMA #2
Compression Plate (material: EPP)
CMA #3
Compression Plate (material: EPP)
Al Cooling Plate
#8 Cell
Al Cooling Plate
#7 Cell
Al Cooling Plate
#6 Cell
Al Cooling Plate
#5 Cell
Al Cooling Plate
#2 Cell
Al Cooling Plate
#1 Cell - Event Cell
Al Cooling Plate - replaced by film heater
Compression Plate (material: EPP)
Al Cooling Plate
#8 Cell
Al Cooling Plate
#7 Cell
Al Cooling Plate
#6 Cell
Al Cooling Plate
#5 Cell
Al Cooling Plate
#4 Cell
Al Cooling Plate
#3 Cell
Al Cooling Plate
#2 Cell
Al Cooling Plate
#1 Cell
Al Cooling Plate
Compression Plate (material: EPP)
CMA #6
Compression Plate (material: EPP)
CMA #7
Compression Plate (material: EPP)
Rear of Module

Figure 23 Initiating Module Sample Layout

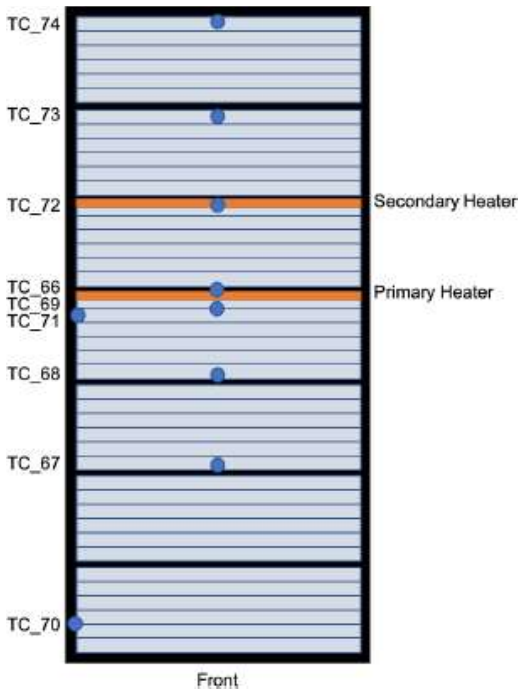


Figure 24 Section view of the initiating module with thermocouple placement

The team assured that all measurement equipment including both the electrical and gas analysis equipment were properly collecting and logging the data. Once confirmed, the team initiated the test by applying a voltage source capable of achieving a 5°C/min to 7°C/min heating rate of the initiating cell. Once the cell reached thermal runaway, the team immediately de-energized the film heaters. The initiation event was then monitored to understand cell to cell propagation, module to module propagation, and ultimately rack to rack propagation. All parameters required to be monitored by UL9540A were adhered to throughout the testing.

1.6.2. Fire Suppression Deployment

Deployment of the fire suppression system occurred per the following sequence of events (see Figure 25):

a. Smoke and off gassing from the initiating module triggered the two smoke detectors positioned over the initiating rack.
b. The PFC-4410RC panel annunciated the alarm condition (display panel, horn, strobe)
c. A 30 second countdown began; after 41 seconds, the Stat-X FSS manual pull station was activated to release the FSS.

The testing would terminate if:

a. Temperatures measured inside each module within the initiating BESS unit returned to ambient temperature; or
b. The fire propagated to the adjacent racks, walls; or
c. A condition hazardous to testing staff or the test facility required mitigation.



Figure 25 Stat-X Fire Suppression System Activation Sequence

1.7. Performance Requirements

As listed in UL9540A the following are the performance requirements of the testing:

1. The surface temperature of modules within the target BESS units adjacent to the initiating BESS unit shall not exceed the temperature at which thermally initiated cell venting occurs, as determined in the cell level tests.
2. Explosion hazards are not observed, including deflagration, detonation, or accumulation (to within the flammability limits) of battery vent gases.
3. For installation near exposures, surface temperature measurements on wall surfaces shall not exceed 97 °C of temperature rise above ambient.

1.8. Data Acquisition

A number of data acquisition requirements are imposed by UL9540A at the unit level. To satisfy these requirements, the team incorporated additional assistance from Fire Risk Alliance (FRA), who managed gas-based data acquisition requirements. Rescue Methods and their partners managed all video and IR video recording. NRTL verified the list of monitoring requirements with the team at least two weeks in advance of the testing date, to assure alignment with the governing recommended practice.

Version 4 of the Test Plan was signed by all parties: Fireaway, Intertek, BESS OEM, and PVEL. Version 5 of the Test Plan was approved by all parties via email confirmation.

2 Test Results Summary

2.1. Test results as reported by PVEL

Refer to PVEL test report R5097C-3 for details on test data.

Table 3 Overview of test timeline and key events

Test Time	Event (ID)	Description
0:00:00 (0s)	Test Start	Heater on.
0:40:00 (2400s)	Cell Failure Event	Temperature drop consistent with cell venting or thermal decay observed in temperature measurements.
0:42:22 (2556s)	Thermal Runaway (E0)	Thermal Runaway and first visible gas; Figure 14a.
0:43:12 (2592s)	Smoke Alarm (E1)	Zone 1 smoke alarm activated; Figure 14b.
0:43:18 (2598s)	Release Event	Second gas release event observed; Figure 14c.
0:44:45 (2685s)	Smoke Alarm (E2)	Zone 2 smoke alarm activated.
0:45:26 (2726s)	FSS Discharge (E3)	Stat-X aerosol fire suppression system activated.
0:50:15 (3015s)	Ventilation (E4)*	Roof section removed to ventilate dangerous concentrations of flammable gas; Figure 14d.
0:51:54 (3114s)	Deflagration (E5)	Deflagration resulting from ignition of combustible exhaust gases; Figure 14e.
0:54:02 (3242s)	Test End	Test was terminated, enclosure disassembled, data collection stopped.

* The Intertek report (104621551CRT-001) issued 22 June 2021, indicates the testing was "terminated @11:14:13 of May 14, 2021 (3015 seconds after the testing started)" at which time the roof of the structure was manually ventilated "when a potential of explosion [was] observed within the testing enclosure with high concentration[s] of vented gases". Thus, the data presented in the Intertek report is only representative of "the results within the testing duration of 3015 seconds and is for reference only, it is not the final results of the performance of the EUT (unit under testing)".

There are 3 distinct phases illustrated in the above table:

- Phase 1: E0 (start of thermal runaway) to E3 (activation of Stat-X)
- Phase 2: E3 (activation of Stat-X) to E4 (termination of test per the NRTL / enclosure ventilation)
- Phase 3: E4 (end of test per NRTL / start of free burn) to end of data collection

Figure 26, Figure 27, and Figure 28 show the temperature trends at the adjacent target racks, and indicate a temperature lower than 100°C, far below the free burn temperatures of the initiating unit, up to E4. Significant temperatures at the target units were only see after event E4, particularly after deflagration at event E4.

As shown in Figure 29, gas temperatures recorded at different elevations of the test enclosure were below 100°C (212°F) between the Stat-X FSS holding period between E3 and E4, 20 inches to 80 inches from the floor level. Propagation only occurred after the test enclosure was breached following event E5 ventilation, which also resulted in a deflagration event.

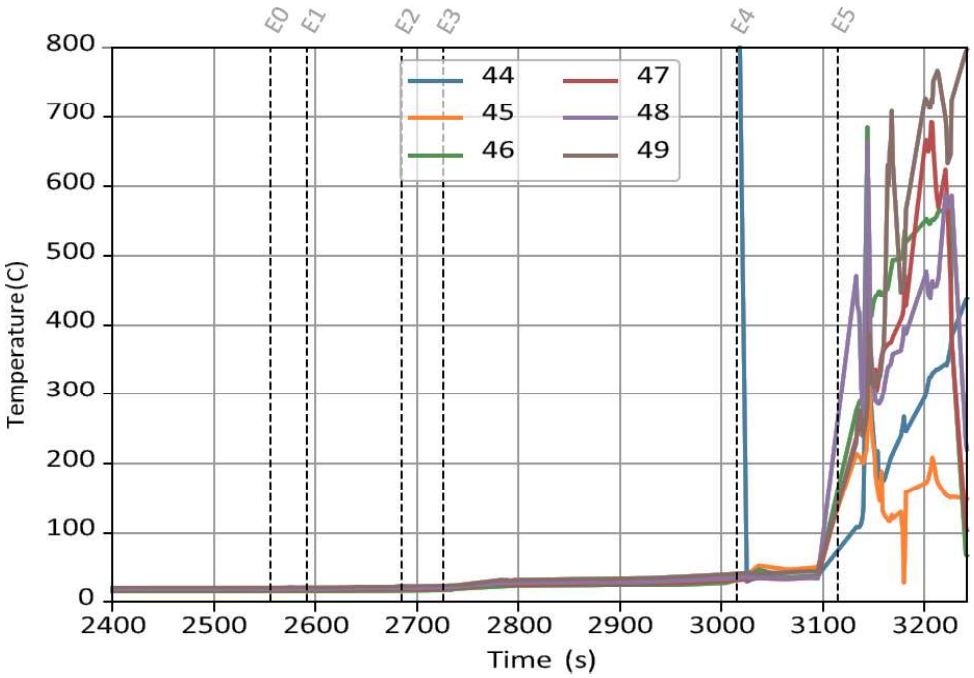


Figure 26 Temperature measurements of right target unit.

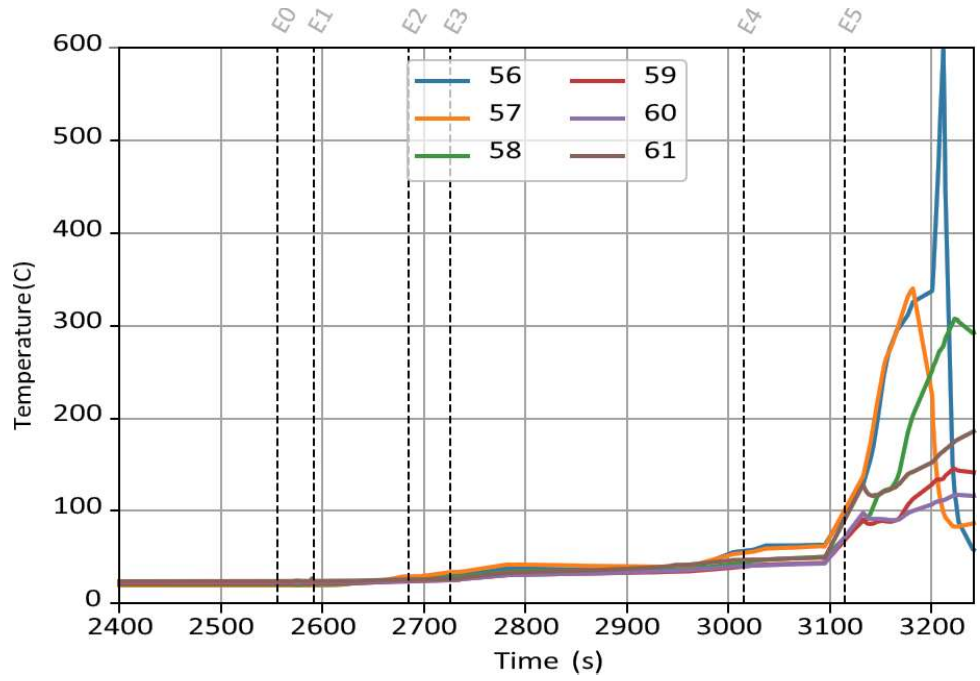


Figure 27 Temperature measurements of rear target unit

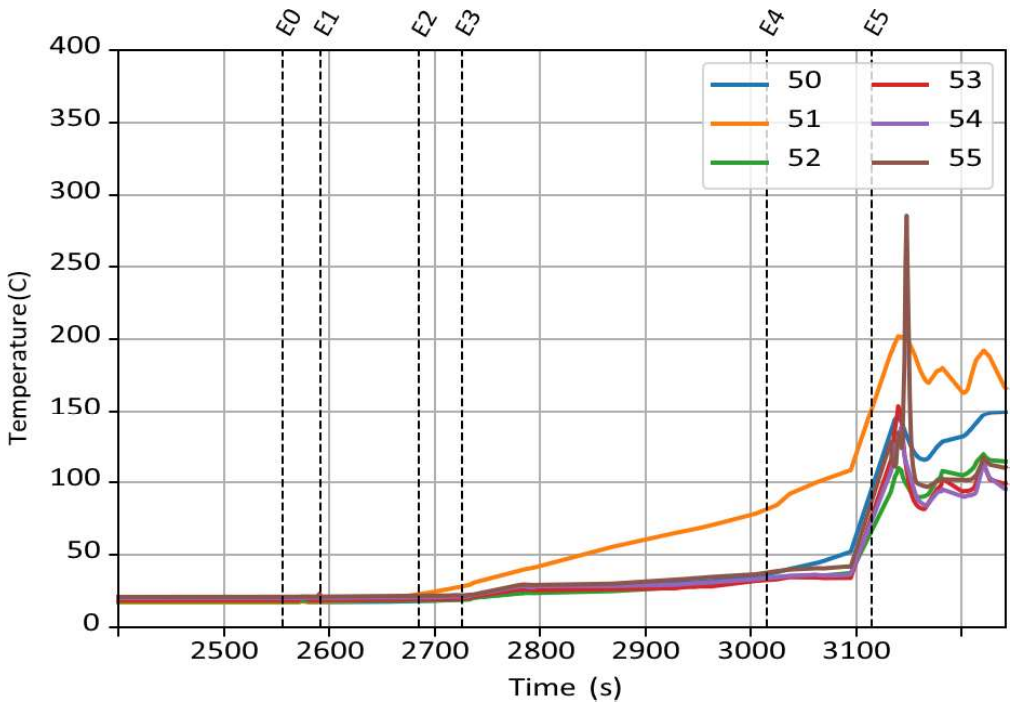


Figure 28 Temperature measurements of left target unit

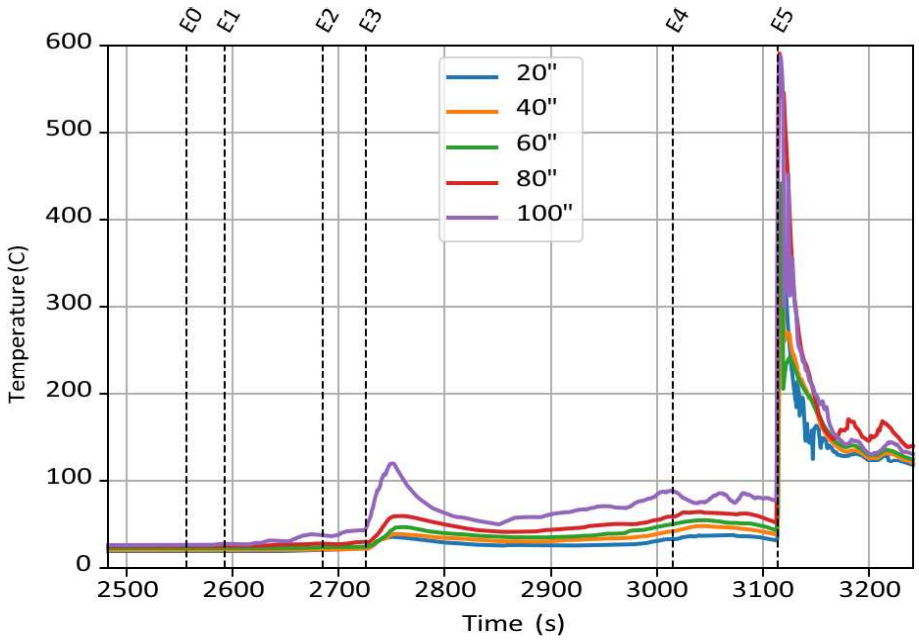


Figure 29 Temperature measurements of enclosure gas temperature; presented as distance above the floor

2.2. Test results as reported by NRTL

Please note that sections of the standard with verdicts of “Not Applicable” may have been truncated in the Report.

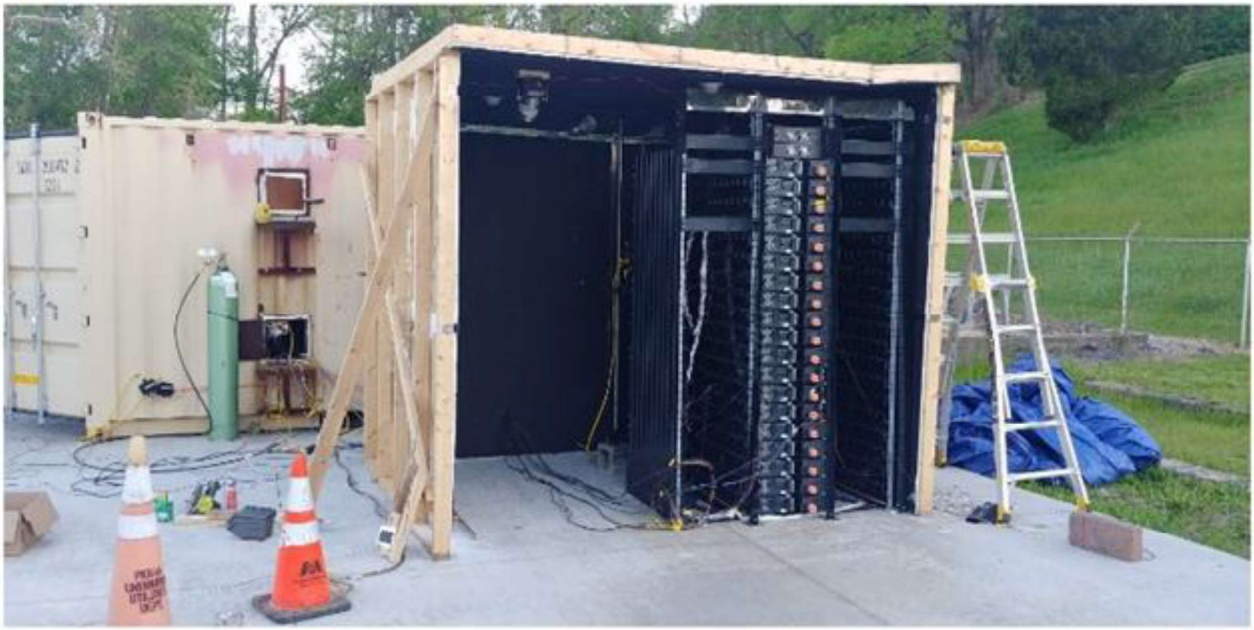
TEST REPORT ANSI/CAN/UL 9540A:2019 Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems	
Report Reference No.	104621551CRT-001
Tested by (name + signature)	Fred Z. Zhu
Approved by (name + signature)	Steven Pasternack
Pages of report	1 of 31
Date of issue	June 22, 2021
Testing Laboratory	**Intertek Testing Services NA, Inc.**
Address	3933 US Route 11, Cortland, NY 13045, USA
Testing location/ procedure	ESRG – Energy Safety Response Group / Witness
Testing location/ address	9300 OH-66, Piqua, OH 45356, USA
Applicant’s name	[redacted]
Address	[redacted]
Test specification:	
Standard	ANSI/CAN/UL 9540A: 2019 + *UL CRD’s*
Test procedure	N/A
Non-standard test method	N/A
Test Report Form No.	ANSI/CAN/UL 9540A
Test Report Form(s) Originator	Intertek
Master TRF	N/A

Summary of testing	
Tests performed (name of test and test clause):	**Testing location:**
☐ Cell level testing ☐ Module level testing ☒ Unit level testing ☐ Installation level testing	ESRG – Energy Safety Response Group 9300 OH-66, Piqua, OH 45356, USA

(MARKING PLATE REDACTED DUE TO BESS OEM PROPRIETARY RIGHTS)

Test item particular	Battery Energy Storage System (ESS)
Equipment mobility	☒ stationary ☐ mobile ☐ portable
Installation method	☒ floor ☐ wall-mount ☐ rooftop/open garage
Installation location	☐ residential ☒ non-residential
Environmental category	☒ outdoor ☐ indoor conditional ☐ indoor unconditional
Connection to the mains	☒ permanent connection ☐ direct plug-in ☐ pluggable equipment ☐ for building-in
Class of equipment	☒ Class I ☐ Class II ☐ Class III ☐ Not classified
Mass of equipment (kg or lb)	87,110 lb*
Dimension of equipment (cm or inch)	20' (L) x 8' (W) x 9.6' (H)*
Pollution degree	☐ PD1 ☐ PD2 ☒ PD3
IP protection class or NEMA rating	NEMA Type 4

*Remarks: the tested sample is a simulated container – half sized with only one fully loaded rack and Stat-X fire suppression system 500E (4 installed), see photo below (per clause 9.1.3 of ANSI/CAN/UL 9540: 2019, as a representative of the [redacted] BESS model [redacted]).



Possible test case verdicts:

- test case does not apply to the test object	N/A
- test object is not evaluated for the requirement	N/E
- test object reaches the specified condition(s) / info	Yes or No
- test object setup completed as specified	Completed (C)
- test object does meet the requirement	Pass (P)
- test object does not meet the requirement	Fail (F)

Testing:	
Date of receipt of test items ..... :	N/A
Date(s) of performance of tests ..... :	May 14, 2021

General remarks:

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

"(see appended table)" refers to a table appended to the report.

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

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

List of test equipment must be kept on file and available for review.

Additional test data and/or information provided in the attachments to this report.

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

Determination of the test results includes consideration of measurement uncertainty from the test equipment and methods.

ANSI/CAN/UL 9540A			
Clause	Requirement – Test	Result – Remark	Verdict
5	**Construction – General**		
5.1	**Cell**		
5.1.1	The cells info associated with the BESS, including:		Yes
	• including cell chemistry (e.g. NMC, LFP);	[redacted] li-ion chemistry (NMC)	P
	• the physical format of the cell;	Pouch	P
	• the cell electrical rating in capacity and nominal voltage;	72.5 Ah, 3.67 V	P
	• the overall dimensions of the cell, and weight.	100mm x 353mm x 16mm, 1170g	P
5.1.2	The cells associated with the BESS comply with ANSI/CAN/UL 1973 or not.	The [redacted] cells are certified to UL 1642 (stated in cell level testing report - 9540A_[redacted] Cell Final Report 3-21-19)	N/A
5.1.3	Further details included in the cell level test report.	(Refer to cell level testing report - 9540A_[redacted] Cell Final Report3-21-19)	N/E
5.2	**Module**		
5.2.1	The modules info associated with the BESS, include:		Yes
	• the generic enclosure material;	Metal enclosure	P
	• the general layout of the module contents;	Consists of 56 [redacted] cells with built-in thermal management	P
	• the electrical configuration of the cells in the modules and the modules in the BESS.	Module rated 51.8 V and 290 Ah	P
5.2.2	The modules associated with the BESS comply with UL 1973 or not.	No cert info for the tested module (Model EM048218P5B9)	N/E
5.2.3	Further details included in the module level test report.	(refer to module EM048290P5B1 testing report – 9540A [redacted] module report_12-12-18_final)	N/E
5.3	**Battery energy storage system unit**		
5.3.1	The BESS unit info, include:		
	• the units comply with UL 9540 or not;	The [redacted] BESS [redacted] with UL 9540 Limited Production Certificate	N/E

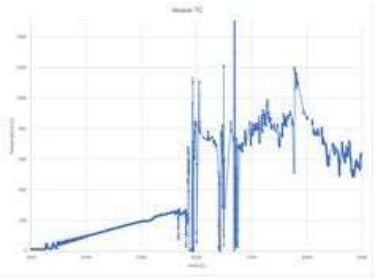
	• the manufacturer and model number;	(see page 2)	P
	• electrical ratings;	(see page 2 for the whole system)	P
	• energy capacity of all BESS.	(see page 2 for the whole system)	P
5.3.2	For BESS units, which UL 9540 compliance cannot be determined, to include:		
	• the number of modules in the BESS;	19 modules in one rack (tested)	P
	• electrical configuration of the module;	Module rated 51.8V, 290Ah	P
	• physical layout of the modules in the BESS;	(see photo in page 3)	P
	• battery management system (BMS); and	No info provided	N/E
	• other major components of the BESS;	No info provided	N/E
	• the BESS enclosure overall dimensions and generic material;	(see page 2)	P
	• battery system(s) may be tested as representative of the BESS;	A fully loaded BESS rack (19) modules with (2) BPU converters	P
	• battery system complies with UL 1973 or not.	No updated certificate info	N/E
5.3.3	Any fire detection and suppression systems that are an integral part of the BESS.	Stat-X fire suppression system 500E installed and tested together	Yes
5.3.4	Further details included in the unit level and if applicable, installation level test reports.	(refer to 9.7, 10.4 and 10.7)	Yes
5.4	**Flow Batteries**		**N/A**
6	**Performance – General**		
6.1	The tests in this standard are extreme abuse conditions conducted on electrochemical energy storage devices, which may result in various kind of hazards.	Safety measures ensured during the testing day	P
6.2	At the conclusion of testing, samples discharged in accordance with the manufacturer' specifications.	Sample handled by local authorities after the testing	P
	All samples disposed of in accordance with local regulations.	Sample disposed by local authorities after the testing	P
7	**Cell Level**		
7.1	**General**		**N/A**
7.2	**Sample**		**N/A**
7.3	**Determination of thermal runaway methodology**		**N/A**

7.4	**Cell vent gas composition test**		**N/A**
7.5	**Off gas composition for flow battery systems**		**N/A**
7.6	**Cell level test report**		**N/A**
7.7	**Performance – cell level test**		**N/A**
7.8	**Performance – flow battery thermal runaway determination tests**		**N/A**
8	**Module Level**		
8.1	**Sample**		**N/A**
8.2	**Test method**		**N/A**
8.3	**Module level test report**		**N/A**
8.4	**Performance at module level testing**		**N/A**
9	**Unit Level**		
9.1	**Sample and test configuration**		
9.1.1	The unit level test shall be conducted with BESS units installed as described in the manufacturer's instructions and this section.	Tested for "Outdoor ground mounted non-residential use BESS"	Yes
9.1.2	The unit level test requires one initiating BESS unit and target adjacent BESS units representative of an installation.	An internal fire condition as in the module level test is initiated	C
	Tests conducted for indoor floor mounted *installations for residential BESS may be* considered representative of both indoor floor mounted and outdoor ground mounted installations.	*(modified by UL CRD-2020.10.21)*	N/A
	Exception: Testing can be conducted outdoors for outdoor only installations with controlled environment.	Unit was tested for outdoor installation	C
9.1.3	Depending upon the configuration and design of the BESS (e.g. the BESS is composed of multiple separate parts within separate enclosures), this testing to determine fire characterization can be done at the battery system level.	A fully loaded BESS rack tested within the simulated container with 4 Stat-X 500E installed, which is agreed between the applicant and the testing labs	C
9.1.4	The initiating BESS unit shall contain components representative of a BESS unit in a complete installation. Combustible components that interconnect the initiating and target BESS units shall be included.	The initiating module installed at the lower part (#7 from the bottom) of the tested BESS rack (See the photo of page 3 too)	C
9.1.5	Target BESS units shall include the outer cabinet, racking, module enclosures, and components that retain cells components. The target BESS unit module enclosures do not need to contain cells.	Three target BESS racks installed near the initiating BESS rack, but nomodules in the target racks (agreedwith the relevant parties)	C

9.1.6	The initiating BESS unit shall be at the maximum operating state of charge (MOSOC) for conducting the tests in this standard. After charging and prior to testing, the initiating BESS shall rest for a maximum period of 8h at room ambient.	All 19 modules within the initiating BESS, charging conditions were measured before the testing	C
9.1.7	If a BESS unit includes an integral fire suppression system, there is an option of providing this with the DUT. If the BESS unit is provided with an optionalintegral fire suppression system, the system shall notbe provided on the DUT.	Stat-X fire suppression system (model 500E, 4pcs.) installed as integral part and tested together	C
9.1.8	Electronics and software controls such as the battery management system (BMS) in the BESS are not relied upon for this testing.	Unit protection means were disabled during the testing	N/A
	This does not include a fire suppression control that is external to the BESS, but provided as part of an integral fire suppression system per 9.1.7	The Stat-X fire 500E was considered as integral parts of inside the BESS	N/A
9.2	**Test method – Indoor floor mounted BESS units**	(referred by clause 9.3 as well)	
9.2.1	During the test, the test room environment shall be controlled to prevent drafts that may affect test results.	(Ambient is 19.1°C at the testing start with humidity of 30.1% RH)	P
9.2.2	Any access door(s) or panels on the initiating BESS unit and adjacent target BESS units shall be closed, latched and locked.	Closed enclosure tested to simulate the BESS conditions	C
9.2.3	The initiating BESS unit shall be positioned adjacent to two instrumented wall sections.	(See photo in page 3)	C
9.2.4	Instrumented wall sections shall extend not less than 0.49m horizontally beyond the exterior of the target BESS units.	Simulating the actual installation within the container	C
9.2.5	Instrumented wall sections shall be at least 0.61m taller than the BESS unit height, but not less than 3.66m in height above the bottom surface of the unit.	Simulating the actual installation within the container	C
9.2.6	The surface of the instrumented wall sections shall be covered with 16-mm (5/8-in) gypsum wallboard and painted flat black.	The simulated testing enclosure is consisting of 5/8” gypsum wall board and painted flat black	C
9.2.7	The initiating BESS unit shall be centered underneath an appropriately sized smoke collection hood of an oxygen consumption calorimeter.	Excluded by clause 9.3.1 for outdoor use only installation	N/A
9.2.8	The light transmission in the calorimeter’s exhaust duct shall be measured for the duration of the test, and the smoke release rate shall be calculated.	Excluded by clause 9.3.1 for outdoor use only installation	N/A
9.2.9	The chemical and convective heat release rates shall be measured for the duration of the test, respectively.	Excluded by clause 9.3.1 for outdoor use only installation	N/A
9.2.10	The heat release rate measurement system shall be calibrated using flows of 3.8, 7.6, 11.4 and 15.2 L/min (1, 2, 3 and 4 gpm) of heptane.	Excluded by clause 9.3.1 for outdoor use only installation	N/A

9.2.11	The convective heat release rate shall be measured using a thermopile, a velocity probe, and a Type K thermocouple, located in the exhaust system of the exhaust duct.	Excluded by clause 9.3.1 for outdoor use only installation	N/A
9.2.12	The convective heat release rate shall be calculated using the following equation: $$HRR_c = V_e A \frac{353.22}{T_e} \int_{T_o}^{T} C_p dT$$	Excluded by clause 9.3.1 for outdoor use only installations	N/A
9.2.13	The physical spacing between BESS units (both initiating and target) and adjacent walls shall be representative of the intended installation.	As specified in intended installation (side to side no gap, back-to-back with 8" distance)	C
9.2.14	Separation distances shall be specified by the manufacturer for distance between:		C
	a) The BESS units and the instrumented wall sections; and	Side ¾" and front 5-1/2" from the instrumented walls	C
	b) Adjacent BESS units.	No spacing between side BESS racks, 8" away from back BESS target rack (as specified by [redacted])	C
9.2.15	Wall surface temperature measurements shall be collected for BESS intended for installation in locations with combustible construction.	(see figure 11 of reference 1)	C
	If the intended installation is composed completely of noncombustible construction in which wall assemblies, cables, wiring and any other combustible materials are not to be present in the BESS installation, then the report should note that the installation shall contain no combustible construction and that surface temperature rises can be deemed not applicable.	Not intended for noncombustible installation surface only	N/A
9.2.16	Wall surface temperatures shall be measured in vertical array(s) at 152-mm (6-in) intervals for the full height of the instrumented wall sections.	#24-gauge, Type-K exposed junction thermocouples used	C
	The thermocouples for measuring the temperature on wall surfaces shall be horizontally positioned in the wall locations anticipated to receive the greatest thermal exposure from the initiating BESS unit.	The thermocouples were positioned as required, see figure 11 of reference 1 too	C
9.2.17	Thermocouples shall be secured to gypsum surfaces by the use of staples placed over the insulated portion of the wires.	The thermocouples were fixed as required	C
	The thermocouple tip shall be depressed into the gypsum so as to be flush with the gypsum surface at the point of measurement and held in thermal contact with the surface at that point by the use of pressure-sensitive paper tape.	The thermocouples were depressed into the instrumented wall as required	C
9.2.18	Heat flux shall be measured with the sensing element of at least two water-cooled Schmidt- Boelter gauges at the surface of each instrumented wall:		C

	a) Both are collinear with the vertical thermocouple array;		C
	b) One is positioned at the elevation estimated to receive the greatest heat flux due to the thermal runaway of the initiating module; and	(see figure 11 of reference 1)	C
	c) One is positioned at the elevation estimated to receive the greatest heat flux during potential propagation of thermal runaway within the initiating BESS unit.	(see figure 11 of reference 1)	C
9.2.19	Heat flux shall be measured with the sensing element of at least two water-cooled Schmidt-Boelter gauges at the surface of each adjacent target BESS unit that faces the initiating BESS unit:		C
	a) One is positioned at the elevation estimated to receive the greatest heat flux due to the thermal runaway of the initiating module within the initiating BESS; and	(see figure 11 of reference 1)	C
	b) One is positioned at the elevation estimated to receive the greatest surface heat flux due to the thermal runaway of the initiating BESS.	(see figure 11 of reference 1)	C
9.2.20	For non-residential use BESS, heat flux be measured with the sensing element of at least one water-cooled Schmidt-Boelter gauge positioned at the mid height of the initiating unit in the center of the accessible means of egress.	(see figure 11 of reference 1)	C
9.2.21	Measure the temperature of:	(#24-gauge, type-K exposed TC)	C
	• the surface proximate to the cells and between the cells and exposed face of the initiating module;	(see figure 11 of reference 1)	C
	• Each non-initiating module enclosure within the initiating BESS unit;	(see figure 11 of reference 1)	C
	• convoluted enclosure interior geometries.	(see figure 11 of reference 1)	C
9.2.22	For residential use BESS, the DUT shall be covered with a single layer of cheese cloth ignition indicator.	Not residential use BESS	N/A
9.2.23	An internal fire condition in accordance with the module level test shall be created within a single module in the initiating BESS unit:		C
	a) The position of the module shall be selected to present the greatest thermal exposure to adjacent modules, based on the results from the module level test; and	Initiating module located at the bottom area (#7)	C

	b) The setup (i.e. type, quantity and positioning) of equipment for initiating thermal runaway in the module shall be the same as that used to initiate and propagate thermal runaway within the module level test (Section 8).	Same thermal runaway method used as that of module testing. The heater's temperature vs. time curve: 	C
9.2.24	The composition, velocity and temperature of the initiating BESS unit vent gases shall be measured within the calorimeter's exhaust duct as in 8.2.10.	Excluded by clause 9.3.1 for outdoor use only installations	N/A
	The hydrocarbon content of the vent gas shall be measured using flame ionization detection.		N/A
	Hydrogen gas shall be measured with a palladium-nickel thin-film solid state sensor		N/A
9.2.25	*The hydrocarbon components of the vent gas composition may additionally 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, or an equivalent gas analyzer.	*(modified by UL CRD-20200110)*	N/A
9.2.26	The test shall be terminated if:		
	a) Temperatures measured inside each module within the initiating BESS unit return to ambient temperature;		N/A
	b) The fire propagates to adjacent units or to adjacent walls; or		N/A
	c) A condition hazardous to test staff or the test facility requires mitigation.	Testing terminated @11:14:13 of 05-14-2021 (3015 seconds after testing started) when a potential of explosion observed within the testing enclosure due to the high concentration of vented gases	Yes
9.2.27	For residential use systems, the gas collection data shall be compared to the smallest room installation specified by the manufacturer to determine if the flammable gas collected exceeds 25% LFL in air.	Not a residential use BESS (see table 9.1)	N/A
9.3	**Test method – Outdoor ground mounted units**		
9.3.1	Outdoor ground mounted non-residential use BESS being evaluated for installation in close proximity to buildings and structures.	(see relevant info in clause 9.2)	C

	If intended for 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 need not be measured.	Tested for outdoor installations	C
9.3.2	Outdoor ground mounted residential use BESS being evaluated for installation in close proximity to buildings and structures.	(the test method described in section 9.2)	C
	Heat flux measurements for the accessible means of egress.	(measured in accordance with 9.2.20)	C
	If intended for 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 need not be measured.	Outdoor used installations tested	C
9.3.3	Test samples shall be installed as shown in Figure 9.2 in proximity to an instrumented wall section.	(see photo in page 3)	C
	The sample shall be mounted on a support substrate and spaced from the wall in accordance with the minimum separation distances specified by the manufacturer.		C
	Exception: If the manufacturer requires installation against non-flammable material, the test setup may include manufacturer recommended backing material between the unit and plywood wall.	Not specified by manufacturer	N/A
9.3.4	Target BESS shall be installed on each side of the initiating BESS and keep the min. separation distances specified by the manufacturer.	Two racks side and one rack back to the initiating rack	C
9.4	**Test Method – Indoor wall mounted units**		**N/A**
9.5	**Test Method – Outdoor wall mounted units**		**N/A**
9.6	**Rooftop and open garage installations**		**N/A**
9.7	**Unit level test report**		**--**
9.7.1	The report on the unit level testing shall identify the type of installation being tested, asfollows:		Yes
	a) Indoor floor mounted non-residential use BESS;		N/A
	b) Indoor floor mounted residential use BESS;		N/A
	c) Outdoor ground mounted non-residential use BESS;	Tested in this application	Yes
	d) Outdoor ground mounted residential use BESS;		N/A
	e) Indoor wall mounted non-residential use BESS;		N/A
	f) Indoor wall mounted residential use BESS;		N/A

	g) Outdoor wall mounted non-residential use BESS;		N/A
	h) Outdoor wall mounted residential use BESS;		N/A
	i) Rooftop installed non-residential use BESS; or		N/A
	j) Open garage installed non-residential use BESS.		N/A
9.7.2	If testing is intended to represent more than one installation type, this shall be noted in the report.	Tested in outdoor mounted non-residential use BESS	N/A
9.7.3	The report shall include the following, as applicable:		--
	a) Unit manufacturer name and model number (and whether UL 9540 compliant);	The [redacted] with Limited Production Certificate per UL 9540, the tested sample is a simulation to the [redacted] model [redacted]. (see page 3 description of this report too)	N/E
	b) Number of modules in the initiating BESS unit;	19 modules within the tested rack	Yes
	c) The construction of the initiating BESS unit per 5.3;	(see clause 5.3 for details)	Yes
	d) Fire protection features/detection/suppression systems within unit;	Tested together with Stat-X fire suppression system 500E	Yes
	e) Module voltage(s) corresponding to the tested SOC;	Measured 58.85Vdc to 58.90Vdc for the modules after fully charged	Yes
	f) The thermal runaway initiation method used;	Heating cell by film heaters	Yes
	g) Location of the initiating module within the BESS unit;	#7 module initiated (counted from the bottom), total of 19 modules in one rack	Yes
	h) Diagram and dimensions of the test setup including mounting location of the initiating and target BESS units, and the locations of walls, ceilings, and soffits;	(see reference 1)	Yes
	i) Observation of any flaming outside the initiating BESS enclosure and the maximum flame extension;	No observation of any flaming before the testing terminated @11:14:13 of 05-14-2021 (*see table 9.1 for details)	N/E*
	j) Chemical and convective heat release rate versus time data;	Excluded by clause 9.3.1 for outdoor use only installation	N/A
	k) Separation distances from the initiating BESS unit to target walls (A and C in Figure 9.1);		Yes
	l) Separation distances from the initiating BESS unit to target BESS units (D and H in Figure 9.1);		Yes

	m) The maximum wall surface and target BESS temperatures achieved during the test and the location of the measuring thermocouple;	(*see table 9.1)	N/E*
	n) The maximum ceiling or soffit surface temperatures achieved during the indoor or outdoor wall mounted test and the location of the measuring thermocouple;	Not wall mounted BESS	N/A
	o) The maximum incident heat flux on target wall surfaces and target BESS units;	(*see table 9.1)	N/E*
	p) The maximum incident heat flux on target ceiling or soffit surfaces achieved during the indoor or outdoor wall mounted test;	Not wall mounted unit	N/A
	q) Gas generation and composition data	(*see table 9.1)	Yes*
	r) Peak smoke release rate and total smoke release data;	Excluded by clause 9.3.1 for outdoor use only installation	N/A
	s) Indication of the activation of integral fire protection systems and if activated the time into the test at which activation occurred;	At the moment of 2726 seconds from testing started, the integral Stat-X 500E discharged	Yes
	t) Observation of flying debris or explosive discharge of gases;	No observation of flying debris before the testing terminated @11:14:13 of 05-14-2021 (*see table 9.1 for details)	N/E*
	u) Observation of re-ignition(s) from thermal runaway events;	No observation of re-ignitions before the testing terminated @11:14:13 of 05-14-2021 (*see table 9.1 for details)	N/E*
	v) Observation(s) of sparks, electrical arcs, or other electrical events;	None observed before the testing terminated @11:14:13 of 05-14-2021 (*see table 9.1 for details)	N/E*
	w) Observations of the damage to:		N/E*
	1) The initiating BESS unit;	Testing terminated @11:14:13 of 05-14-2021 (*see table 9.1 for details)	N/E*
	2) Target BESS units;	Testing terminated @11:14:13 of 05-14-2021 (*see table 9.1 for details)	N/E*
	3) Adjacent walls, ceilings, or soffits; and	Testing terminated @11:14:13 of 05-14-2021	N/E*

		(*see table 9.1 for details)	
	x) Photos and video of the test.	(Recorded)	Yes
9.8	**Performance at unit level testing**		**--**
9.8.1	Installation level testing in Section 10 is not required if the performance conditions outlined in Table 9.1 are met during the unit level test.	Performance conditions outlinedin table 9.1 is undetermined (*see table 9.1 of this report)	N/E*
10	**Installation Level**		
10.1	**General**		**N/A**
10.2	**Sample**		**N/A**
10.3	**Test method 1 – Effectiveness of sprinklers**		**N/A**
10.4	**Installation level test report – Test method 1 – Effectiveness of sprinklers**		**N/A**
10.5	**Performance – Test method 1 – Effectiveness of sprinklers** (also for Test method 2)		**N/A**
10.6	**Test method 2 – Effectiveness of fire protection plan**		**N/A**
10.7	**Installation level test report – Test method 2 – Effectiveness of fire protection plan**		**N/A**
10.8	**Performance – Test method 2 – Effectiveness of fire protection plan**		**N/A**

Table 9.1	**Unit Level Performance Criteria**	**N/E***
1. Non-Residential Installations		
(1) Indoor Floor Mounted	a) Flaming outside the initiating BESS unit is not observed;	--
	b) Surface temperatures of modules within the target BESS units adjacent to theinitiating BESS unit do not exceed the temperature at which thermally initiatedcell venting occurs, as determined in 7.3.1.8;	--
	c) For BESS units intended for installation in locations with combustible constructions, surface temperature measurements on wall surfaces do not exceed 97°C of temperature rise above ambient per 9.2.15;	--

	d) Explosion hazards are not observed, including deflagration, detonation or accumulation (to within the flammability limits in an amount that can cause a deflagration) of battery vent gases; and	--
	e) Heat flux in the center of the accessible means of egress shall not exceed 1.3 kW/m^2.	--
(2) Outdoor Ground Mounted	a) If flaming outside of the unit is observed, separation distances to exposures shall be determined by greatest flame extension observed during test.	*N/E (see NOTES)
	Remarks: no flaming observed before testing stopped @11:14:13 of 05-14-2021	--
	b) Surface temperatures of modules within the target BESS units adjacent to theinitiating BESS unit do not exceed the temperature at which thermally initiatedcell venting occurs, as determined in 7.3.1.8;	* N/E (see NOTES)
	Remarks: the target racks' surface temperatures are not exceeded the temperature at which thermally initiated cell vented occurs before testing stopped @11:14:13 of 05-14-2021, see below temperature data (max. from 0 to 3015s): Right BESS rack (TC# 48): 42.4°C Left BESS rack (TC# 54): 36.8°C Rear BESS rack (TC# 55): 57.8°C Initiating BESS cell (venting, TC# 69): 373.1°C	--
	c) For BESS units intended for installation near exposures, surface temperature measurements on wall surfaces do not exceed 97°C of temperature rise aboveambient per 9.2.15;	N/E* (see NOTES)
	Remarks: (1) the max. temperature rise data before the testing stopped @11:14:13 of 05-14- 2021 is exceeded 97°C above the ambient (19.1°C) at ceiling and front wall, details: Right Wall (TC# 14): 64.3°C (ΔT = 45.2°C < 97°C) Ceiling (TC# 18): 130.9°C (ΔT = 111.8°C > 97°C) Front Wall (TC# 37): 169.1°C (ΔT = 150.0°C > 97°C) (2) if the final installation is not near exposures, as specified in note 1) of table 9.1,this requirement can be excluded.	--
	d) Explosion hazards are not observed, including deflagration, detonation or accumulation (to within the flammability limits in an amount that can cause a deflagration) of battery vent gases; and	N/E* (see NOTES)
	Remarks: (1) Potential explosion hazards observed (see below NOTES for detailed gas info)and the testing terminated @11:14:13 of 05-14-2021. (2) The result for this item is undetermined, as the test configuration changed (the roof was opened at 11:14:13 of 05-14-2021, thus the testing was not continued as designed per reference 1).	--

	e) Heat flux in the center of the accessible means of egress shall not exceed 1.3 kW/m^2.	N/E* (see NOTES)
	Remarks: (1) the max. heat flux (in kW/m^2) before the testing stopped @11:14:13 of 05-14-2021 is listed here:	--

HFG #	Location	Max. measured heat flux (kW/m^2)
01	Left Target (High)	≥100*
02	Left Target (Low)	45.6
03	Right Target (High)	24.9
04	Right Target (Low)	34.7
05	Back Target (High)	≥100*
06	Back Target (Low)	≥50*
07	Right Wall (High)	≥20*
08	Right Wall (Low)	≥20*
09	Front Wall (High)	≥50*
10	Front Wall (Low)	≥50*
11	Ceiling (Front)	134.6
12	Ceiling (Right)	≥200*

*The measured data over the measurement range of the heat flux gauge.

(2) if the final installation is made without accessible means of egress as specifiedin note 2) of table 9.1, this requirement can be excluded.

NOTES:

- *Testing terminated @11:14:13 of May 14, 2021 (3015 seconds after the testing started) by opened the testing enclosure roof near the tested battery rack when a potential of explosion observed within the testing enclosure with high concentration of vented gases (see below data at the moment). This is for the safety of testing facilities and the people per clause 9.2.26 condition c) of UL 9540A: 2019, thus the data collected in this report is only representing the results within the testing duration of 3015 seconds and is for reference only, it is not the final results of the performance of the EUT (unit under testing).*

Gas & Maximum Concentration

Carbon Dioxide	≥54543 ppm
Carbon Monoxide	≥ 3091 ppm
Hydrogen	29235 ppm
Unburned Hydrocarbons	≥31751 ppm

(3) Indoor Wall Mounted	a) Flaming outside the initiating BESS unit is not observed;	--
	b) Surface temperatures of modules within the target BESS units adjacent to the initiating BESS unit do not exceed the temperature at which thermally initiated cell venting occurs, as determined in 7.3.1.8;	--

	c) For BESS units intended for installation in locations with combustible construction, surface temperature measurements on wall surfaces do not exceed 97°C of temperature rise above ambient per 9.2.15;	--
	d) Explosion hazards are not observed, including deflagration, detonation, or accumulation (to within the flammability limits in an amount that can cause a deflagration) of battery vent gases; and	--
	e) Heat flux in the center of the accessible means of egress shall not exceed 1.3 kW/m^2.	--
(4) Outdoor Wall Mounted	a) Flaming outside the initiating BESS unit is not observed;	--
	b) Surface temperatures of modules within the target BESS units adjacent to the initiating BESS unit do not exceed the temperature at which thermally initiated cell venting occurs, as determined in 7.3.1.8;	--
	c) For BESS units intended for installation on walls with combustible construction, surface temperature measurements on wall surfaces do not exceed 97°C of temperature rise above ambient per 9.2.15;	--
	d) Explosion hazards are not observed, including deflagration, detonation or accumulation (to within the flammability limits in an amount that can cause a deflagration) of battery vent gases; and	--
	e) Heat flux in the center of the accessible means of egress shall not exceed 1.3 kW/m^2.	--
(5) Rooftop and Open Garages	a) If flaming outside the unit is observed, separation distances to exposures shall be determined by greatest flame extension observed during test;	--
	b) Surface temperatures of modules within the target BESS units adjacent to the initiating BESS unit do not exceed the temperature at which thermally initiated cell venting occurs, as determined in 7.3.1.8;	--
	c) For BESS units intended for installation in locations with combustible construction, surface temperature measurements on wall surfaces do not exceed 97°C of temperature rise above ambient per 9.2.15;	--
	d) Explosion hazards are not observed, including deflagration, detonation or accumulation (to within the flammability limits in an amount that can cause a deflagration) of battery vent gases; and	--
	e) Heat flux in the center of the accessible means of egress shall not exceed 1.3 kW/m^2.	--
2. Residential Installations		**Result**
		N/A

Annex 1: Testing Equipment List:

Item #	Equipment	S/N	Calibration Due Date
1	Fluke multimeter 119	45260379SV	07/27/2021
2	FRA temperature measurement scope - National Instruments NI-9214	1720AE4	10/09/2021
3	Enclosure pressure data collection -National Instruments NI-9207	1A056F9	10/07/2021
4	HFG measurement module – National Instruments NI-9205	1BD3AD2, 17E9D35	10/08/2021
5	Ambient temperature and humidity probe - Omega HX303AV	50768	10/08/2021
6	Enclosure pressure measurement – Setra 26410R5WB2DT1F	10144247	04/19/2022
	Enclosure pressure measurement - Setra 26411R5WD2DT1F	9232163	06/29/2021
	Enclosure pressure measurement – Setra 2641003WD2DT1F	10144248	04/19/2022
7	Heat flux gauge secondary calibrations. Reference calibrations provided – Hukseflux SBG01	12851 and 13194	09/29/2021
8	Gases used for calibration of FRA gas analysis system - Praxair NI ME2.5P-AS	700010212UD	Varied (see calibration documents)
	Gases used for calibration of FRA gas analysis system - Praxair NI CD4.5CO5P-AS	700010213UB	
	Gases used for calibration of FRA gas analysis system - Praxair NI 5.0UH-T	200402005105	
	Gases used for calibration of FRA gas analysis system - Praxair HY 4.5Z-K	700010211D1	

About PVEL

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